Commission of the European Communities

energy

A GUIDEBOOK for effective analysis and presentation of risks and benefits in alternative energy systems

Report

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for effective analysis and presentation of risks and benefits in alternative energy systems

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IN

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FINAL REPORT

1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to provide guidelines for conducting analyses of the risks and benefits of alternative energy systems in an effective manner. There are considerable difficulties in carrying out such analyses as described in our previous study for The European Atomic Energy Community entitled "Assessment of Comparative and Non-Comparative Factors In Alternate Energy Systems". The objective of the present study is to carry out several of these recommendations made in the initial study, leading to rational and effective approaches for analyzing risks and benefits in alternate energy systems and meaningful presentation of the results to the user community. The result will be guidelines and methods that can be directly employed in such analyses and presentations. Except for examples illustrating the methodologies described in the guidelines, no actual analyses are carried out in this report.

1.2 Background

Many studies have attempted to compare the risks and benefits of alternative sources of energy production with mixed degrees of success. A review, "Assessment of Comparative and Non-Comparative Factors In Alternate Energy Systems", has been made of many of these studies to determine what is valid and useful in such studies, and what should be discarded. Based upon this review and critique, an approach has been developed that provides for meaningful analysis and presentation of risks and benefits of alternative energy systems for specific purposes and audiences.

Results of our previous review show that there is no such thing as a universal risk analysis or risk/benefit analysis of alternative energy systems, rather there is an array of different risk and benefit analyses directed to a whole spectrum of different uses and audiences. Improper use of a risk analysis for an application different than that for which the risk analysis was made, errant use of value judgement for aggregation of results, overuse of aggregation, and improper matching of the capability of the analysis to the use intended are just a few of the factors that have caused most of the analyses we have reviewed to be less than useful.

We have developed a structure for addressing the analysis of risks and benefits of alternate systems that starts at the top (namely, specifying the uses and target audiences of the analysis) and works downward to: determine 1) the precision of results needed for a decision, 2) whether it is possible to achieve the precision needed, and 3) how the results may be presented meaningfully to the target audience whether they be the technical community, policy and decision makers, or the general public. This approach only requires data to be acquired to a level that either resolves the problem or makes evident to the target audience the value judgements that cannot be resolved by any quantitative analysis. For those aspects of the analysis that are usefully quantified, this approach leads to a multiplicity of sublevel risk analyses which are retained for the audience in an understandable manner. Identification of all value judgements and interval estimates of risk are used in a manner that makes uncertainty both visible and manageable.

We will first discuss the problems we have observed with existing studies of alternative energy source risks and benefits. Next we will present the major components of our structure for getting around many of these problems.

1.3 Major Deficiencies In Existing Studies

In the original study: "Assessment of Comparative and Non-Comparative Factors In Alternate Energy Systems", Chapter Three on qualitative risks analysis began with the following statement:

> All of the studies reviewed here, comparing risks from alternative energy sources, have been attempted on a quantitative basis. In all cases, value judgements were used to aggregate data from an array of sources with different levels of variability, incommensurate measurement scales and different reliance on the degree of subjective and objective information available. Such value judgements are only meaningful for those involved in specific decisions when such judgements are made visible to the decision maker. The need to aggregate data and the associated value judgements are requirements of a quantitative comparison of risks from alternative energy sources. However, on a qualitative basis the differences in risks from energy sources and how they impact on different risk recipients can be displayed with minimal need for aggregation or value judgement.
>
> As a point of departure for describing the difficulties in quantitative analyses, a qualitative analysis provides a baseline for discussion. A first cut qualitative analysis is presented here for this purpose. While the analysis made is reasonably comprehensive, no attempt has been made to break down each source of energy into details...

In addition Table 3.1. summarized the qualitative comparison, shown here as Table 1.1 as a reference point.

The problem is to provide a means to combine the common sense, but limited decision making usefulness, of the qualitative approach and sufficient quantification to lead to reasonable and persuasive decisions. This can only be accomplished by a broader framework for risk analysis than has been generally used to date.

Another of the fundamental findings of the previous report was that there are a multitude of different uses for analyses of alternative energy systems, and that no single analytical approach to quantification that purports to address all uses was of any value. Specific analyses addressing specific, narrow decisions had a much better track record. This implies that any framework for risk and benefit analysis must be explicit as to the use made of it, and as a result the analysis within the framework must be tailored to the application. The guidelines developed here attempt to provide such a framework, whereby the approaches within the framework are tailored to the specific use at the minimum level of quantification needed to resolve decisions among alternative energy system choices.

1.4 How Should Proper Risk Analyses Be Accomplished?

In addressing the question of how risk assessment should be accomplished, Detlof von Winterfeldt[1] has laid down four theses for conducting assessments:

1. The first question in any risk assessment should be: risk assessment for whom and for what purpose? Failure to answer this question can lead to the most common pitfall of analysis - addressing the wrong problem.
2. Risk assessment should aid specific institutions in solving real and complex decision problems. Risk assessments for pure informational or comparative purposes are likely to be irrelevant for decision making purposes.
3. Solving complex decision problems requires a comprehensive approach which carefully defines the available alternatives and assesses the direct and indirect costs, risks and benefits of these alternatives in the light of the decision making institution. Thus, if risk assessment is to serve specific decision aiding purposes, it must be seen as a part of a more comprehensive analysis, rather than as a separate tool.
4. Decision analysis is the only comprehensive and practical methodology for aiding complex decisions. However, decision analysis needs to

be adapted to the political and institutional realities of decision making on problems of technological risks.

While many will disagree with specific aspects of these theses, the author considers them as basic guides to the problem. The methodology described here provides guidelines to meet these objectives in terms of evaluating alternative energy systems.

1.5 Risk and Benefits

Any framework for decision must address both risks and benefits as well as the costs of implementing alternative energy system choices. However, those who assess the risks have a different array of professional skills than those who assess costs and benefits. Therefore, it is usually necessary to separate the risk assessment from the benefit and cost assessments; and then use the aggregate analyses in the decision framework. One of the dangers of this specialization is that the specialists are often not told what analyses are to be made explicitly, and how these analyses will be used in the broader balancing of the decision framework. Without explicit direction, it should not be surprising that the assessors, be it risk or benefit or cost assessors, develop large and elegant assessments that may have little use in resolving the ultimate decision; or, conversely, the decision maker may attempt to use the assessments in inappropriate ways. Thus, any framework for decisions must take into account the need to explicitly provide detailed guidance to the technical risk, benefit, and cost assessors.

The guidelines developed here recognize the separation of risk and benefit assessments, but retains the direction and coordination of separate assessments. While the framework combines the risk and benefit analyses, they are addressed separately in this report.

TABLE 1.1

MAJOR IMPACTS FROM THE USE OF VARIOUS ENERGY SOURCES

	HYDROPOWER	COAL	OIL	NATURAL GAS	LIQUIFIED GAS	NUCLEAR	RENEWABLE ENERGY SOURCES	SYN FUEL	OTHER FOSSIL SUPPLIES
MINING AND EXTRACTION									
Workers	-	•Large Accidents, •Pneumocosis	•Medium (offshore) Accidents	-	-	•Small Accidents, •Radon	•Maintenance accidents	-	-
Public	-	•Accidents, •Mine drainage	•Oil spills	-	-	•Tailings piles, •Chemicals	-	•Water demand	•Large area of disruption, •Water demand (for oil shale)
PREPARATION	•Changes in living patterns	-	•Refining wastes and effluents	-	-	-	-	•Carcinogenic chemicals, •Waste	•Waste volume
TRANSPORTATION OF FUELS									
Workers	-	•Low	•High	•Medium	•High	•Low	-	•High	•High (dependin on fuel type)
POWER GENERATION	•Dam failure leading to floods	•Thermal loading	•Thermal loading	•Thermal loading	•Thermal loading	•Thermal loading •Accidents of various sizes	•Extensive land use •Interruptible	-	-
WASTE MANAGEMENT									
Effluents	-	•Particulates •SO_x, NO_x, •CO_x	•SO_x, NO_x, •CO_x	•CO_x	•CO_x	•Radioactive effluent	-	•NO_x, CO_x	•NO_x, CO_x
Wastes	-	•Fly ash •Culm piles	-	-	-	•Radwaste	-	-	-

1.6 Definitions

Several basic definitions are given here as they differ from other interpretations. Other definitions may be found in the Glossary.

A. **RISK**

Risk is the downside of a gamble. One cannot consider risk without the broader gamble in which it is imbedded. Although a gamble may be involuntary, there is always a benefit, including reductions of adverse conditions, against which the risk is undertaken. If one loses sight of the larger gamble, one tends to become risk averse. That is, one can over emphasize the importance of risks if one only addresses the risks alone.

Nevertheless, the above definition is consistent with definitions only focusing on risk such as: "the potential for harm"[2] or more formally: "the probability that a particular adverse event occurs during a stated period, or results from a particular challenge"[3].

B. **RISK ANALYSIS**

Risk Analysis is a policy analysis tool, using a knowledge base consisting of scientific and science policy information, to aid in resolving decisions. With this definition a good or useful risk analysis may be differentiated from an inadequate one. The measure of usefulness is whether the analysis aids in resolving the decisions addressed. Any risk analysis, regardless of its elegance, that does not fulfill the requirement fails.

Risk analysis should be based upon reliable scientific and economic information, and should explicitly differentiate between hard scientific information and science policy. The judgement of experts in the face of uncertainty is in the realm of science policy, not science. Risk analysis should identify and clarify judgements, scientific and otherwise; but such value judgements should not be made in the course of the analysis by the analyst. Although the implica tions of making alternative value judgements can be made explicit in the analysis, the judgements should only be made by those responsible for establishing policy. These "decision makers", whether operating in an autocratic or democratic mode or any of the many variations in between, are the ones responsible for making policy judgements; and their needs for aids in making such judgements will vary with the situation.

Risk analysis must be responsive to this spectrum of needs if it is to be useful as a policy tool. It then follows that no single risk analysis or risk analysis methodology can serve all purposes.

C. TOP-DOWN RISK ANALYSIS

Top-down risk analysis is a methodology for determining the most appropriate type risk analysis for a given situation, for making visible the decision parameters and value judgements involved, for identifying viable alternative strategies for resolution of issues, for identifying scientific and other information critical to the decision process as well as defining the needed precision of such information, and for communicating the decision process to those affected. The top-down risk analysis approach tailors the risk analysis to resolve the issues at hand, and this aspect of the approach does not itself analyse the risks. The top-down analysis will show whether a risk analysis can help resolve policy issues; and, if not, will identify the value conflicts that prevent issue resolution by other than political means.

In contrast, bottom-up risk analysis starts from basic science information and attempts to use this information for policy analysis by way of various prescriptive methodologies. In nearly all cases, problems arise from large uncertainties in the scientific information base. These problems are addressed by retaining and aggregating the ranges of uncertainty, most often in a semi-qualitative manner, or by use of the value judgement of experts or groups of experts. In the first case, the uncertainties are often too large for arriving at meaningful conclusions; and in the second case science policy is substituted for science. This does not imply that all bottom-up analyses are not useful; but often the resources entailed in making such analyses are very large; and the results often inconclusive, especially when such an analysis attempts to serve all policy purposes.

The risk analysis that uses a top-down risk approach as a part of the overall analysis need only use information necessary to resolve the decision (if it is resolvable), and the information used must be only as precise as is necessary. This means that a risk analysis using this approach will be quite different from the bottom-up approach, so separate identification is needed. For this reason the following terms are used:

<u>Top-Down Risk Analysis</u> - The process whereby the risk analysis methodology is tailored to the policy needs, and its feasibility determined.

<u>Bottom-up Risk Analysis</u> - Taking each event that can occur in a system and analyzing the pathways leading to the range of possible consequences, and aggregating these over the total spectrum of events and their associated probabilities.

<u>Joint Risk Analysis</u> - The total risk analysis, combining both the top-down and bottom-up analyses into a useful presentation for decision making and presentation.

D. DECISION FRAMEWORK

The framework whereby the decison parameters of a risk, benefit and cost analysis among alternatives may be structured, tailored to the need, analyzed, and presented meaningfully and usefully to those responsible for making policy decisions. The decision framework provides a means relating the analyses conduc ted to policy decisions required. Both top-down and bottom-up risk analyses are conducted within the framework.

1.7 The Joint Approach To Risk Analysis

The joint approach to risk analysis presented here provides means: to determine the specific uses for which an analysis of alternative energy choices is to address, to identify the specific decisions to be addressed, for isolating those specific criteria which will be relevent to the decision (top-down aspect), to concentrate resources on scientific analyses that address the relevent criteria so isolated (bottom-up aspect). Essentially the top-down aspect determines the relevant decision parameters and provides the guidence for the bottom-up aspect which involves carrying out the scientific and technical studies. The results of the technical studies are then brought back into the decision framework of the top-down aspect for presenting the decision alternatives and their implications to the decision makers.

1.8 Steps In A Joint Risk Analysis

The joint risk analysis consists of two parts, divided into 19 steps (as shown in Table 1.2): a top-down risk analysis and a limited bottom-up analysis aimed at filling the requirements called out in the top-down analysis. The details of Part A and B for the top-down risk analysis are shown in Table 1.3. We will explore, step by step, how this structure can be used to address the risks and benefits of alternative energy systems. It is important to note that the use of the generic structure of the decision framework as means to assure that useful, meaningful analysis of risks and benefits of alternate energy systems is emphasized in this report, and that the particular steps and the detailed implementation of the these steps is flexible in application. The particular steps shown are those that have been shown to be useful in past applications, and are not fixed in concrete. The purpose of the framework is more of a checklist to insure that all issues are identified and addressed.

Chapters 2, 3, & 4. will address the steps in the joint analysis, as shown in Table 1.2, in brief form. Chapters 5, 6, 7, & 8 will address specific aspects of the methodology in further detail as well as other related issues: uses, benefits, and special problems in applying analytical methodologies to alternate energy systems.

TABLE 1.2

GENERIC STEPS IN A JOINT RISK ANALYSIS

I. TOP-DOWN RISK ANALYSIS (Steps 1-13)

Part A. - DEVELOP A FRAMEWORK AND IDENTIFY KEY VALUE ISSUES AND CONFLICTS

Part B. - SPECIFY THE FRAMEWORK OF THE ANALYSIS

II. BOTTOM-UP RISK ANALYSIS (Steps 14-16)

Part C. - DATA ACQUISITION

Step 14. - CONDUCT REQUIRED STUDIES TO OBTAIN REQUIRED INFORMATION:

Step 15. - ACQUIRE THE DATA:

Part D. - IMPLEMENT THE ANALYSIS

Step 16. - CONDUCT THE ANALYSIS

III. IMPLEMENT THE DECISION FRAMEWORK (Steps 17-19)

Part E. - MERGE THE RESULTS OF THE BOTTOM-UP ANALYSIS INTO THE FRAMEWORK

Step 17. - REDUCE THE CONCLUSIONS TO THE IMPLICATIONS OF ALTERNATIVE POLICY OPTIONS BASED UPON THE ANALYSIS

Part F. PRESENT THE RESULTS OF THE ANALYSIS

Step 18. - EXECUTIVE SUMMARY AND POLICY ANALYSIS DOCUMENT

Step 19. - TECHNICAL BACKUP DOCUMENTS

TABLE 1.3

GENERIC STEPS IN A TOP-DOWN RISK ANALYSIS

Part A. - DEVELOP A FRAMEWORK AND IDENTIFY KEY VALUE ISSUES AND CONFLICTS

Step 1. DETERMINE THE USE FOR WHICH THE ANALYSIS IS TO BE MADE

Step 2. IDENTIFY A MINIMUM SET OF CRITICAL VARIABLES

Step 3. GENERATE A SET OF COMBINATIONAL SCENARIOS FOR THE INTERSECTION OF THE VARIABLE CONDITIONS (STATES OF NATURE)

Step 4. DEVELOP A SET OF ALTERNATIVE STRATEGIES FOR SOLUTION (ALTERNATIVES)

Step 5. DEVELOP A DECISION MODEL PROBLEM STRUCTURE

Step 6. IDENTIFY THE CRITICAL DECISION MAKERS

Step 7. HAVE EACH (OR GROUP OF) DECISION MAKER DETERMINE HIS CHOICE OF ALTERNATIVES FOR EACH SCENARIO OR IDENTIFY THE INFORMATION NEEDED TO MAKE SUCH A CHOICE

Step 8. CLASSIFY EACH SCENARIO INTO ONE OF THREE CLASSES

Step 9. FIND MEANS TO RESOLVE VALUE CONFLICTS, IF POSSIBLE. IF NOT, STOP

Part B. - SPECIFY THE FRAMEWORK OF THE ANALYSIS

Step 10 FINALIZE THE STRUCTURE OF THE ANALYSIS

Step 11. DEVELOP THE DATA REQUIREMENTS FOR THE BOTTOM-UP ANALYSIS

Step 12. IDENTIFY THE LIMITATIONS DUE TO UNCERTAINTIES, AND ESTIMATE THE ROBUSTNESS OF THE JOINT ANALYSIS

Step 13. PROVIDE A REPORT ON THE TOP-DOWN ANALYSIS, PROVIDING SPECIFICATIONS, LIMITATIONS, AND RECOMMENDATIONS.

PART I.

STEPS IN A GENERIC JOINT RISK ANALYSIS

The steps addressed in Table 1.2 are considered here in more detail to provide guidance in the use of the overall methodology and decision framework. When feasible we have used a specific case as an illustration of the process. The illustration is not real, and is only used as a vehicle for illustration of the methodology. The subject notation follows that of Table 2.1, and is broken out into a similar structure containing three Chapters.

TOP-DOWN RISK ANALYSIS (Steps 1-13)

The objective of the top-down analysis is to determine the specific bottom-up analyses that will most effectively aid in resolving the issues that policy makers identify as being important. The purpose is to constrain and focus the resources used in the bottom-up analyses, leading to efficient use of scientific methodolgy and meaningful results.

Chapter 2. DEVELOP A FRAMEWORK FOR THE ANALYSIS AND IDENTIFY KEY VALUE ISSUES AND CONFLICTS - (Steps 1-9)

Chapter 3, SPECIFY THE FRAMEWORK OF THE ANALYSIS - (Steps 10-13)

BOTTOM-UP RISK ANALYSIS AND IMPLEMENTING THE DECISION FRAMEWORK (Steps 14-19)

The bottom-up risk analysis and the means to implement the framework are both shown in Chapter 4.

Chapter 4. IMPLEMENTING, ANALYZING AND PRESENTING THE RESULTS

CHAPTER 2

2.0 DEVELOP A FRAMEWORK FOR THE ANALYSIS AND IDENTIFY KEY VALUE ISSUES AND CONFLICTS

The first nine steps involve identifying the critical decision variables which nearly always are associated with major value issues. These value issues often involve apparent value conflicts which, if not reconcilable, no amount of risk analysis will contribute to a decision. In this case, political means must be used to resolve such value issues, although the analysis can contribute to better understanding of such issues.

These steps are aimed at extracting these issues in a systematic manner, making them visible, and determining the extent of real and apparent value conflicts among decision makers and stake holders, and resolving these to the extent possible before proceeding further. The initial effort is directed at identifying the uses of the analysis, and the critical variables for each use of levels cited, at least for the exemplary case used in this report. This will provide insight into the nature of the crucial variables and their variability over the array of uses.

2.1 STEP 1. Establish Uses And Objectives

The first step identifies the particular uses and objectives of the risk analysis to be conducted. In the evaluation of alternate energy systems, the objective will depend upon the type of the decision to be made for specific applications. Table 2.1 lists the types of alternative energy system analysis applications cited in the original study. The risk and benefit analysis for each application type will be somewhat different. There seems to be a pervading notion that there is only one type of risk or benefit analysis. This is far from the case; for example, there are a spectrum of different risk analyses based upon how they are to be used. Table 2.2 provides a categorization of some different

TABLE 2.1

CLASSIFICATION OF RISK ANALYSES BY SCOPE OF THE APPLICATION

MICRO TO MACRO CLASSIFICATION

SITE SPECIFIC STUDIES

UTILITY PLANNING STUDIES

POWER GRID PLANNING STUDIES

NATIONAL ENERGY SUPPLY PLANNING

GLOBAL PLANNING

INTERNATIONAL ENERGY PLANNING

SPECIAL PURPOSE APPLICATIONS

ENERGY SUBSYSTEM INVESTMENT

EVALUATION OF POTENTIAL PROBLEMS IN NEW ENERGY SOURCES

TO SUPPORT OR REJECT AN ENERGY OPTION

TABLE 2.2.

DIFFERENT USES OF RISK ANALYSES REQUIRING DIFFERENT APPROACHES

I. REGULATORY ANALYSES

A. KINDS OF ANALYSES CONDUCTED BY REGULATORY AGENCIES

1). Screening Analyses - To Determine If A Risk Exists And Is High Enough To Be Considered For Regulatory Control.

2). Regulatory Impact Analysis - To Justify Regulatory Actions And Satisfy Administrative Law Requirements.

3). Compliance Analyses - To Demonstrate Regulatory Violations.

4). Responding Analyses - In Response To Judicial And Legislative Challenges.

B. ANALYSES MADE BY OTHERS IN RESPONSE TO EXISTING REGULATIONS

1). Environmental Impact Statements
2). Permitting Requirements
3). Compliance Monitoring

C. ANALYSES MADE BY OTHERS TO DEFEND AGAINST UNWARRANTED REGULATORY ACTION

1). Response To Requests For Comments By Regulators -Industry response to agency actions above.

2). Support Of Judicial Actions
 a. Response To Improper Agency Actions
 b. Defense Against Enforcement Proceedings

II. MANAGEMENT SUPPORT ANALYSES

A. MARKETING

1). Absolute Risk - Demonstrate that a product or process is safe or harmless on an absolute risk basis, that is, the risk on an absolute basis is below some standard or regulation implying an acceptable level of risk.

2). Relative Risk - Demonstrate that a product or process is relatively safer and less harmful than alternative and competative products or processs.

TABLE 2.2. Continued

DIFFERENT USES OF RISK ANALYSES REQUIRING DIFFERENT APPROACHES

B. PLANNING

1). Research And Development
  a. Risk Reduction - Identify areas of high risk (or relatively high risk) in particular products or processes to:
    1. Forestall the need for regulation.
    2. Reduce exposure to future liability claims.
    3. Develop defensive strategies to bound risk liability.
    4. Identify new markets for risk control technology.
  b. Improved Analysis Capability

2). Cost-Effective Use Of Resources - Focus resources on the most risk reduction for a dollar.

3). Evaluation Of Alternative - Systems or processes

C. RISK MANAGEMENT

1). Prevent Risks from Occurring - by anticpating and controlling them.

2). Reducing Exposure - for health and safety and financial risks for a given, existing process or product. Conduct analyses for:
  a. System Safety - Reduction of risk within a system.
  b. Product Safety and Liability.- Reduce exposure to legal proceedings.
  c. Third Party Assumption Of Risk
    1. Insurance - As a means to hedge against risks
    2. Malpractice - Laws to limit liability

III. PUBLIC EDUCATION

A. INCREASE PUBLIC AWARENESS

1). Seek Rational Public Responses - a knowledgeable public will hopefully act on information rather than preset beliefs.

2). Fulfill Regulatory Requirements For Public Disclosure -a good, simplified and accurate disclosure can also be a useful educational tool.

B. ANXIETY FACTORS

1). Bring Perceived Risks More Closely Into Alignment With Objective Risks - anxiety reduction; may also be a defensive strategy

2). Frighten People Into Action Or Ageement - an offensive strategy attempting to stir fear and anxiety

---

uses. The uses and their interface with different users will be addressed in more detail in Chapter 5.

A risk analysis is undertaken by a sponsor for influencing three types of users:

1. Policy Makers And Risk Managers - Establishing controls both in industry and government.

2. Technical Community - Scientists, engineers, technicians, economists, ecologists, etc.

3. Public - The public at large.

The sponsor is usually one of these users, but may not be. It is important to identify the biases that a sponsor may have in influencing any of the user community. An analysis may be classifed as defensive, offensive, and, perhaps, neutral. A defensive risk analysis attempts to demonstrate that an estimated level of risk is acceptable, while an offensive risk analysis tends to demonstrate that an estimated level of risk is unacceptable. Conversely, a neutral risk analysis is one where no predisposition exists as to the acceptability of findings.

In the non-neutral cases, it is important to recognize that the position of the analyst is only respectable and honourable if there is an understanding by all concerned that the risk analyst is acting for a client, and is entitled to concentrate on those aspects which favor his client, just as a lawyer acts in court. One should not allow risk analysts to be subtly influenced by the purpose of his paymasters, while appearing to serve the public as a disinterested party. In any case the analyst must use scientific rigor in scientific areas, and must explicitly make science and science policy judgements he has made visible to all parties for their examination.

EXAMPLE

For the purposes of illustrating the application of top-down and joint risk analysis to selection of alternative energy systems in consideration of the risks and benefits involved, an example has been selected. The use and goals of the example are as follows:

USE - A National Authority Wishing To Make An Explicit Policy Decision On The Best Mix Of Energy Systems For Increasing Its Electrical Energy Capacity By a Percentage X Of Its Present Capacity Over The Next Y Years.

(We have not been specific in the example as to the amount of increase or the time span of the increase to avoid the problems of forecasting demand, a separate problem with its own range of uncertainties and risks)

GOAL - To have a decision document outlining the policy implication in terms of the risks and benefits of alternate energy options that the national authorities may use as an aid in setting the future policy, and,

A. To have the analysis supporting the policy options to be defensible on technical grounds, and,

B. To provide the public with an understanding of the risks and benefits of the alternatives, and the rationale for decisions made by the national authorities.

(In this case we are assuming a somewhat autocratic form of government where the decision making power is vested in an identified authority acting in the best interests of those governed however that authority is vested. In other cases public participation in the decision may be necessary, but not for our example. Rather public approval by the majority of those governed of the alternatives selected is sought.)

2.2 STEP 2. Identify A Minimum Set Of Critical Variables

For evaluation of alternate energy systems, the benefits, risks and costs must be evaluated and balanced in a decision. Section 4.0 deals with possible benefits of energy production and the interchangeability of energy sources. For a particular type of use only a few of these benefits will apply. The minimum set of critical variables are most likely some combination of the three variables cited below:

1. Fuel Availability And Cost

   Long Term Strategic Availability

   Cost Esculation

2. Lifecycle Costs

   Operational (excluding Fuel)

   Capital

   Financial Responsibility

3. Risks

   Normal Operation - The systems operating as it is designed to operate.

   Abnormal Operation - Occassional or periodic excursions for which the system is designed to withstand.

   Rare Event Conditions - Infrequent events for which the system may or may not be designed to withstand.

There are apparently more than three variables as shown above, namely, seven; but, for the initial set of variables, one or more of the subvariables in each of the critical variables will usually dominate. If not the case, then more than three critical variables will be necessary. These variables are at best only partially controllable by the sponsor.

In order to identify the minimum set of critical variables, an understanding of the types of variables involved is necessary.

2.2.1. Types Of Variables

For risk analysis aspects, we are primarily concerned with risk variables. These variables will be of different kinds, and will have varying degrees of uncertainty associ-ated with them. Three kinds of variables must be considered, situational, conditional, and operational variables.

> Situational Variables - Those variables, internal to the system, whose values are determined by the specific situations associated with the extent of coverage for which the system is designed. For example, siting of an energy source depends upon the particular sites available and their characteristics. Different energy systems will have different siting requirements, each with its own parameters that must be covered in the design of the system. Another example is the relative toxicity of releases to the environment. Radiation can cause cancer at low exposure levels while nitrogen dioxide causes increased probability of respiratory infection at low levels. Control of these variables is primarily through restriction of specific ranges of a variable or a situation by regulatory limits (for example, limiting the use of a chemical) when it is possible to do so. What is unknown is the specific situation one will encounter in advance. See Table 2.3 for examples.
>
> Conditional Variables - Those variables, external to the system, which can affect the behavior of the alternative system risks. Environmental conditions, system failures caused by external factors, etc. are examples of conditional variables. Depending on the controllabilty of these variables, design limits are set to cope with these variables by adding margins of safety in the design limits. These margins of safety must take into account. See Table 2.4 for examples.
>
> Operational Variables - Those variables which are directly controllable through the operation of the process being analyzed to the extent that the relationship among variables can be specified. An example is controlling the combustion process and stack releases from a coal boiler. Again the variation is not due to lack of information, but rather the range of possible conditions that can occur in actual situations. The costs of different control methods, and means for monitoring the operational performance for the process may limit some control options, but regulatory performance standards are one approach to operational control. See Table 2.5 for examples.

2.2.2. Degree Of Control Of Variables

Each of these classes of variables have some measure of controllability. There are three different degrees of control that can be exercised: controllable,

TABLE 2.3

SITUATIONAL VARIABLES

THOSE VARIABLES, INTERNAL TO THE SYSTEM, WHOSE VALUES ARE DETERMINED BY THE SPECIFIC SITUATIONS ASSOCIATED WITH THE EXTENT OF COVERAGE FOR WHICH THE SYSTEM IS DESIGNED.

EXAMPLES

SITING OF AN ENERGY SOURCE DEPENDS UPON THE PARTICULAR SITES AVAILABLE AND THEIR CHARACTERISTICS. DIFFERENT ENERGY SYSTEMS WILL HAVE DIFFERENT SITING REQUIREMENTS, EACH WITH THEIR OWN PARAMETERS THAT MUST BE COVERED IN THE DESIGN OF THE SYSTEM.

THE RELATIVE TOXICITY OF RELEASES TO THE ENVIRONMENT, RADIATION CAN CAUSE CANCER AT LOW EXPOSURE LEVELS WHILE NITROGEN DIOXIDE CAUSES INCREASED PROBABILITY OF RESPIRATORY INFECTION AT LOW LEVELS.

CONTROL

CONTROL OF THESE VARIABLES IS PRIMARILY THROUGH RESTRICTION OF SPECIFIC RANGES OF A VARIABLE OR A SITUATION BY REGULATORY LIMITS (FOR EXAMPLE, LIMITING THE USE OF A CHEMICAL) WHEN IT IS POSSIBLE TO DO SO. WHAT IS UNKNOWN IS THE SPECIFIC SITUATION ONE WILL ENCOUNTER IN ADVANCE.

EXAMPLES OF SITUATIONAL VARIABLES FOR ALTERNATE ENERGY SOURCES

- SITING
  - POPULATION DENSITY
  - WATER AVAILABILITY
  - TRANSPORTATION & TRANSMISSION DISTANCES
  - SITE AVAILABILITY
- CLIMATIC CONDITIONS
  - WET/DRY, HOT/COLD, BENIGN/EXTREME, Etc,
- FUEL AVAILABILITY
  - FOREIGN OR DOMESTIC
- FUEL CONTENT
  - COAL - SULFUR AND HEAT CONTENT
  - NUCLEAR - NATURAL OR ENRICHED

TABLE 2.4

CONDITIONAL VARIABLES

THOSE VARIABLES, EXTERNAL TO THE SYSTEM, WHICH CAN AFFECT THE BEHAVIOR OF THE ALTERNATIVE SYSTEM RISKS.

EXAMPLES

ENVIRONMENTAL CONDITIONS,

SYSTEM FAILURES CAUSED BY EXTERNAL FACTORS
- SABOTAGE
- MISSILES (OTHER THAN MILITARY)
- WAR

CONTROL

DESIGN LIMITS ARE SET TO COPE WITH THESE VARIABLES BY ADDING MARGINS OF SAFETY IN THE DESIGN LIMITS. THESE MARGINS OF SAFETY MUST TAKE INTO ACCOUNT:

RANDOM FLUCTUATIONS, FAILURES, AND STRESSES
WEAROUT AND FAULTY COMPONENTS
HUMAN ERROR
ENVIRONMENTAL FACTORS
VIOLATION OF RULES

EXAMPLES OF CONDITIONAL VARIABLES FOR ALTERNATIVE ENERGY SYSTEMS

- ENVIRONMENTAL FACTORS
  - EVENTS - STORMS, FLOODS, EXTREME WEATHER CONDITIONS, EARTHQUAKE, VOLCANOS
- DEGREE OF REGULATION
- SABOTAGE
- CHANGES IN ENERGY DEMAND
- FUEL COST ESCALATION
- TRAINING LEVEL OF PERSONNEL
- DEGREE OF ANTI-NUCLEAR SENTIMENT IN NATION
- ORDINARY ACCIDENTS
- MAJOR RARE EVENT ACCIDENTS

TABLE 2.5

OPERATIONAL VARIABLES

THOSE VARIABLES WHICH ARE DIRECTLY CONTROLLABLE THROUGH THE OPERATION OF THE PROCESS BEING ANALYZED TO THE EXTENT THAT THE RELATIONSHIP AMONG VARIABLES CAN BE SPECIFIED.

EXAMPLES:

THE COMBUSTION PROCESS AND STACK RELEASES FROM A COAL BOILER.

THE POWER OUTPUT VERSUS PLANNED RELEASES FOM A NUCLEAR REACTOR

CONTROL

THE SYSTEM VARIATION MAY BE DUE TO LACK OF INFORMATION OR THE RANGE OF POSSIBLE CONDITIONS THAT CAN OCCUR IN ACTUAL SITUATIONS CAN ONLY BE MODELLED. THE COSTS OF DIFFERENT CONTROL METHODS AND MEANS FOR MONITORING THE OPERATIONAL PERFORMANCE FOR THE PROCESS MAY LIMIT SOME CONTROL OPTIONS, BUT REGULATORY PERFORMANCE STANDARDS ARE ONE APPROACH TO OPERATIONAL CONTROL.

EXAMPLES OF OPERATIONAL VARIABLES FOR ALTERNATIVE ENERGY SYSTEMS

- ELECTRICAL CONVERSION SYSTEM
  - CONTROL PARAMETERS FOR A GIVEN TYPE OF REACTOR
  - CONTROL PARAMETERS FOR A GIVEN TYPE OF COMBUSTOR
- CONTROL OF RELEASES
  - NORMAL OPERATION
  - ABNORMAL OPERATION
- SAFETY SYSTEMS
  - ORDINARY ACCIDENTS
  - LARGE RARE EVENT RISKS

avoidable, uncontrollable. These are further defined as:

Controllable - Parameters are under control of designers and operators.

Avoidable - Applied limits on parameters may be used to avoid exposure.

Uncontrollable - Parameters independent of designers and operators.

Table 2.6 illustrates how designers may cope with the three types of variables and their degrees on controllability in each case. The bold entries illustrate the design concepts, and the entries provide further detail. In each case the design concepts provide guidance as to how risks may be controlled in design, and provide insight on how the risks associated with each variable might be addressed in subsequent bottom-up analyses. Table 2.7 provides some examples of critical variables and the degree to which they are contollable.

2.2.3. Order Of Addressing Variables

It is most appropriate to address situational variables first. The situation determines the limits and conditions that have to be met by the system. Since every situation will be different in some respect from all others, the selection of alternatives and the risks and benefits associated with the alternatives will vary accordingly. Once the situation is determined, the selection of operational and conditional variables can be made. If one starts from system design, operational variables should be addressed before conditional ones; otherwise the order should be reversed. The operational variable for each alternative energy system will, of course, be different. Therefore, consideration of situational and conditional variables will generally preceed consideration of operational variables. This is especially the case when scoping the analysis.

2.2.4. Selection Of Situational Variables

The selection of variables for the generic problem, used as an example, is a difficult one because of the wide variations in conditions among nations. This

TABLE 2.6

DEGREE OF CONTROL OF VARIABLE TYPES

VARIABLES	CONTROLLABLE	AVOIDABLE	UNCONTROLLABLE
SITUATIONAL (Internal to Problem)	Design to cover explicit range of situations	Exclude cases outside of range when possible	Must extend range to cover all cases, but may be grouped e.g. Normal Abnormal Extreme
	Design Coverage	**Limits of Coverage**	**Total Range Coverage**
CONDITIONAL (External to Problem)	Design with margins of safety to cope <u>with</u> Random Fluctuations Wearout & Failure Human Error Environmental Factors Violation of Rules	Curtail operation during extreme levels of: Environmental Stress, Human Limitations, Rule Violation Preventive maintenance to avoid wearout Q.C. to control failure rate	Recovery System Capability Required
	Design Limits	**Shutdown Outside Design Limits**	**Extreme Excursions Beyond Design Limit**
OPERATIONAL (Manages Internal and External Conditions To Reach Goals)	Relationships among variables known well enough to establish control relationships	Establish limits of operation and margins of safety to cope with conditional variables	Compound Margins of safety provide some measure of redundancy
	Operational Design Capability	**Operational Limits**	**Operational Redundancy**

TABLE 2.7

EXAMPLES OF TYPES OF VARIABLES AND THEIR DEGREE OF CONTROLLABILITY

SITUATIONAL			
	SITING		
		POPULATION DENSITY	A
		WATER AVAILABILITY	C-U
		TRANSPORTATION & TRANSMISSION DISTANCES	C-U
		SITE AVAILABILITY	U
	FUEL AVAILABILITY		
		FOREIGN OR DOMESTIC	U-C
	CLIMATIC CONDITIONS		
		WET/DRY, HOT/COLD, BENIGN/EXTREME, Etc,	U
	FUEL CONTENT		
		COAL - SULFUR AND HEAT CONTENT	A
		NUCLEAR - NATURAL OR ENRICHED	C
CONDITIONAL			
	ENVIRONMENTAL FACTORS		
		STORMS, FLOODS, EXTREME WEATHER CONDITIONS,	U-A
	EARTHQUAKE		U-A
	DEGREE OF REGULATION		C-U
	SABOTAGE		U
	CHANGES IN ENERGY DEMAND		U
	FUEL COST ESCALATION		U
	TRAINING LEVEL OF PERSONNEL		C
	DEGREE OF ANTI-NUCLEAR SENTIMENT IN NATION		A-U
	ORDINARY ACCIDENTS		U-A
	MAJOR RARE EVENT ACCIDENTS		U
OPERATIONAL			
	ELECTRICAL CONVERSION SYSTEM		
		CONTROL PARAMETERS FOR A GIVEN TYPE OF REACTOR	C
		CONTROL PARAMETERS FOR A GIVEN TYPE OF COMBUSTOR	C
	CONTROL OF RELEASES		
		NORMAL OPERATION	C
		ABNORMAL OPERATION	C
	SAFETY ASPECTS		
		ACCIDENTS	A-U
		LARGE RARE EVENT RISKS	U-A

U=UNCONTROLABLE A=AVOIDABLE C=CONTROLLABLE - ORDER IMPLIES PRECEDENCE means that it is necessary to first consider a variety of situations; and, then having identified the applicable situations, identify the critical uncontrolled variables for that situation. In order to illustrate this process three situational variables are addressed, each assigned three levels of precision. These are shown in Table 2.8.

2.2.5. Selection of Conditional Variables

For the generic example described here, consideration of conditional variables procedes the operational variables. Depending on the situational variables selected above and the particular scenarios that are adopted (see the next section), a set of key conditional varibles is selected in a manner similar to those above. An example of these are shown in Table 2.9. and are especially selected for a particular scenario.

2.3 STEP 3. Generate a set of combinational scenarios (States Of Nature)

Each critical variable is broken down into about three classifications such as high, medium and low. The classification separations are designed as to be meaningful to the decision. Using these designations the intersection of the value conditions for each critical variable is formed. For three variables with three value conditions there will be 27 such intersections. The intersections for the situational variables described in Table 2.8 are shown in Table 2.10. A verbal description of each intersection, including its implications, is termed a scenario. A scenario is developed for each intersection.

An example, based upon the previous case, follows:

TABLE 2.8

CRITICAL SITUATIONAL VARIABLES

1. SITE AVAILABILITY

HPOP	ONLY HIGH POPULATION DENSITY SITES AVAILABLE
MPOP	MODERATE POPULATION DENSITY SITES AVAILABLE
LPOP	LOW POPULATION DENSITY SITES AVAILABLE

2. FUEL AVAILABILITY

DOM	DOMESTIC SOURCES ADEQUATE
PART	PARTIAL DOMESTIC SOURCES
ALL	ALL FUEL IMPORTED

3. CLIMATIC CONDITIONS

EXTR	EXTREME
MOD	MODERATE
BEN	BENIGN

TABLE 2.9

CRITICAL CONDITIONAL VARIABLES

FOR SITUATIONAL SCENARIO #26

F. FUEL COST ESCALATION

LOW	PRESENT SITUATION
MODERATE	RISING SLIGHTLY FASTER THAN INFLATION
HIGH	HIGH ENERGY PRICES DUE TO CARTEL CONTROLS

D. EXPECTATION OF DISRUPTION (ACCIDENTS, SABOTAGE, FUEL AVAILABILTY)

LOW	LARGE ACCIDENTS WILL NOT OCCUR, FUEL HIGHLY AVAILABLE, AND NO SABOTAGE EXPECTED IN ANY WIDE SPREAD PATTERN
MODERATE	LARGE ACCIDENTS WILL NOT OCCUR, BUT HIGH VISIBILILITY ACCIDENTS WILL OCCUR, OR FUEL AVAILABLITY MAY BE LIMITED TO SOME EXTENT, OR SABOTAGE OCCURS ON A SELCTIVE BASIS.
HIGH	LARGE ACCIDENTS OCCUR, OR FUEL AVAILABILITY LIMITED SEVERELY, OR SABOTAGE OCCURS ON A WIDEPREAD BASIS.

A. DEGREE OF ANTI-NUCLEAR SENTIMENT IN NATION

LOW	NO ORGANIZED OPPOSITION TO NUCLEAR, UNLIKELY TO BE ORGANIZED
MODERATE	ORGANIZED OPPOSITION TO NUCLEAR DEVELOPS, BUT DOES NOT BECOME A MAJOR POLITICAL ISSUE.
HIGH	MAJOR OPPOSITION FORMS TO NUCLEAR, AND BECOMES A MAJOR POLITICAL FACTOR.

TABLE 2.10

SCENARIOS DERIVED FROM THE SITUATIONAL VARIABLES

27 SCENARIOS

SITE AVAILABILITY

FUEL AVAILABILITY

DEGREE OF CLIMATIC STRESS

1.	EXTR	DOM	HPOP	______
2.	EXTR	DOM	MPOP	______
3.	EXTR	DOM	LPOP	______
4.	EXTR	PART	HPOP	______
5.	EXTR	PART	MPOP	______
6.	EXTR	PART	LPOP	______
7.	EXTR	FOR	HPOP	______
8.	EXTR	FOR	MPOP	______
9.	EXTR	FOR	LPOP	______
10.	MOD	DOM	HPOP	______
11.	MOD	DOM	MPOP	______
12.	MOD	DOM	LPOP	______
13.	MOD	PART	HPOP	______
14.	MOD	PART	MPOP	______
15.	MOD	PART	LPOP	______
16.	MOD	FOR	HPOP	______
17.	MOD	FOR	MPOP	______
18.	MOD	FOR	LPOP	______
19.	BEN	DOM	HPOP	______
20.	BEN	DOM	MPOP	______
21	BEN	DOM	LPOP	______
22.	BEN	PART	HPOP	______
23.	BEN	PART	MPOP	______
24.	BEN	PART	LPOP	______
25.	BEN	FOR	HPOP	______
26.	BEN	FOR	MPOP	______
27.	BEN	FOR	LPOP	______

EXAMPLE

An example of a scenario for intersection #1 in the example case is:

Situational Scenario #1 - EXTR/DOM/HPOP

A country (or part of a country) that has extreme climatic conditions, has domestic fuel available and only high population density sites available. In this case, if the domestic fuel were coal, oil or natural gas in plentiful supply, the choice of an alternative energy is source is almost self-selected for short term solutions to the energy problem cited in the example.

It is obvious that different scenarios may apply to specific countries or parts of a country. Moreover, two countries with different situational scenarios, require different sets of conditional and operational variables. Therefore, it should not be surprising that the results of the analysis for the two countries would be entirely different. The required analyses are different, and the results are different. The identification of these diffences, and an understanding of the reasons for the differences are very important results of the top-down approach.

EXAMPLE

For the example shown previously, we will use Scenario #26 which may be described as follows:

Situational Scenario #26 - BEN/FOR/MPOP

A country (or part of a country) with benign climatic conditions, depending totally on imported fuels, and having medium density sites available. The particular conditional variables for this scenario are those shown in Table 2.9. They are primarily uncontrolled variables.

For the conditional variables we will have another set of intersections and scenarios. For three variables with three levels, we again have twenty-seven scenarios. For example, the 27 intersections for situational scenario #26 are shown in Table 2.11. In this case, the scenarios for these uncontrollable variables are somewhat more descriptive of conditions. These scenarios now become the critical values for the particular situation previously selected.

EXAMPLE

The conditional scenario for the first intersection is:

Conditional Variable Scenario #1

(For Situational Variable Scenario #26)

Fuel Cost Escalation	High
Expectation Of Disruption	High
Degree Of Anti-Nuclear Sentiment	High

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, with sabotage attempts and civil disobedience highly probable.

A major nuclear event likely to occur - may or may not involve loss of life, but has high coverage by the media.

All 27 of the scenarios are described in Appendix A.

TABLE 2.11

SCENARIOS DERIVED FROM THE CONDITIONAL VARIABLES

FOR SITUATIONAL SCENARIO #26

27 SCENARIOS

F. FUEL COST ESCALATION

D. EXPECTATION OF DISRUPTION

A. DEGREE OF ANTI-NUCLEAR SENTIMENT

1.	A-HIGH	D-HIGH	F-HIGH	______
2.	A-HIGH	D-HIGH	F-MOD	______
3.	A-HIGH	D-HIGH	F-LOW	______
4.	A-HIGH	D-MOD	F-HIGH	______
5.	A-HIGH	D-MOD	F-MOD	______
6.	A-HIGH	D-MOD	F-LOW	______
7.	A-HIGH	D-LOW	F-HIGH	______
8.	A-HIGH	D-LOW	F-MOD	______
9.	A-HIGH	D-LOW	F-LOW	______
10.	A-MOD	D-HIGH	F-HIGH	______
11.	A-MOD	D-HIGH	F-MOD	______
12.	A-MOD	D-HIGH	F-LOW	______
13.	A-MOD	D-MOD	F-HIGH	______
14.	A-MOD	D-MOD	F-MOD	______
15.	A-MOD	D-MOD	F-LOW	______
16.	A-MOD	D-LOW	F-HIGH	______
17.	A-MOD	D-LOW	F-MOD	______
18.	A-MOD	D-LOW	F-LOW	______
19.	A-LOW	D-HIGH	F-HIGH	______
20.	A-LOW	D-HIGH	F-MOD	______
21	A-LOW	D-HIGH	F-LOW	______
22.	A-LOW	D-MOD	F-HIGH	______
23.	A-LOW	D-MOD	F-MOD	______
24.	A-LOW	D-MOD	F-LOW	______
25.	A-LOW	D-LOW	F-HIGH	______
26.	A-LOW	D-LOW	F-MOD	______
27.	A-LOW	D-LOW	F-LOW	______

We will not know what scenario will occur, and it is possible to assign some initial measure of probability to each scenario. This will provide some perspective on whether or not some of the scenarios can be eliminated from consideration because it is either impossible or highly improbable that the situation occurs. Eventually we will use the bottom-up risk analysis to assign some expected probability of occurrence for those that remain. The scenarios are analogous to the states of nature in a decision problem.

2.4 STEP 4 Develop A Set Of Alternative Strategies (Alternative Strategies)

The alternate energy systems shown in qualitative form in Table 1.1 are the set of alternatives to be considered in the analysis for alternative energy systems. These are shown at the gross level, but can be broken down to more specific designs as well. The alternatives are similar to the alternative strategies in a decision problem.

As an extension of the example, Table 2.12 provides a more limited set of energy alternatives for consideration.

2.5 STEP 5 Develop A Decision Model Structure.

Each of the scenarios (S_i), considered as an uncontrollable state-of-nature, can be evaluated for each of the alternative strategies (A_j). This provides a decision model structure for the problem, at least in terms of the states-of-nature (i = 1,2, ... 27) and alternative strategies (j = A, B, ... I) for the example shown. This decision model structure is illustrated in Table 2.13 which also shows a probabilty assignment (p_i) for each scenario. If one were to assign a value or utility to each intersection (V_{ij}), this process would be analagous to assigning utility in a decision problem. Since such assignments represent value judgements, we choose not to do this. Rather we would like to assign the preferred alternative for each scenario. This also represents a

TABLE 2.12

EXAMPLE

ALTERNATIVE ENERGY SYSTEMS

(LIMITED TO COAL AND NUCLEAR HERE)

COAL

A. LARGE - HIGH DEGREE OF CONTROL OF RELEASES

B. SMALL - HIGH DEGREE OF CONTROL OF RELEASES

C. LARGE - LOW DEGREE OF CONTROL OF RELEASES

D. SMALL - LOW DEGREE OF CONTROL OF RELEASES

NUCLEAR

E. LARGE - ENRICHED FUEL

F. SMALL - ENRICHED FUEL

G. LARGE - UNENRICHED FUEL

H. SMALL - UNENRICHED FUEL

COMBINATION

I. VARIOUS MIXES

TABLE 2.13

CLASSICAL DECISION STRUCTURE FOR RISK ANALYSIS

STATES-OF-NATURE	PROB.	ALTERNATIVE STRATEGIES								
		A_a	A_b	A_c	A_d	A_e	A_f	A_g	A_h	A_i
S_1	p_1	V_{1a}	V_{1b}	V_{1c}	V_{1d}	V_{1e}	V_{1f}	V_{1g}	V_{1h}	V_{1i}
S_2	p_2	V_{2a}	V_{2b}	V_{2c}	V_{2d}	V_{2e}	V_{2f}	V_{2g}	V_{2h}	V_{2i}
S_3	p_3	V_{3a}	V_{3b}	V_{3c}	V_{3d}	V_{3e}	V_{3f}	V_{3g}	V_{3h}	V_{3i}
S_4	p_4	V_{4a}	V_{4b}	V_{4c}	V_{4d}	V_{4e}	V_{4f}	V_{4g}	V_{4h}	V_{4i}
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
S_i	p_i	V_{ia}	V_{ib}	V_{ic}	V_{id}	V_{ie}	V_{if}	V_{ig}	V_{ih}	V_{ii}
.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.
S_{24}	p_{24}	V_{24a}	V_{24b}	V_{24c}	V_{24d}	V_{24e}	V_{24f}	V_{24g}	V_{24h}	V_{24i}
S_{25}	p_{25}	V_{25a}	V_{25b}	V_{25c}	V_{25d}	V_{25e}	V_{25f}	V_{25g}	V_{25h}	V_{25i}
S_{26}	p_{26}	V_{26a}	V_{26b}	V_{26c}	V_{26d}	V_{26e}	V_{26f}	V_{26g}	V_{26h}	V_{26i}
S_{27}	p_{27}	V_{27a}	V_{27b}	V_{27c}	V_{27d}	V_{27e}	V_{27f}	V_{27g}	V_{27h}	V_{27i}

value judgement, but in terms of a preference for an alternative as opposed to an assigned cardinal utility or value. The choice is from a nominal scale of alternatives rather than ordinal or cardinal scales. The analyst should not make these value choices. They should be made by the decision makers.

2.6 STEP 6 Identify The Critical Decision Makers

The array of decision makers in the sponsoring organization and the users must be identified. This will include, initially, the policy makers and risk managers involved, but eventually will have to include other stakeholders in the decision such as the public and the technical community. It may not always be possible to gain access or attention from all decision makers. In these cases, the best the analyst can do is to examine previous decisions, ascertain what can be found about the values of the decision makers, and sample the attitudes and beliefs of groups of decision makers (for example, the public or particular groups of stakeholders). This is particularly the case for energy system analysis, where it may not be possible to get direct input from all the stakeholders and users. In this case generic studies of the beliefs, attitudes and anxieties of different groups can be ascertained to some extent. Studies, such as those conducted by Otway et al[1], Slovik and Fischoff[2], Twersky and Kahnemen[3], etc., can serve to identify opposing value systems; and, perhaps, indicate which alternatives might be favored by such groups for each scenario. For the purpose of the example, it will be assumed that government policy makers act for the public and make coherent decisions for them either as representatives of the public (democratic approach) or impose them undemocratically. This does not imply universal acceptance by the population affected.

2.7 STEP 7 Each Decision Maker Is Asked To Identify His Choice Of Alternatives

Each decision maker or each coherent group of decision makers should be asked to determine his or its choice of alternatives for each scenario or, if a choice cannot be made, to identify the information needed to make such a choice. The process of making the choices is not burdensome if the number of critical values is small, for example, twenty-seven, and the scenarios decriptive of what might occur in verbal terms. Table 2.14 provides a space at the right of each scenario for such entry, and Appendix C. provides the complete array of 27 scenarios.

Each participant is asked to select the appropriate alternative for each scenario. This represents selecting one alternative for each scenario in Table 2.13 rather than assigning values or utilities to all the V_{ij}'s. It is at this juncture that the methodolgy departs from classical decision theory approaches. The decision maker is asked to reduce his selection to one alternative for each scenario, if possible. If not, he is asked to indicate the multiple choices for that scenario, and specifically what information is necessary to resolve it to one alternative; or, if he is indifferent among those selected alternatives, to so indicate it and leave the multiple choices as they stand. An illustration of this process is shown in Table 2.14. OK means that one alternative has been selected for a given scenario. IND indicates indifference among multiple alternative selections, and ST indicates that a study is required to provide further information to resolve the ambiguity among the multiple alternatives. The information required to resolve the decision among the alternatives must be specified; and, if possible, the selection criteria that will be used to evaluate the results of study ascertained. The compilation of the studies identified will be the specification for the bottom-up risk analyses required. The studies will generally require the identification of a new set of variables, situational, conditional or operational as is necessary to conduct the studies. These variables will become the critical variables for the next steps in the analysis.

TABLE 2.14

EXAMPLE OF USE OF THE SELECTIVE DECISION STRUCTURE FRAMEWORK

FOR A DECISION PARTICIPANT

STATES-OF-NATURE	PROB.	ALTERNATIVE STRATEGIES									
		A_a	A_b	A_c	A_d	A_e	A_f	A_g	A_h	A_i	
S_1	p_1				A_{1d}						OK
S_2	p_2		A_{2b}	A_{2c}							IND
S_3	p_3	A_{3a}									OK
S_4	p_4				A_{4d}						OK
.	.	.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	.	.	
S_i	p_i					A_{ie}	A_{if}	A_{ig}			ST
.	.	.	.	.	.	.	.	.	.	.	
.	.	.	.	.	.	.	.	.	.	.	
S_{24}	p_{24}				A_{24d}	A_{24e}			ST		
S_{25}	p_{25}	A_{25a}									OK
S_{26}	p_{26}								A_{26h}		OK
S_{27}	p_{27}						A_{27f}				OK

OK = Single Selection   IND = Indifferent   ST = Study Required

2.8 STEP 8. Classify Each Scenario Into One Of Three Classes

After all the decision makers have classified their choices for the scenarios, each scenario is classified into one of three classes:

I. All participants agree to the selection of the best alternative

II. Apparent conflicts among participants as to choice result, i.e, two or more participants would select different alternatives for a given scenario.

III. Further information is required for selection. For this condition it is possible to go back and ask some "what if" questions in order to see if a decision point can be agreed upon. That is, a decision condition can be established a priori against which further information can be judged a postiori after it has been obtained. If such agreement cannot be obtained, it is important to establish the precision of the information required to make such decisions.

If case I. above occurred for each scenario, then the bottom-up cost, risk, benefit analysis would only have to proceed to a precision necessary:

1) to provide the liklihood of scenario outcomes, and

2) to resolve the critical parameters to the gross level used (High, Medium, Low, etc.) in the values for the critical variables.

For case III. where further information is required, the needed precision can be established, and the information can be obtained in the most cost effective manner via the bottom-up analyses once the problem structure is defined.

2.9 STEP 9 Find Means To Resolve The Value Conflicts

For case II above, if apparent value conflicts arise, that is, decision makers differ about which alternative energy system to adopt should a particular scenario occur, these value conflicts must be resolved before any risk analysis can be undertaken. In general, the value conflicts involved will be social value conflicts rather than judgements about scientific issues at this level of the joint risk analysis procedure. If such value conflicts are more than just apparent conflicts that cannot be resolved, then it will be apparent that any subsequent risk analysis will have little impact on the decisions to be made, except as the analysis serves to better define the value differences and sharpen the decision arguments. A.V. Cohen, in his review[4] of the interim report of this study has commented: "quantification of relevant parameters is always useful, since a disagreement around objective truth with margins of error stated, or differences in interpretation of data openly declared, is better than arguments from entrenched and qualitative positions. I do see that this may only be meaningful within certain kinds of rational decision making structures". It must also be recognized that many policy makers, particularly those in public offices, may not want to disclose their value systems to constituents for political reasons. Too often bureaucratic organizations attempt to hide such value judgements behind planned obfuscation and purposeful ambiguity. This is especially true for sensitive issues and equity problems. Never-the-less the framework here will make these judgements quite visible, and the analyst must take steps to avoid embarrassing the decision makers unexpectedly.

Value conflicts are resolved by policy, political and organizational processes, not technical ones. If there is only one key decision maker then, of course, this is a moot point, as in the case of the example used here.

If the opposing views are from groups whose values have only been ascertained indirectly, value conflicts may not be avoided, although educational presentations can help minimize conflict. If major value conflicts remain, it must be recognized at the outset that the choices of alternative will be a political solution as opposed to a rational balancing of risks and benefits. The politics will depend upon national policy, the role and power of regulatory agencies, and the form of government.

Further risk analysis may be useful only if the sponsors understand that the risk analysis will not resolve the value conflicts, but can help sharpen the arguments in the manner proposed be A. V. Cohen[4]. Whenever those with decision making power may be in agreement among themselves, but have external opposition groups, a risk analysis to help establish the preferred alternative for the decision making group may be still useful internally to sharpen the subsequent political debate.

CHAPTER 3

3.0. SPECIFY THE FRAMEWORK OF THE ANALYSIS

The results of Part A. are now used to layout the framework for the bottom-up analyses that have to be undertaken and the framework for using this information in the decision process.

3.1. Step 10 Finalize The Structure Of The Analysis

The structure of the analysis has two aspects: a) laying out the requirements for a decision structure and b) specifying the bottom-up analyses that must be undertaken. The first aspect involves analyzing the decision structure already developed in further detail, assuming that either all value conflicts have been resolved or it is shown that the analysis will be useful in spite of such value conflicts. The second aspect involves identification, grouping and specifying the studies identified in Part A.

3.1.1. Establishing Decision Structure Requirements

3.1.1.1. Sequencing Decisions

The various aspects of the decision among alternatives can be sequenced to simplify the process. In the case for the example given here, the decision sequence can be broken into several steps in the form of a decision tree. This tree is shown in Figure 3.1.

The first step is to determine whether coal, nuclear or both should be selected, the second is to determine the size of individual plants, the third is to determine the appropriate degree of environmental control or fuel type, and the next is to consider any secondary variables that must be addressed. Table 3.1 provides an illustration of the first level of decision for coal, nuclear or both. The cases shown for these three alternatives are agreed to by all in the example (Note that the reader may not agree with these choices, but agreement is

FIGURE 3.1

DECISION SEQUENCE TREE

FOR EXAMPLE PROBLEM

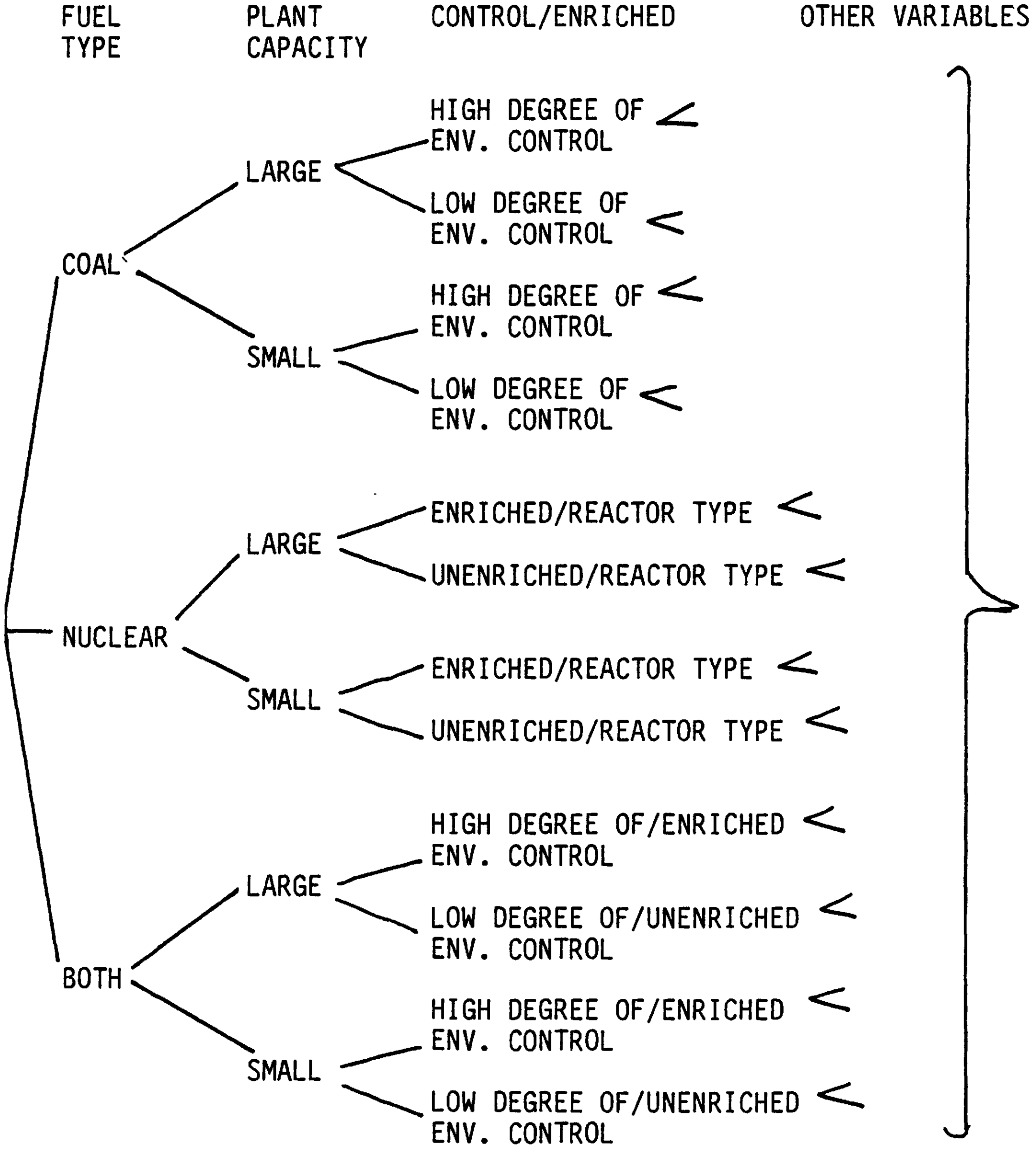

TABLE 3.1

SELECTED DECISION MAKER OUTCOMES FOR THE SAMPLE EXAMPLE

FOR SITUATIONAL SCENARIO #26
(A BENIGN CLIMATE, DEPENDANCE ON FOREIGN FUEL, MEDIUM POPULATION DENSITY)

27 SCENARIOS

F. FUEL COST ESCALATION
D. EXPECTATION OF DISRUPTION
A. DEGREE OF ANTI-NUCLEAR SENTIMENT

	A	D	F	ALTERNATIVE OR STUDY REQUIRED
1.	A-HIGH	D-HIGH	F-HIGH	COAL
2.	A-HIGH	D-HIGH	F-MOD	COAL
3.	A-HIGH	D-HIGH	F-LOW	COAL
4.	A-HIGH	D-MOD	F-HIGH	STUDIES #1 & #2
5.	A-HIGH	D-MOD	F-MOD	COAL
6.	A-HIGH	D-MOD	F-LOW	COAL
7.	A-HIGH	D-LOW	F-HIGH	STUDY #2
8.	A-HIGH	D-LOW	F-MOD	STUDY #2
9.	A-HIGH	D-LOW	F-LOW	STUDY #2
10.	A-MOD	D-HIGH	F-HIGH	STUDIES #1 & #2
11.	A-MOD	D-HIGH	F-MOD	COAL
12.	A-MOD	D-HIGH	F-LOW	COAL
13.	A-MOD	D-MOD	F-HIGH	STUDIES #1 & #2
14.	A-MOD	D-MOD	F-MOD	COAL
15.	A-MOD	D-MOD	F-LOW	COAL
16.	A-MOD	D-LOW	F-HIGH	STUDY #2
17.	A-MOD	D-LOW	F-MOD	STUDY #2
18.	A-MOD	D-LOW	F-LOW	BOTH
19.	A-LOW	D-HIGH	F-HIGH	STUDY #1
20.	A-LOW	D-HIGH	F-MOD	STUDY #1
21	A-LOW	D-HIGH	F-LOW	COAL
22.	A-LOW	D-MOD	F-HIGH	NUCLEAR
23.	A-LOW	D-MOD	F-MOD	BOTH
24.	A-LOW	D-MOD	F-LOW	BOTH
25.	A-LOW	D-LOW	F-HIGH	NUCLEAR
26.	A-LOW	D-LOW	F-MOD	BOTH
27.	A-LOW	D-LOW	F-LOW	BOTH

Study #1 = Probability Of Disruption And Its Impact

Study #2 = Expectation and Impact Of Anti-Nuclear Movement assumed for purpose of illustration). However, several cases are dependent upon studies that have to carried out prior to making a decision:

Study #1

Determine the probability of a further serious nuclear accident any place in the world such as those at Three Mile Island and Chernobyl, and the impact of such an event on nuclear power in the country (Scenario #26). Determine the probability of accidents, disruption, possible impact and recovery for a nuclear accident within the country. This will involve selection of specific reactor types and conducting whatever probablistic risk analyses (PRA's) that may be appropriate.

Study #2

Determine the likelihood, intensity, and impact of developing a major anti-nuclear movement within the country as a major political factor. Are there steps that can be taken that can minimize the growth of such movements?

3.1.1.2. Simplify The Decision Structure

All scenarios with the same alternative actions may be grouped together, allowing the factors that influence the alternative to be evaluated together. This has been done for the example being follwed in Table 3.2.

3.1.1.3. Make An Initial Evaluation Of Scenario Probabilities

In order to estimate the meaningfulness of the scenarios, a first cut analysis of the probability of the scnarios must be made. There are several different approaches that may be undertaken for this purpose:

Qualitative - Scenario Specific

Each scenario is assigned a likelihood of occurrence from the qualitative descriptions in a table such as:

TABLE 3.2

SELECTED DECISION MAKER OUTCOMES FOR THE SAMPLE EXAMPLE

FOR SITUATIONAL SCENARIO #26
(A BENIGN CLIMATE, DEPENDANCE ON FOREIGN FUEL, MEDIUM POPULATION DENSITY)

27 SCENARIOS

F. FUEL COST ESCALATION
D. EXPECTATION OF DISRUPTION
A. DEGREE OF ANTI-NUCLEAR SENTIMENT

	A	D	F	ALTERNATIVE OR STUDY REQUIRED
1.	A-HIGH	D-HIGH	F-HIGH	COAL
2.	A-HIGH	D-HIGH	F-MOD	COAL
3.	A-HIGH	D-HIGH	F-LOW	COAL
5.	A-HIGH	D-MOD	F-MOD	COAL
6.	A-HIGH	D-MOD	F-LOW	COAL
11.	A-MOD	D-HIGH	F-MOD	COAL
12.	A-MOD	D-HIGH	F-LOW	COAL
14.	A-MOD	D-MOD	F-MOD	COAL
15.	A-MOD	D-MOD	F-LOW	COAL
21	A-LOW	D-HIGH	F-LOW	COAL
22.	A-LOW	D-MOD	F-HIGH	NUCLEAR
25.	A-LOW	D-LOW	F-HIGH	NUCLEAR
18.	A-MOD	D-LOW	F-LOW	BOTH
23.	A-LOW	D-MOD	F-MOD	BOTH
24.	A-LOW	D-MOD	F-LOW	BOTH
26.	A-LOW	D-LOW	F-MOD	BOTH
27.	A-LOW	D-LOW	F-LOW	BOTH
4.	A-HIGH	D-MOD	F-HIGH	STUDIES #1 & #2
10.	A-MOD	D-HIGH	F-HIGH	STUDIES #1 & #2
13.	A-MOD	D-MOD	F-HIGH	STUDIES #1 & #2
19.	A-LOW	D-HIGH	F-HIGH	STUDY #1
20.	A-LOW	D-HIGH	F-MOD	STUDY #1
7.	A-HIGH	D-LOW	F-HIGH	STUDY #2
8.	A-HIGH	D-LOW	F-MOD	STUDY #2
9.	A-HIGH	D-LOW	F-LOW	STUDY #2
16.	A-MOD	D-LOW	F-HIGH	STUDY #2
17.	A-MOD	D-LOW	F-MOD	STUDY #2

Probability Level	Probability Associated
Very High	Above 0.5
High	Above 0.1
Moderate	Above 0.05
Low	Below 0.05
Very Low	Below 0.001

The associated probabilities are suggestive, and are only to help in assignment of qualitative levels. Scenarios with very low and, perhaps, low likelihood assignments may be eliminated from further concern.

Qualitative - Conditional Variable Likelihood

Each of the conditions of the critical variables are assigned descriptive levels of likelihood such as those used above. The intersection descriptions for the 27 intersections are derived from the combination of variables in a descriptive sense (e.g., Low/High/High) and ranked. Scenarios at the bottom of the ranking may be eliminated.

Quantitative - Scenario Specific

Each scenario is assigned a numerical probability. The sum of the 27 assignments is used to normalize each individual probability. Very low values may be eliminated as above.

Quantitative - Conditional Variable Likelihood

Each of the conditions of the critical variables are assigned quantitative levels of probability. These must add to unity for the three choices for each variable. The intersection probabilities for the 27 intersections are derived from multiplying the three probabilities from the three variables, and normalizing to unity with the sum of the intersections as a divisor. Scenarios at the bottom of the probability list may be eliminated.

Assignments using the last method are shown in Tables 3.3 and 3.4. The latter Table also shows the probability assignments by the decision alternative groupings. On this basis, the probabilities for the nuclear choice and for Study #1 alone are so small as to be eliminated. However, this is not necessary since the nuclear option must be addressed in the BOTH case and in the cases which need both Study #1 and #2. Since study #1 is needed in any case where both studies are required, it must also be done.

Never-the-less, at this point in the top-down risk analysis, a number of limitations on alternative solutions can often be ascertained. In the example shown, the low probability of conditions for the nuclear option alone almost preclude the deployment of large nuclear power plants as the sole option. Either coal or both coal and small nuclear plants remain viable options for the particular country situation. The moderate population density situation and the conditional variables may limit the option for large nuclear plants, but small nuclear plants with minimal potential for large accidents might be acceptable solutions. Studies #1 and #2 should be directed at these limited options.

3.1.2. Specify The Bottom-up Analysis That Must Be Undertaken

The following bottom-up analyses are required:

3.1.2.1. CRITICAL VARIABLES

Study #1

Determine the probability of a further serious nuclear accident any place in the world such as those at Three Mile Island and Chernobyl, and the impact of such an event on nuclear power in the country (Scenario #26). Determine the probability of accidents, disruption, possible impact and recovery for a nuclear accident within the country. This will involve selection of specific reactor types and conducting a whatever probablistic risk analyses (PRA's) that may be

TABLE 3.3

EXAMPLE OF VARIABLE PROBABILITY ASSIGNMENTS

FOR SITUATIONAL SCENARIO #26

PROBABILITY ASSIGNMENT	VARIABLES	
	F. FUEL COST ESCALATION	
0.1	LOW	PRESENT SITUATION
0.4	MODERATE	RISING SLIGHTLY FASTER THAN INFLATION
0.5	HIGH	HIGH ENERGY PRICES DUE TO CARTEL CONTROLS
	D. EXPECTATION OF DISRUPTION (ACCIDENTS, SABOTAGE, FUEL AVAILABILTY)	
0.6	LOW	LARGE ACCIDENTS WILL NOT OCCUR, FUEL HIGHLY AVAILABLE, AND NO SABOTAGE EXPECTED IN ANY WIDE SPREAD PATTERN
0.39	MODERATE	LARGE ACCIDENTS WILL NOT OCCUR, BUT HIGH VISIBILILITY ACCIDENTS WILL OCCUR, OR FUEL AVAILABLITY MAY BE LIMITED TO SOME EXTENT, OR SABOTAGE OCCURS ON A SELCTIVE BASIS.
0.01	HIGH	LARGE ACCIDENTS OCCUR, OR FUEL AVAILABILITY LIMITED SEVERELY, OR SABOTAGE OCCURS ON A WIDEPREAD BASIS.
	A. DEGREE OF ANTI-NUCLEAR SENTIMENT IN NATION	
0.1	LOW	NO ORGANIZED OPPOSITION TO NUCLEAR, UNLIKELY TO BE ORGANIZED
0.6	MODERATE	ORGANIZED OPPOSITION TO NUCLEAR DEVELOPS, BUT DOES NOT BECOME A MAJOR POLITICAL ISSUE.
0.3	HIGH	MAJOR OPPOSITION FORMS TO NUCLEAR, AND BECOMES A MAJOR POLITICAL FACTOR.

TABLE 3.4

PROBABILITY VALUES FOR SELECTED DECISION MAKER OUTCOMES FOR THE SAMPLE EXAMPLE

FOR SITUATIONAL SCENARIO #26
(A BENIGN CLIMATE, DEPENDANCE ON FOREIGN FUEL, MEDIUM POPULATION DENSITY)

27 SCENARIOS

F. FUEL COST ESCALATION
D. EXPECTATION OF DISRUPTION
A. DEGREE OF ANTI-NUCLEAR SENTIMENT

PROBABILITY		SCENARIO NUMBER	CONDITIONS			ALTERNATIVE OR STUDY REQUIRED
.0025*		1.	A-HIGH	D-HIGH	F-HIGH	COAL
.0020		2.	A-HIGH	D-HIGH	F-MOD	COAL
.0005		3.	A-HIGH	D-HIGH	F-LOW	COAL
.0787		5.	A-HIGH	D-MOD	F-MOD	COAL
.0197		6.	A-HIGH	D-MOD	F-LOW	COAL
.0040		11.	A-MOD	D-HIGH	F-MOD	COAL
.0010		12.	A-MOD	D-HIGH	F-LOW	COAL
.1570		14.	A-MOD	D-MOD	F-MOD	COAL
.0394		15.	A-MOD	D-MOD	F-LOW	COAL
.0002		21	A-LOW	D-HIGH	F-LOW	COAL
	0.31					
.0328		22.	A-LOW	D-MOD	F-HIGH	NUCLEAR
.0505		25.	A-LOW	D-LOW	F-HIGH	NUCLEAR
	0.08					
.0606		18.	A-MOD	D-LOW	F-LOW	BOTH
.0262		23.	A-LOW	D-MOD	F-MOD	BOTH
.0066		24.	A-LOW	D-MOD	F-LOW	BOTH
.0262		26.	A-LOW	D-LOW	F-MOD	BOTH
.1010		27.	A-LOW	D-LOW	F-LOW	BOTH
	0.13					
.0984		4.	A-HIGH	D-MOD	F-HIGH	STUDIES #1 & #2
.0505		10.	A-MOD	D-HIGH	F-HIGH	STUDIES #1 & #2
.0197		13.	A-MOD	D-MOD	F-HIGH	STUDIES #1 & #2
	0.12					
.0008		19.	A-LOW	D-HIGH	F-HIGH	STUDY #1
.0009		20.	A-LOW	D-HIGH	F-MOD	STUDY #1
	0.002					
.1510		7.	A-HIGH	D-LOW	F-HIGH	STUDY #2
.1210		8.	A-HIGH	D-LOW	F-MOD	STUDY #2
.0303		9.	A-HIGH	D-LOW	F-LOW	STUDY #2
.0303		16.	A-MOD	D-LOW	F-HIGH	STUDY #2
.0242		17.	A-MOD	D-LOW	F-MOD	STUDY #2
	0.36					
	1.00					

* Probabilities To Three Significant Figures Are Only To Show The Method And Overstate The Precision and Accuracy Of The Estimates By Orders Of Magnitude

appropriate. Emphasis should be on small nuclear plants with minimal capacity for sustaining large accidents.

Study #2

Determine the likelihood, intensity, and impact of developing a major anti-nuclear movement within the country as a major political factor. Are there steps that can be taken that can minimize the growth of such movements? Will small nuclear plants without accident potential be accepted where large plants would not?

3.1.2.2. Probability Determination Refinement

Based upon the above studies and other data, refine the probabilities of the decision conditions shown in Table 3.4. These refined probabilities will specify the conditions leading to the three fuel cycle options: NUCLEAR, BOTH, COAL, although the option for nuclear alone may already be eliminated.

3.1.2.3. OTHER VARIABLES

In order to determine costs and benefits in addition to risks, there will be a number of additional studies required for the options. These include:

Specific Design Options - Performance and costs of various methods of achieving the coal and nuclear options, including plant size and design concepts.

Environmental Impacts - Normal and abnormal releases (See Step #2) and the cost-effectiveness of reduction of detriment for coal and nuclear. The cost-effectiveness of particulate and sulfur removal for the coal option must be addressed along with global conditions of acid rain and carbon dioxide build up.

Capital Investment And Operating Costs - Investment and operating costs under different fuel costs associated with the different de signs under different fuel cost conditional scenarios.

Financial Responsibility And Sources

The role of finance and financial responsibility, specifically the respective financial positions of providers of finance, public or private, and end users may be a fundamental factor in determining the actual viability of proposed alternatives. The financing arrangements for different alternatives involve an array of unbalanced financial risk factors. Some of the risk factors that must be evaluated for providers are:

- Capacity of the provider for an alternative to perform as intended.
- Relative importance assigned by the provider to rendering performance for the energy alternatives selected among all other projects being financed by the provider.
- Total capital resource pool available and reserves.
- Nature and quality of the performance of the provider.
- Timing and schedule of performance

Essentially financial risk factors may be understood as a definition and conversion of value. In any given instance the means by which the provider, public or private, achieves an ability to perform its function will depend upon both its own financial condition and the financial structure supporting a specific performance characterized as an alternate energy alternative.

The converse of value issues for the provider may be characterized for the end-user (energy system owner) as reliance factors which may be enhanced or diminished by the presence or absence of certain derivative opportunities such as 1) the capacity to save, 2) the capacity to participate in and/or generate capital markets which may promote or suppress demand for energy, and 3) the capacity to diversify expenditures in terms of maximization of choice. Positive reinforcement of these three end-user capabilities by external markets and by the

TABLE 3.5

DATA REQUIREMENT STEPS FOR THE BOTTOM-UP RISK ANALYSIS

a Identify The Specific Kind Of Information Required For Each Critical Variable.

b Determine The Levels Of Precision And Accuracy Required For Resolution.

c Determine The Kinds Of Uncertainty Present In Each Variable And How These Errors Propagate.

d Determine What Measurements Can Be Made Versus Cost In Terms Of Time And Resources.

e In The Absence Of Direct Measurements, What Models Are Needed And How May They Be Verified?

f. Establish The Kinds Of Margins Of Safety That Will Be Required, And Estimate The Impact Of These Safety Margins On Cost And Benefits.

g Adopt Cost-Effective Strategies For Obtaining The Needed Precision In Terms of Interval Estimates Of Risk.

providers of finance themselves will, in turn, diversify financing methods available for R & D, production and marketing of alternative energy technologies.

Others As Required By The Situation

3.2 Step 11. Develop The Data Requirements For The Bottom-up Analysis

The steps involved in obtaining needed information are shown in Table 3.5, and discussed here in further detail.:

3.2.1. Identify The Specific Kind Of Information Required For Each Critical Variable.

The specific kinds of information needed for each critical variable as well as all other variables that must be addressed must be identified in sufficient detail to facilitate subsequent data acquisition steps. For example, using the variables from the illustration, the follwing descriptions of needed information might be developed.

EXAMPLE INFORMATION REQUIREMENTS

CRITICAL VARIABLES

Fuel Cost Escalation - For coal determine the probable cost ranges for different grades of coal under the three cases for this variable, and make any interpolations that make sense from the analysis (i.e., breaking down the variable to more than the three cases shown). Determine the political and economic factors that make each case viable. Determine the probability of these factors for each case in at least a qualitative sense. Determine if there are any leading indicators for these factors along with their lead time.

Note that this is primarily a political/economic study.

Expectation Of Disruption - There are three different aspects to this variable: 1) If one or more large accidents occur in nuclear power plants around the world, what will be the probable impact on small nuclear power plant operations within the country (also taking into account the next critical variable) should the BOTH option be implemented, and what is the likelihood of such events; 2) what is the likelihood and range of consequences of significant accidents in the country (also taking into account the next critical variable) should the BOTH option be implemanted; and 3) what is the vulnerability of both the COAL and BOTH options to sabotage, terrorism, and civil disobedience, and what are the likely consequences.

Note that these studies are partly technical and partly political. The technical studies must address the vulnerability of small nuclear power plants of the type chosen for the BOTH option to: a) accidents resulting in increased risks to the population, and b) service disruption. A technical assessment must be made of the likelihood of accidents in other countries, using existing information sources.

Degree Of Anti-Nuclear Sentiment - Determine the existing level of anti-nuclear sentiment and the factors that would make this sentiment increase or decrease. What would the impact be of increased or decreased activity on BOTH option. What is the likelihood of an incease on the BOTH option.

Note that this is a social/political study.

OTHER VARIABLES

Specific Design Options - determine the performance and costs of various methods of achieving the coal and nuclear options, including plant size and design concepts. The nuclear facilities should address small sized plants with designs for which waste heat removal in the event of an accident is not critical. The coal facilities should address the types of coal to burn, the combustion processes, and the stack cleaning requirements.

Primarily a technical design study.

Environmental Impacts - The studies for the expectation of disruption variable address accidents both within and without the design basis. The environmental impacts addressed here are for normal and abnormal releases that take place within the design basis, and consider the cost-effectiveness of reduction of detriment for coal and nuclear. The cost-effectiveness of particulate and sulfur removal for the coal option must be addressed along with global conditions of acid rain and carbon dioxide build up as well as normal and abnormal releases from nuclear plants.

Both a technical design study and risk analysis of normal and abnormal events.

Capital Investment And Operating Costs - Ascertain the investment and operating costs under different fuel costs associated with the different designs under different fuel cost conditional scenarios.

Primarily an economic study.

3.2.2. Determine The Levels Of Precision And Accuracy Required For Resolution.

In any of these studies the precision in the variables should not be more than that required to make the necessary decisions. Conversely it is not always possible to achieve the degree of precision required for a decision. Even if the precision is achieved, the required accuracy may not be achievable. (See the Glossary for definitions of precision and accuracy).

In a decision for this type of framework, values for technical and monetary variables can usually be determined more precisely than values for political and social variables. Thus, if social and political variables play an important role in the decision, values for technical and economic variables need not be more precise than, at most, an order of magnitude more precise than the political or social variables. Greater precision for technical and economic variables, because they can be measured or counted more precisely, will not aid in the decision process; and may detract from it by using resources more effectively applied elsewhere. This is especially true when accuracy of the values are questionable or involve wide ranges of uncertainty. For example, there is little sense in estimating the cost of an alternative to six significant figures, if a fifty percent overrun can be reasonably expected.

Table 3.6 provides a list of types of variables, giving appropriate levels of precision, and is aimed at providing a first order idea of the needed levels of precision. Of course, there be may specific situations where greater precision can be justified.

In cases where the desired level of precision is not attainable, value judgements and forms of quasi-quantification are used. The imprecision and inaccuracy involved will be very large. These "swing" variables determine the level for the other variables. The error in the swing variable estimates may easily encompass the error in the other variables combined, making it unneccesary and undesirable to state the other variables with much greater precision than for the swing variables.

3.2.3. Determine The Kinds Of Uncertainty Present In Each Variable And How These Errors Propagate.

There are three main types of uncertainty that must be addressed as a minimum: measurement uncertainty, model uncertainty, and value diversity, the latter somewhat different from the first two.

3.2.3.1 Measurement Uncertainty

Addresses the inability to measure process, control and cause-effect variables whether situational, conditional or operational. Actual measurement is involved, resulting in a level of precision of measurement

TABLE 3.6

NEEDED PRECISION OF VARIABLES IN DECISION FRAMEWORK

VARIABLE	LEVEL OF PRECISION	COMMENTS AND EXAMPLES
SOCIAL	1 in 10 to 1 in 20	Equity questions, economic allocation problems, non-economic benefits
POLITICAL	1 in 10 to 1 in 20	allocation of rights, effectiveness of political opposition
PROBABILITY	1 in 20 above .01	
	1 in 10 from .000001 to .01	
	Orders of Magnitude below .000001	
TECHNICAL		
Operational	1 in 100	Process paramters, higher precision may be required in actual design, but not for the decision process.
Conditional	1 in 100	Environmental and risk parameters are rarely measured accurately beyond this level.
Situational	1 in 20	These parameters are usually more descriptive than normative
ECONOMIC (Estimates for Future)		
Costs	1 in 100	Accuracy of estimates often less than this level of precision.
Prices	1 in 10	Precision is relative to a base or present price.

(resolution error), and errors due to inaccuracy in measuremnt (random, bias and systematic error).

a) Error Ranges And Propagation

The range of error is expressed by upper and lower bounds. Interval estimates are provided by statistical confidence limits and a best estimate, which may be any measure of central tendency (mean, mode, median etc.). Depending on the decision framework, measurement errors may propagate additively or multiplicatively. For additive cases the largest error in an addend will dominate. For the multiplicative case, the square root of the sum of the variances is used to determine the overall error range.

b) Measurement Of Probabilities

Measurement of probabilty is a special problem, especially for rare events. When events are frequent enough to provide an estimate of the frequency of similar events, then the measurement process based upon the various definitions of probability provide useful information. All probability measurements are based upon a "degree of belief" in the behavior of the systems under study. Three approaches whereby one attempts to estimate probability are given in increasing order in terms of the degrees of belief required in each case:

i) a priori information - prior knowledge about the behavior of a system for which one has a degree of belief that similar behavior can be expected to occur in the future, e.g., knowing in advance that a particular coin toss is "fair".

ii) likelihood of occurrence (Frequentist Approach) - study of historic or experimental data to determine the behavior of a system in order to evaluate its future behavior, e.g., observing the outcomes of a roulette wheel to determine possible imbalance. Here there is a degree of belief about the validity of the experiments as well as for the continuance of similar behavior. Moreover, there is always an assymtotic assumption error involved in such measurements. The expected value of random variable assymtotically approaches the expected value of the variable as the number of measurements increase, but never reaches the expected value (except by chance alone). When the error is small it is "accepted" as negligible.

iii) subjective estimates - in the absence of historical data, use any available information to estimate probabilities, and subjectively evaluate the meaningfulness of the information used, e.g., betting on a particular football game. Here the degree of belief involves the validity of available information as well as the kinds of degrees of belief involved in the two cases above. Bayesnian methods are tradionally applied in these approaches.

c) Problems In Measuring Rare Event Probabilities

Is it possible to address rare events through use of historical data alone? Sparse data makes it virtually impossible to gain significant information about rare events in this manner. What has been attempted in the past is to look at either events of higher probability and smaller consequences whose cause and effect relationships are hypothesized to be similar to the rare events to be studied, or to look at other rare events that have occurred and hypothesize that the same processes are involved as those of concern. In the first case, a profile of frequency of occurrence versus the magnitude of the consequence is made using historic data, and extrapolation from these data to rare events are attempted. In the latter case, the data base is increased since the number of events is larger, but the validity of grouping these events is questionable. For example, the number of nuclear reactor accidents versus reactor years of operation sometimes group ship propulsion reactors with electrical generation reactors, or operating data for small and large pressurized water, boiling water and other types of power reactors are aggregated without close examination of the validity of such approaches. The need to evaluate the possibility of future catastrophes from existing and new technological systems exists. For rare events whose potential consequence magnitudes are only limited by man's imagination, the usual methods of probability and statistics do not work.

3.2.3.2. Model Uncertainty

In the absence of good measurements, models are used to project results. In many cases the validity of models cannot be established by measurement, for example, extrapolating dose-effect measurements made in animals at high doses to effects at very low doses in man. Unless the models can be verified by actual testing, they remain as hypothetical constructs. In all cases the range of uncertainty in models spans the range from lower to upper limits of verification. For example, the extrapolation from high radiation doses to low doses in man has zero as a lower limit, and the statistical evidence from actual exposures in man privides an upper limit (e.g. Hiroshima and Nagasaki, uranium miner data, etc.).

a) Error Ranges And Propagation

Unless the range of uncertainty can be narrowed by actual test verification, all values within the range are equally likely. Different models may be developed to explain behavior in the uncertainty range; but without verification, all plausible models are equally likely. The reasonableness of models and judgement of the modellers may provide some feel for what models are prudent to use, but only represent value judgements, not hard science. The uncertainty involved in the choice of reasonable, alternative models is what is addressed by model uncertainty. The propagation of error may be additive or multiplicative. For additive cases the largest error in an addend will dominate. For the multiplicative case, there is no way to measure the variance in the choice of alternative models since there is no "right" model without verification, and the square root of the sum of the variances may not be used to determine the overall error range. The total range of uncertainty by choice of models must be used, and the range narrowed only by demonstrating the implausibilty of a model. For multiplicative error propagation, the ranges themselves are multiplicatively related.

b) Modelled Probability Measurement Methods

For rare events, it has been traditional to use a combination of the measurement approaches cited above to form two models for obtaining these probabilities.

i) modelled estimates - a study of the behavior of similar systems for which data is available which, with reasoned modification, is used as a model for the system under analysis, e.g., the estimate of rupture of steam boilers in general to provide an estimate of the probability of rupture of nuclear reactor boilers. Here the belief structure involves the confidence one has in comparing such systems, e.g., does radiation damage increase failures in boilers?

ii) system structure models - the failure of systems may be rare because of redundancy so analysis of the failure probability of component parts and their interconnection is used to synthesize an estimate of system behavior, e.g., event trees and fault trees in nuclear reactors. The belief structures involve the degree of know ledge about individual component behavior, how components behave in a system, and the degree to which all important system combinations can be ascertained. Such systems are always open-ended since the combinational possibilities are astronomical in number.

The propagation of multiplicate errors in such models may be somewhat better than for other modelled parameters since the binomial and Poisson among other distributions provide means of ascertaining variances, although this has yet to be verified.

3.2.3.3. Value Diversity In Interpretation Measurements and Models - Given a particular measurement or model result, there is wide diversity in how this information is interpreted. For example, a liter bottle containing 500 ml. of water may be cosidered half full or half empty depending on ones framework. Value diversity in interpretation of information addresses the diversity of values involved in such value judgments. Some of the value choices in the risk analysis involve diversity about:

a) Framing of The Problem Presentation

As in the case above, the manner in which a problem is framed may have a major impact on the interpretation of results of measurements and other information. Twersky and Kahnemen[1] have provided substantative evidence of the framing of the problem on interpretation of results. Since this will always occur to some extent, one has to recognize the existence of value diversity from framework formation and be on guard against such traps. The way to address this problem is to start with the use for which the study is to be made, and then test to see if alternate frameworks will provide substantial value diversity.

b) The Meaning Of Probability

There are several aspects in the manner in which people interpret probabilities. The most obvious one is whether one is an objectivist or a subjectivist in terms of belief system. This difference is addressed in most textbooks on probability, and will not be addressed further here. But this difference must be recognized.

A much more significant problem in risk analysis is how people address the probability of events, especially rare events. One aspect of the problem can be addressed by whether absolute or relative risk estimates are used. Absolute risk and relative risk may be defined as follows:

Absolute Risk - an estimate of the likelihood of an event with a specific consequence in terms of its probability of occurrence. Both point and interval estimates may be made.

Relative Risk - an estimate of the relative likelihood of an event as compared to the likelihood of other events external to the analysis of a similar magnitude or a similar comparison of event magnitudes for events with the same likelihood.

Comparative Risk - An estimate of the probability of several events in a system by comparing them to each other. Since the events are all compared to each other, many of the uncertainties are eliminated. However, the system has no relation to absolute risk unless one of the estimates is "pegged" to a reference external to the system in a relative risk manner.

For a go/no-go type of decision, one would like to have a meaningful absolute risk estimate. For selection of one of a set of alternatives only relative risk estimates are required. As will be seen relative risk and comparative risk evaluations can be quite useful in decision making.

Since absolute risk estimates have very wide ranges of error for rare events, they may or may not be useful for decision making, depending upon where the risk estimates and their ranges of uncertainty lie. Absolute risk decisions are usually made against some reference level of probability. Whether or not very low absolute values of probability are meaningful in terms of such abstract references, especially with large ranges of uncertainty is doubtful, except, perhaps, for the expert. As noted in the first report, "Assessment of Comparative and Non-Comparative Factors In Alternate Energy Systems", for a single rare event, one standard deviation (standard error) is the square root of the expected value of probability of occurrence. The square root of a small probability is, therefore, always larger than the expected value. The standard deviation is narrowed as the number of events increases (by the square root of the number of events): but, if the number of events becomes large, the events may no longer be considered rare.

Relative risk involves comparing a risk against meaningful references. Benchmarks are one form of reference that do not necessarily imply acceptability. They are risks of a similar nature that people have experienced, and provide a reference to real conditions. There may, of course, be uncertainty in the reference risk estimate; and, if this range of uncertainty is very different from that of the estimate of the rare events, then the comparison may not be valid.

c. Dealing With Different Levels Of Uncertainty Among Variables

Even when the magnitude of the variables are identical, either for the probability of occurence or the magnitude of consequences, different ranges of uncertainty among variables can lead to differing interpretations of comparisons. For example, is a probability estimate of 0.05 with an error range of $\pm.03$ considered to be lower than a probability estimate of .06 with a similar error range of $\pm.005$? This is a standard problem in applied probability, and must not be ignored.

d. Risk Neutrality, Aversion And Proneness

As demonstrated by Twersky and Kahnemen[1] and Rowe[2] individuals behave differently in how they compare probablistic conditions with conditions of certainty or with conditions that have less uncertainty than the primary conditions. Three kinds of behavior have been identified. The definitions used here are from Smith[3]:

Risk Neutral - Indifferent toward a fair bet. Five dollars with certainty and a 50 percent chance of ten dollars are equally attractive. Tries to simply maximize expected return. Does not buy insurance or lottery tickets because both have negative expected returns.

Risk-Averse - Turns down fair bets. Prefers five dollars to a 50 percent chance at ten dollars. Will sacrifice expected return to reduce risk. Buys insurance, but not lottery tickets.

Risk-Seeking - (Risk Prone) Accepts fair bets. Prefers a 50 percent chance at ten dollars to a sure five dollars. Will sacrifice expected return to increase risk. Buys lottery tickets, but not insurance.

Rowe[2] has shown that the range of behavior toward risks in the probability range of a 0.01 to 0.001 chance per year extend over four orders of magntude in comparing the gamble at these probabilites versus consequences occurring with certainty. This is an extremely important consideration in the evaluation of risks.

e. Degree Of Margins Of Safety To Be Used

In dealing with uncertainty in risk estimates, it may be important to assure that the actual risk may be below a specified value. This is done by adding margins of safety to the best estimate that can be made or by choosing models that provide conservative (higher) estimates of risk. One way to deal with these uncertainties is to use margins of safety. Critical questions must be addressed in using this approach:

- o What are the proper uses for margins of safety?
- o Who establishes the margins of safety?
- o What levels of safety are needed?
- o How do the margins of safety build up in terms of an overall margin of safety?
- o How much do the margins of safety cost?

Table 3.7, in addressing the first item, lists some uses of margins of safety that can be appropriately applied in risk analysis. The last question is critical. There is nothing wrong with using margins of safety if we determine how much it will cost before we apply them. To apply such margins without regard to their implications is ludicrous, but we do it all the time. The problem is not the margins of safety themselves, but the absence of even a rudimentary cost benefit analysis of their application.

In dealing with uncertainty, whether dealing with risks or any other variable, a point estimate of the value of a variable by itself provides no information on the uncertainties involved. An interval estimate is preferred, using a range of risk estimates to provide both the level of risk and a measure of its variability simultaneously. This dual presentation of the risk estimate (i.e., level and variability) is necessary to provide credibility to the analysis. However, in this case for use of margins of safety, the interval is always expressed in terms of the increased assurance that the real risk lies below a given estimate. It is a one sided range above the best estimate which is the lower limit of the range. The

Table 3.7.

BASIS FOR USE OF MARGINS OF SAFETY IN RISK ANALYSIS

1. Ranges of Sensitivity In Exposed Populations
   A. Used to account for different sensitivities in population to risks, including age, sex, genetic, and general state of health factors.
   B. Generally not more than a factor of 2 or 3. Factor of three has been used in radiation protection*.

2. Inability to Measure Precisely or Accurately
   A. Exposure Pathways - Dispersion, mixing, deposition, dilution, uptake, metabolic fate, dose levels in air, water, tissue, etc.
   B. Potency - Dose/effect relationships, epidemiological studies, animal testing, converting animal studies to man,etc.
   C. Performance - Measurement, monitoring, and sampling of system performance in test and in service.
   D. Synergistic And Interactive Relationships.
   E. Can be orders of magnitude, depending upon <u>measurement</u> capability and limits of detection; both accuracy and precision affected.

3. Lack of Information
   A. Data not available due to lack of resources - Money, time, capital investment, acquisition sources, data validation and storage, data analysis.
      i. Data is beyond reach in terms of reasonable resources.
      ii. Data can be obtained, but requires time to acquire which is too long.
      iii. Data must be obtained for specific sites and conditions as needed.
      iv. A trade off must be made in terms of the fineness of the data versus the generic use level desired, and the resources involved.
   B. Data not available due to restrictions - Confidentiality of information, regulatory restrictions (privacy), trade secrets, etc.
   C. At the limits of knowledge
      i. Complexity is too large to handle.
      ii. Processes and conditions not repeatable or too rare to obtain data.
      iii. Signal to noise ratio too low, i.e., variance of the signal too large compared to the variations in ambient and competing information.
   D. Many orders of magnitude in uncertainty involved, but can often be adjusted to the decision to be made and vice versa.

4. Margin For Operational Variations
   A. Accounts for short term excursions and minor abnormalities in operational practice.
   B. Seldom more than a factor of two.

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*Originally used by the U.S. Federal Radiation Council to take into account 500 millirem individual exposure to the population at 170 millirems in 1960. (ICRP uses .5 and .1 mSV, but with a different explanation).

range of risk can be provided by three separate sets of asssumptions for each variable addressed:

a) realistic assumptions

b) conservative assumptions

c) worst case assumptions

These will be defined below. However, it should be noted that the range between the realistic and worst case is a direct measure of the level of conservatism used to encompass the range of uncertainty associated with a variable for which margins of safety have been used..

3.2.4. <u>Determine What Measurements Can Be Made Versus Cost In Terms Of Time And Resources.</u>

This step is a basic analysis of the difficulty of gaining further information on a variable versus the cost in getting it. One wants to use the best scientific means available and affordable to get the data. The earlier report "Assessment of Comparative and Non-Comparative Factors In Alternate Energy Systems" provides a review of the problems in acquiring and using such data.

3.2.5. <u>In The Absence Of Direct Measurements, What Models Are Needed And How May They Be Verified?</u>

When direct measurements cannot be made, models are used. The uncertainty in the use of the models must be established and verified to the extent feasible. The choice of models which tend toward the conservative practice of overestimating risks is analagous to using margins of safety. This means, that an interval estimate of model uncertainty is appropriate. One can, in this case show models which are less conservative than the realistic estimate as well as conservative and worst cases to show the total range of uncertainty. The only selection criteria for making one model more appropriate than others is the reasonableness of the model and the degree of conservatism involved. Conservatism is expensive, and should be considered explicitly in the choice of models and ranges of models used.

3.2.6. Establish The Kinds Of Margins Of Safety That Will Be Required, And Estimate The Impact Of These Safety Margins On Cost And Benefits.

All of the conservatisms and margins of safety to be used should be determined. The manner in which these conservatisms propagate must be examined, and the total margins of safety in the analysis determined to the extent possible. The cost of the margins of safety may then be determined by going back to the decision framework, and determining how the choice of alternatives will change as margins of safety are varied. It is important to realize that increasing a margin of safety does not decrease the actual risk that may be experienced for an alternative, but only increases the confidence that the estimate bounds the actual risk. The cost of selecting a more costly alternative is traded off against the increased confidence in the risk estimate. This increased cost is sometimes erroneously equated with increased credibility.

The important thing to note is, that for this decision framework, the cost of margins of safety are obtained directly by determining whether a change in the margin of safety, without a change in the basic data, will cause a different alternative to be selected. If no changes are forced, then the margins of safety do not affect cost.

3.2.7. Adopt Cost-Effective Strategies For Obtaining The Needed Precision In Terms of Interval Estimates Of Risk.

The cost of acquiring data along with ranges of uncertainty about the data is usually traded-off against the value of the additional data in resolving the decision. In this framework the cost of more precise data is only justified when the reduced uncertainty in a critical decision variable will possibly affect the choice among alternatives.

3.3. <u>Step 12.</u> Identify The Limitations Due To Uncertainties, And Estimate The Robustness Of The Joint Analysis

All of the uncertainties addressed in the the previous step must be identified, and an error analysis made on how the uncertainties propagate. If changes in data, such as getting more precise and accurate measurements, better verified models, and narrower margins of safety, or means for minimizing the impact of differing interpretations of data can be identified which would make the choice among alternatives more reasonable, these limitations should be identified. It may not be possible to obtain these requirements because of time, cost and measurement limitations. These limitations should be identified. Having identified them, the complement procedure is to indicate how well the analysis to be undertaken, including the uncertainties, will help in resolving the decision among alternatives. This is called the robustness of the analysis. A robust analysis need not be precise, but sufficiently adequate to assure that an alternative may be decisively selected.

3.4 <u>Step 13.</u> Provide A Report On The Top-down Analysis, Providing Specifications, Limitations, And Recommendations.

Once the first twelve steps are completed, a report should be prepared summarizing the findings and specifying the bottom-up risk analysis requirements. In some cases the top-down analysis may in itself provide adequate information to make a decision among alternatives. If this is the case, this will be a final report. Otherwise it will be an interim report, and will also be a specification for the subsequent analyses. In any case the structure of the report should be similar to the presentation of results discussed in the next Chapter.

CHAPTER 4

4.0 IMPLEMENTING, ANALYZING AND PRESENTING THE RESULTS OF THE ANALYSIS

In this Chapter we examine the remaining steps in carrying out the generic analysis. This covers acquiring and analyzing the data. And reconciling the results and presenting them.

4.1 (Part C.) Data Acquisition

4.1.1. Step 14. - Conduct Required Studies To Obtain Required Information:

This step is straight forward. It involves scheduling time and resources to conduct the necessary studies.

4.1.2. Step 15. - Acquire The Data:

Acquire the data, using the best scientific approaches available, within the resources allocated. Determine the measurement errors entailed in results of the measurements. Depending on data needs this can be a long and expensive process. Thus, it is important to ascertain that the data acquired will be useful in selecting an alternative as specified in the previous steps.

4.2 (Part D.) Implement The Analysis

4.2.1. Step 16. - Conduct The Analysis

4.2.1.1. Separation Of Risk Parameters

In conducting the analysis for critical parameters involving risk, the separation of different risk mechanisms is desirable. Since only a few categories exist, the risks from these mechanisms should not be aggregated, but left as separate results for the decision makers. The framework has been set up with this in mind. In analyzing the results, significant risk factors for a proposed or ongoing activity may occur from any one of three different mechanisms: 1) normal operations, 2) abnormal operations, and 3) rare events as indicated in the critical variables for risk.

Normal operations refer to the everyday operational procedures that are carried out in any undertaking and take into account the variations that are expected to occur when the procedures are working properly. This is the manner in which the system is designed to work for all parts of the fuel cycle. Risks from normal operations involve releases of pollutents and radiation to the environment and the general public and to workers.

Abnormal operation takes into account special conditions that may rarely occur, lead to higher risk exposure than for normal operations, and involve excursions beyond normal procedures. The abnormal conditions may arise from changes in demand, equipment breakdown, environmental stress and human error. Never-the-less, these conditions may be anticipated, and have been incorporated into system design. A design basis accident in a nuclear system is an example of an extreme, but abnormal event.

Rare Events are both expected and unexpected conditions, leading to a range of exposures to risks. In the expected case the events are anticipated to be so rare, as to, hopefully, not occur within the life of the system. In nuclear energy systems these would be called accidents beyond the design basis accident. Unanticipated events are surprises, hopefully rare, but for which the system has not been specifically designed to cope.

There are several different consequences that must be addressed for abnormal operations and rare events which will have different probabilities, and should not be aggregated prematurely. These are:

Vulnerability To Disruption - Loss of power production for short or long periods as a result of accidents or sabotage or civil disturbances. This includes both operating losses and loss of capital investments.

Injury, Illness and Fatalities - Events leading to direct trauma or disease leading to to injury, illness and premature death. The event may lead to a range of number of people affected, both workers and the general public. Classifcation by magnitude of consequence is desirable.

Irreversible Environmental Damage - Events leading to severe environmental damage that may be irreversible in either the short or long run. Both the time element and the amount of damage must be considerd.

4.2.1.2. Uncertainty, Interval Estimates And Error Propagation

For each mechanism, the uncertainty in the historic data and the scenarios used to describe particular exposure situations, make a point estimate of risk inadequate. Interval estimates are needed for each variable and their combination. Interval estimates for measurement uncertainty, model uncertainty, and use of margins of safety all have different characteristics, and the way they combine additively or multiplicatively also is different in each case.

a. Measurement Uncertainty

Interval estimates for uncertainty in the measurement are made up of the usual limits for any measurement. The range of the interval can be the actual range of measurement uncertainty or it may involve the use of statistical confidence limits around a most likely value to account for random error in measurement.

Probabalistic risk analysis is a useful tool for ascertaining probabilities that can be directly measured. However for rare events, the uncertainty ranges may be so wide as to be useless. On the otherhand relative risk estimates are very useful for system safety studies such as finding weak links or determining where to spend additional safety resources most effectively. Some approaches for the development of interval estimates for measurement uncertainty in variables are provided in Table 4.1.

b. Model Uncertainty

There are two aspects to model uncertainty: 1) the uncertainty in specific models and 2) the uncertainty in choice of appropriate models. In the first case, the model used will itself provide a measure of the uncertainty limits in the form of measurement uncertainty. However, for the more important case, the choice of models, the only criteria for limiting model uncertainty derives from the limits that can be verified by actual testing and tests of reasonableness. The tests of reasonableness are useful for excluding models that one is <u>sure</u> are inapplicable.

For rare events the use of modelled estimates and system structuring to determine the probability of events involve models since they are themselves models. There are a number of assumptions which may be unverifiable:

o Completeness of identifying all possible events or faults on a tree

TABLE 4.1

GUIDELINES FOR INTERVAL ESTIMATES FOR MEASUREMENT UNCERTAINTY

BEST ESTIMATE	Maximum likelihood estimator
UPPER LIMIT	Highest value measured
LOWER LIMIT	Lowest value found or the resolution of measurement technique
STATISTICAL ASPECTS	Confidence limits around a measure of central tendency. for probability based upon a frequentist approach, the standard deviation of a rare event is $(np(1-p))^{\frac{1}{2}}$ where p is the best estimate of probability of occurrence.
ADDITIVE PROPAGATION	Add best estimates and show the largest confidence limits. Variables whose value and ranges of uncertainty are a small fraction of the uncertainty in the least certain variables may be deleted from further consideration after stating why.
MULTIPLICATIVE PROP.	Confidence limits are derived using a standard deviation derived from the square root of the sum of the variances or other similar statistics for the upper and lower bound estimates.
INTERVAL	Use statistical confidence limits to extent possible with the most likelihood estimator as a mid-point.

- Unidentified common mode failures
- For system structuring: Does the system behave as its parts would predict?
- For modelled estimates: Are the models used applicable to the case understudy?
- Taking into account multiple, simultaneous failues in a fault tree, including intermittent events.

Table 4.2 provides some for making interval estimates of the uncertainty due to selection of models which cannot be directly verified.

Note that model uncertainty from the particular models chosen must be additionally addressed to that of model choice uncertainty.

c. Use Of Margins Of Safety

Margins of safety are used to provide degrees of conservatism whereby the degree of confidence that actual risk lies below an estimate is increased. This is a one sided measure. It may be used for any of the reasons suggested in Table 3.6. Table 4.3 provides some considerations for establishing interval estimates of the degree of safety afforded.

It is important to leave an audit trail of any variables discarded, i.e., it is important to state negative as well as positive results explicitly.

4.2.1.3 Steps In Environmental Risks Determination

Most readers will be familiar with the bottom-up approach to risk analysis. For example, the process of estimating the risk to humans from a number of effluents from energy producing systems involves several generic steps. Consider as illustrative effluents radiation from a nuclear power plant, toxic hydrocarbons in coal emissions and stack cleaning residues, and nitrogen dioxide from fuel combustion of natural gas.

1) Source Term.

Amount of each substance released to the environment. For a particular

TABLE 4.2

GUIDELINES FOR INTERVAL ESTIMATES FOR MODEL CHOICE UNCERTAINTY

BEST ESTIMATE	The value judgement of the analyst or a group of experts is often employed to select the model which is thought to be most realistic.
UPPER LIMIT	The model which provides highest value below that level which can be experimentally verified.
LOWER LIMIT	The model which provides the lowest value found and may include zero. For example, in extrapolating effects measured at high doses to effects postulated at low doses, the possibility of no effect cannot be excluded.
STATISTICAL ASPECTS	There are no statistical aspects as to model choice. As long as models are deemed reasonable they are all equally likely until verified.
ADDITIVE PROPAGATION	Add the results of using the models that provide lowest, best and highest estimates each, respectively. Variables whose value and ranges uncertainty are a small fraction of the uncertainty the least certain variables may be deleted from further consideration after stating why.
MULTIPLICATIVE PROP.	Multiply the results of using the models that provide the lowest, best and highest estimates, respectively.
INTERVAL	The range of the lowest and highest results. The best estimate may also be given as a point in between the limits.

TABLE 4.3

GUIDELINES FOR INTERVAL ESTIMATES TO EXPRESS MARGINS OF SAFETY

BEST ESTIMATE	The most realistic estimate. Does not use margins of safety. Can represent a 50 percent assurance that actual risk lies below the estimate.
UPPER LIMIT	Worst case estimate where one is sure the actual lies below the estimate.
LOWER LIMIT	The most realistic estimate without margins of safety. The same as the best estimate.
MID-RANGE ESTIMATE	A conservative estimate using adequate margins of safety to provide a very high confidence that the actual risk lies below the estimate.
STATISTICAL ASPECTS	There are no statistical aspects except for expressing the degree of confidence one has that the actual risk lies below a given estimate. The degree of confidence here is not statistically based, but acts somewhat like confidence limits.
ADDITIVE PROPAGATION	Add the results using the realistic, conservative and worst case estimates respectively. Variables whose value and ranges of uncertainty are a small fraction of the uncertainty in the least certain variables may be deleted from further consideration after stating and documenting why.
MULTIPLICATIVE PROP.	Multiply the results of using the realistic, conservative and worst case estimates, respectively. The resulting values for each case form the new range.
INTERVAL	The range between the realistic and worst case estimates with the conservative estimate as a point in between the limits.

energy this involves the measurement of the manufacture and natural production (if it occurs) of the emissons for each part of the fuel cycle. For a specific, continuous release the concentration and amount of each substance, as well as its physical and chemical form must be determined. For an accidental release, the probabilities of the accidents and the probable amount of release is needed in addition to the concentration and amount.

2) Pathways.

Release pathways to the environment via air, water, food, direct contact must all be estimated leading to intake by exposed humans through inhalation, ingestion and dermal absorbtion.

3) Metabolic Pathways and Fate.

Metabolic behavior of the substances in the body must be established. The toxicity of metabolic products must also be determined.

4) Dose Estimate.

Estimation of the concentration at specific organ sites along with a time profile of the dose to each organ. Persistance of the substances in the environment, and existing ambient levels must be added to the dose from the pathway.

5) Dose-Effect Relationship.

Conversion of the dose to a designated individual (real or hypothetical such as a maximum exposed individual) via relationships between dose and effect established by epidemeolgical studies, tests in man, tests in animals, and cellular level tests. Extrapolation from animal to man and from high doses at which tests are made to the low doses at which exposure takes place require models for extrapolation which cannot often be verified as to their validity for such extrapolation. Cancer from radioactive iodine or toxic organic chemicals use non-threshold relationships while nitrogen dioxide has a No Observable Effect Level (NOEL) in humans and animals for increased susceptibilty to respiratory diseases. Cancer can be fatal, while the upper respiratory diseases are seldom fatal.

6) Individual Risk Estimate.

Estimates of the risk to the maximum and/or average exposed individuals, taking into account cumulative effects, time profile of the exposure, and sensitive members of the population, are then derived from the dose-response relationships.

7) Population Risk Estimates.

The population risk is determined by integrating the individual estimation of risk over the population based upon the dose to each member. Because of the difficulty of carrying out such measurements, often the average exposed individual risk is estimated, and simply multiplied by the number of people exposed to get a crude estimate of the population risk.

This type of approach means acquiring very large amounts of data and measurements at the detailed level at each step, and then progressively aggregating the analysis as one procedes from the first to last step. This is a slow, very expensive process. What do you have when you get hone? Because of large uncertainties there are often meaningless results. For example, Table 4.4 provides an estimate of the model uncertainty ranges in the models used in carrying out each step above for three different effluents illustrated. These uncertainty ranges do not address measurement uncertainty, use of margins of safety, or value diversity in interpretation of results. These uncertain ties are associated with how closely the models describe the actual situation, and they do not take into account any uncertainty in the use of particular models. The model ranges used represent the interval between reasonable best and upper estimates. That is, the range has actually been limited by cutting off the lower end of the interval. For this bottom up model, the error propagate multiplicatively. The progression is

TABLE 4.4

MODEL UNCERTAINTY IN THE BOTTOM-UP RISK ANALYSIS
OF ILLUSTRATIVE RELEASES TO THE ENVIRONMENT

STEP	MODEL	UNCERTAINTY FACTOR RANGE		
		Toxic Organic	Radio Iodine	Nitrogen Dioxide
1. Source Term.				
	Averaging in Space	1.1 to 3	1.1 to 2	1.1 to 10
	Averaging in Time	1.1 to 3	1.1 to 3	1.1 to 5
2. Pathways.				
	Diffusion Models	2 to 10	1.1 to 2	1.1 to 3
3 Metabolic Pathways and Fate.				
	Organ Intake Models	2 to 10	1.1 to 3	1.1 to 3
	Distribution Models	2 to 4	1.1 to 2	1.1 to 2
	Retention Models	2 to 4	1.1 to 1.5	1.1 to 1.5
4. Dose Estimate.				
	Exposure Time Profile	2 to 10	1.1 to 10	2 to 10
	Maximum vs. Average Individual	2 to 10	1.1 to 5	2 to 10
5. Dose-Effect Relationship.				
	Extrapolation From Animal To Man			
	Choice of Scaling Model	40	2 to 10	20
	Metabolic Differences	2 to 100	1.1 to 1.5	2 to 5
	Extrapolation From High To Low Dose			
	Choice Of Model*	1000	3	100
	Margins of Safety*	10 to 1000	2	2 to 10
6. Individual Risk Estimate.				
	Real vs Hypothetical Individual	4 to 20	4 to 20	4 to 20
7. Population Risk Estimate				
	Integration vs Averaging Models	2 to 10	2 to 5	2 to 10
Multiplicative Ranges				
	Low	5×10^7	2×10^2	5×10^4
	High	1×10^{15}	4×10^6	3×10^{10}

* Use either, but not both. The first is for non-threshold dose-effect relationships, the latter for threshold types

explained in the previous section for model choice uncertainty. The low multiplicative range represents the best estimate interval, the high range is the upper limit interval.

It is interesting to note the wide difference in model choice uncertainty for these three substances. More is known about radiation effects than for either toxic chemicals or combustion gases, and better models are available for radiation effects. Radiation should not be penalized because its risks can be estimated with less model (and measurement) uncertainty then the other effluents.

4.3 (Part E.) Merge The Results Of The Bottom-up Analysis Into The Framework

4.3.1 Step 17. - Reduce The Conclusions To The Implications Of Alternative Policy Options Based Upon The Analysis

The data from the bottom-up analyses are merged into the decision framework in terms of the particular studies that were required to address indecision of selection of alternatives. In this case the interval estimates are used to provide insight into the levels of uncertainty. The width of the uncertainty intervals is a direct measure of the uncertainty. The difficulties in developing these levels arises in the manner in which the uncertainties are combined. This must be done on a case by case basis. However, since the results for normal, abnormal and rare event cases are all evaluated separately, the uncertainties and general levels of probability will be approximately the same order of magnitude for each case. This is a major reason for keeping these cases separate.

Should the intervals of uncertainty overlap the critical decision values, then the bottom-up analysis will apparently not have helped in the resolution of the decision at first glance. However, one can trade-off margins of safety to determine how much of these margins must be reduced to provide a decision one way or the other.

The primary use of the bottom-up analysis is to provide the input of the studies needed for the decision framework, and for determining the probabilities of the critical conditional variables and/or scenarios.

4.4. (Part F.) Present The Results Of The Analysis

The presentation of the results of the analysis is critical. A final report should have at least two and possibly three parts to it. The first is the body of the report which is addressed primarily to the technical community. It should provide means to allow any competent technical person to be able to repeat and verify the results of the analysis. The analysis should show the analytical conclusions, present error and uncertainty ranges of results, identify where margins of safety have been used and how they aggregate, and indicate any technical value judgements that have been made. These latter judgements address such items as the criteria used for establishing realistic, conservative and worst case assumptions, definitions of normal and abnormal operations and rare events, and interpretations of measurements.

The second part is aimed at policy makers and risk managers and the general public, although a separate presentation for the public may be warranted. This second part should generally be an executive summary of the first part, but without any more of the technical material than absolutely necessary.

4.4.1. Step 18. - Executive Summary And Policy Analysis Document

The executive summary is the primary policy analysis document. It should address all the critical parameters in the decision framework. The results should be shown in terms of the decision framework. Normal, abnormal, accident and rare event conditions should be addressed separately to the extent that they need be addressed in the framework. Absolute probability and risk estimates should be put into perspective by comparing them to similar benchmark risks for which people are familiar and can directly relate. In this manner all relative risk estimates among alternatives need only be considered on a relative basis, and absolute risk may be derived by "pegging" one of the alternatives to a familiar absolute benchmark. In many cases the presently used alternative may serve as the benchmark and "peg" for the absolute risk. Whatever the benchmark, it should also be presented in terms of an interval estimate as well to make valid comparisons over the whole uncertainty intervals.

Once the absolute estimate is put into perspective, the relative risk of alternatives may be described. This may be done in semi-quantitative terms by comparing the interval range of risks with each other. Gross descriptors of the risk comparison may be defined in qualitative terms; e.g., higher, same, much lower, etc. each representing a range of comparison of risk intervals which easily may encompass two orders of magnitude. These formal descriptors provide for a measure of comparative risk with their relative uncertainties taken into account. Table 4.5 provides an example of one set of gross descriptors we have used in another type risk analysis, that might be appropriate for alternative energy systems.

The important point is that the executive summary should provide information in terms the decision maker and the public can understand.

4.4.2. Step 19. - Presentation Of Technical Backup Documents

The details of the study and framework for analysis must be put together into a technical report for the technical community to use. It must provide the framework itself, the supporting analyses with all the uncertainties designated, and with all assumptions explicitly shown. It should provide an audit trail so that a competent technical person can retrace all of the steps. Technical appendices can be used to detail the specific bottom-up analyses undertaken.

TABLE 4.5

SOME GROSS COMPARISON LEVELS USING INTERVAL ESTIMATES

GROSS COMPARATIVE RISK DESCRIPTORS	NUMBER OF ESTIMATES*	DIFFERENCE FACTORS
SAME	2 of 3	Less than 5
SLIGHTLY HIGHER (OR LOWER)	2 of 3	Greater than 5
HIGHER (OR LOWER)	All 3	Between 5 and 100
MUCH HIGHER (OR LOWER)	All 3	Between 100 and 10,000
VERY MUCH HIGHER (OR LOWER)	All 3	Greater than 10,000

* Refers to the three estimates made: realistic, conservative, and worst case, or lower, mid-range, upper limit as appropriate.

PART II..

OTHER FACTORS IN IMPLEMENTING THE FRAMEWORK

There are a variety of other factors involved in carrying out the decision framework. This part deals with a number of these.

Chapter 5. Matching Users and Uses Of Risk Analysis

Chapter 6. Benefit Considerations

Chapter 7. Special Issues For Alternative Energy Systems

CHAPTER 5

5.0 MATCHING USES AND USERS OF RISK ANALYSES FOR ALTERNATE ENERGY SYSTEMS

As stated in the first report, the uses of analyses may be categorized by two classifications, particularly when addressing risk analysis of alternate energy sources. The first classification is based upon the application of the analysis, and ranges from site specific studies to global analyses, i.e., a range from micro to macro analyses. The second concerns the range of users and their purposes. This includes policy setting groups such as utilities, communities, local, regional and national authorities, and international organizations; the technical community consisting of scientists, engineers, economists, environmentalists, etc.; and the general public.

These two classifications are not independent since the level at which a decision is being made and the degree to which the analysis is an input to a decision reflects whether a study will focus on either micro or macro aspects.

5.1 CLASSIFICATION BY SCOPE OF APPLICATION OF ANALYSIS

The scope of application of a risk analysis depends, in turn, on the scope of the project undertaken by a project sponsor. Table 2.1 lists the range of scopes of projects in the energy field for which risk analyses of alternate systems are carried out. This list is from the initial study and the descriptions below are abstracted from that study.

5.1.1 Site Specific Studies

Site specific studies are concerned with selecting an energy option for a particular site. Not only is the type of energy source an alternative, but the particular technology within an energy source is also important. If one is to use coal, the kind of coal (hard, soft, lignite), the kind of combustion process and the type of stack cleaning process are examples of parameters which change within an energy alternative.

5.1.2 Utility Planning Studies

A utility, in planning for future expansion to meet anticipated demand, must make analyses to determine the number and proper mix of alternative energy sources to be installed on a future time table. Both external studies across types of energy sources and internal studies for variations within energy sources must be addressed. While specific sites may or may not be selected, a utility can address the problems of sources of energy, price, investment patterns, and local demand in their service areas. Availability and reliability of fuel supply, transportation and price fluctuation, investment patterns, etc., all enter into such studies.

5.1.3 Power Grid Planning Studies

When more than a single utility is part of a power grid, the sources of energy must be studied from a broader purview. Forecasting of demand for base load and reserve, reliability of supply, and effect of loss of a base load plant of large size on the grid become important factors.

5.1.4 National Energy Supply Planning

National authorities planning to meet national demand forecasts must take into account balance of payments, national security in terms of external fuel supply interruption, integration of national and international needs. The state of industrial development of a nation -- industrialized, developing, underdeveloped -- the existence of domestic energy resources, the size and location of the nation and its type of government affect the type of study to be made and its scope. Environmental impacts on a national scale and, perhaps, an international scale for pollution crossing national boundaries are required, e.g., acid rain from the combustion of coal.

5.1.5 Global Planning

Studies are necessary to address the global impact of environmental problems of energy production. Acid rain, the "greenhouse" effect from the burning of fossil fuels, global impact of radioactive materials such as C^{14}, H^{3}, I^{129}, Kr^{85}, Tc^{99}, change in the libido due to use of biomass, etc. are examples. Such studies generally ignore the site specific aspects of energy production and focus on the broad impact which often cannot be addressed with much certainty. The focus is on scientific aspects of global environmental impacts.

5.1.6 International Energy Planning

The scarcity of fuels, new investment and exploration opportunities, economic cartels, balance of payments, international borrowing and investment make international economic analyses of alternative energy sources important. These are different from the global environmental impact analyses since they focus on economic matters and interests. Nevertheless, these analyses must also take environmental impact into account, at least environmental limitations, if not measures for reducing impact.

5.1.7 Special Purpose Analyses

There are a number of different special purpose analyses which often must be made and some are listed here.

Energy Sub-systems Investment - Overall analysis of short and long term trends to determine investment in fuel exploration and development, transportation of fuels, alternate energy technologies, waste and pollution control industries.

Evaluation of Potential Problems in New Energy Sources - As new energy sources are developed, it is important to identify potential environmental and health problems early in the development. Such analysis should not attempt to prejudice such sources, but only identify potential problems and how they can be mitigated. A good example of such a program is the Health and Environmental Risk Analysis Program of the United States Department of Energy's Office of Research Analysis and their development of Health and Environmental Effects Document (HEEDS) series of reports --"The principal objective of these analyses is to assist in the management of a program of health and environmental research that will provide information necessary to reduce uncertainties in critical areas."

To Support or Reject an Energy Option - Protagonist or antagonist special interest groups providing either micro or macro analyses, or both, in support of their particular position.

5.2 CLASSIFICATION BY OBJECTIVES AND USES OF THE ANALYSIS

There seems to a pervading notion that there is only one type of risk analysis. This is far from the case; there are a spectrum of different risk analyses based upon how they are to be used. Table 2.2 provides a categorization of some different uses, each requiring different approaches for analysis. This set is an expanded version of the set of uses described in the first report.

5.2.1 Project Sponsor Objectives And Biases

It is first necessary to consider the objectives of an analysis from the point of view of the sponsor. A look at some of the sponsor biases present in analyses provides an initial classification. An analysis may be classifed as defensive, offensive, and, perhaps, neutral. A defensive risk analysis attempts to demonstrate that an estimated level of risk is acceptable. Essentially the sponsor is attempting to show that risk levels for the project in question are acceptably low, that is, defend his project. An offensive risk analysis attempts to demonstrate that an estimated level of risk is unacceptable. It represents a challenge to an existing or proposed risk level. Conversely, a neutral risk analysis is one where no predisposition exists as to the acceptability of findings.

It is an overgeneralization to say that the first represents government regulators, the second represents industry, and the latter represents the impartial scientist, since most analyses are made with good intentions to do the best job possible but from a predisposed background. Moreover, if a scientist is a promoter of a particular methodolgy, or is trying to establish a scientific reputation to acquire funding or status, or has a particular mind set about the risks involved (such as protection of public health as a primary objective), scientific neutrality may also be lacking.

There is a much more subtle aspect to defensive and offensive strategies for risk analysis. This has to do with how uncertainties in the risk analysis are handled. Given that there are practical, if not theoretical, limits to knowledge, how does one deal with these uncertainties? Based upon rigorous statistical methods it is possible to set upper and lower limits on risk.

Use of a high upper limit is an offensive strategy, used by regulators, such that an estimated level of risk is set so high as to provide very high confidence that the real level of risk lies below the estimate. It represents a very large overestimate of the true risk, especially when margins of safety are added to account for uncertainties in measurements and models.

The lower bound can be used as a defensive strategy. It sets a lower bound on measurable risk. This bound, based upon available knowledge and measurement techniques, is set at a level for which it is impossible to empirically demonstrate a higher level of risk from the evidence available. For example, one may set a lower bound, say for cancer risk for a toxic chemical based upon animal bioassays, such that it would be impossible to directly measure the effects of exposure to the chemical in epidemeological studies in man. In this sense a user of the substance may be protected from liability, at least from scientific testimony as to cause and effect, since the limits of measurement have been reached.

There are, of course, ethical questions about how such analyses can be used. However, it is just as improper to set overly strict and costly regulations from severe overestimate of risk as it is to attempt to escape the consequences of one's responsibility by attempting to cloud the issues. Perhaps, the most unethical approach is from that of the scientist who claims impartiality when it is not the case, knowingly or unknowingly. This does not mean that defensive and offensive tactics should not be used or that upper and lower bounding analyses should not be made. Only that they should be used openly and with care.

5.2.2 Uses Of Risk Analysis

The uses of risk analysis as outlined in Table 2.2 are explained here more fully. In addition the sponsor and the primary target users are indicated, in terms of risk analysis of alternate energy systems.

5.2.2.1 Regulatory Analyses

Regulatory analyses are conducted by regulatory agencies and their contractors for a variety of reasons, primarily to establish and enforce regulations. Another set of analyses are used to adhere to existing regulations set as those for environmental impact analysis (In the United States this is controlled by National Environmental Policy Act -NEPA - 1970 & Code of Federal Regulations Section 1502) and those made by industry to meet existing regulatory requirements.

A. KINDS OF ANALYSES CONDUCTED BY REGULATORY AGENCIES

These analyses are sponsored by regulatory agencies, and are usually directed at risk managers and the technical community. Many countries require public disclosure as well, and the presentation of technical material to the public presents special problems. For energy systems the primary issues are environmental issues such as siting, water resource and land use, pollution and health and safety issues.

1). Screening Analyses To Determine If A Risk Exists And Is High Enough To Be Considered For Regulatory Control.

Risks to individuals and to exposed populations is estimated using crude estimates, and the results are compared against formal or informal deminimis levels to determine if the risks are high enough to warrant further action. Either the risk level (individual and population risks) or the cost-effectiveness of risk reduction or both can be used as criteria for decision making.

2). Regulatory Impact Analysis To Justify Regulatory Actions And Satisfy Administrative Law Requirements.

Every regulation, establishing standards for health, safety and environment areas, must go through a formal administrative process laid out by the laws of the country involved. In the United States this is governed by a plethora of regulation. Those for environmental regulations have many procedural steps which include an advanced notice of proposed rule-making, a draft regulation and a final regulation, all involving public input and comment. The analysis used to support these regulatory steps generally has very large uncertainties in cause-effect relationships and exposure estimates, and uses margins of safety in the direction of increased protection of human health to address these uncertainties. These margins of safety used at each step are aggregated thoughout the total process leading to large overstatements of risk. Both individual and population risks should be addressed, but are not always done in practice.

Additional margins of safety are often added to provide increased agency credibility in the eyes of the agency's constituency. This process is to be avoided. The large amount of systematic error introduced is often hard to reverse once the process is established. Arguments to keep estimates within realistic ranges must take place at every step of the administrative process. Strategies aimed at providing early input into the analysis process and involvement at every step of the process are necessary and can be effective in keeping estimates of risk realistic. Industry has had a great deal of influence on the process by this approach, although the cost of keeping up, including industry risk analyses to offset the agency analyses, is expensive.

3). Compliance Analyses To Demonstrate Regulatory Violations.

When an agency takes an enforcement action, it makes an analysis of the violation of the standard with a "chain of evidence" to support the violation. Risk analyses are required when the regulation is based upon risk. Once again improper use of margins of safety used as means to address uncertainties must be kept within reasonable limits.

4). Analyses In Response To Judicial And Legislative Challenge.

When regulations are challenged in the courts or by legislative bodies (Congress and state legislatures in the United States) risk analyses are often made by the agencies responsible for the regulation to defend their actions. These analyses are often extensive, and biased to support the action taken.

B. ANALYSES MADE BY OTHERS IN RESPONSE TO EXISTING REGULATIONS

Environmental and safety regulations require utilities or industrial organizations, public or private, to make risk analyses of proposed or existing facilities. The utility or industrial organization becomes the sponsor of the analysis. The regulating authority is the primary target user, but the analysis must survive technical scrutiny and, in many countries, review by the general public.

1). Environmental Impact Statements

The mechanism for carrying out these analyses in the United States is the National Environmental Policy Act (NEPA). It has been in force since 1970, and has been a pace setter in establishing needs for formal environmental analysis. The process was fraught with difficulties in the beginning, but has resulted in better understanding of the risk/cost/benefit process. Some countries in Europe are adapting some of the more advantageous aspects of the NEPA process such as the carrying out of the analysis of alternatives without the overly legalistic framework of the American system.

This process basically requires a relative risk analysis among alternatives; one of which is usually a "no-action" alternative. The process does not require margins of safety, except to account for uncertainties. Essentially only a best estimate is required, but the analysis must assure that an underestimate of risk does not take place. Margins of safety for protection as in regulations are not required; but, when information cannot be acquired or costs of acquisition are exhorbitant, a worst case analysis is required. The sponsors of the analysis and the decision makers must learn to let it all hang out, state the risks as they are, put risks into perspective, and let the decision maker make his decision among the alternatives. In the United States the law implies that if the NEPA procedure is met, the value decision is up to the sponsoring agency, and the courts will not interfere. The analysis must be impartial, and those conducting the analyses should not be an advocate of any alternative prior to the decision. After the analysis is completed, the sponsor may select a preferred alternative; and it may be presented with the other alternatives.

2). <u>Permitting Requirements</u>

Specific regulations requiring permits, such as for the Resource Conservation And Recovery Act (RCRA) in the United States, require some form of risk analysis in the development of the justification for the permit. These analyses are usually conducted by the organization requesting the permit, and must demonstrate that designated criteria are met.

3). Compliance Monitoring

Enforcement actions by national, state or local governments under existing regulations often require analyses, made by the regulating agency to justify the compliance action. These are generally offense risk analyses.

C. ANALYSES MADE BY OTHERS TO DEFEND AGAINST UNWARRANTED REGULATORY ACTION

1). Response To Requests For Comments By Regulators

Utility and industry response to agency actions as undertaken in Paragraph A2. above.

2). Support Of Judicial Actions

a. Response To Improper Agency Actions

Utility and industry response to agency actions as undertaken in Paragraph A2 and A4 above.

b. Defense Against Enforcement Proceedings

Enforcement actions by national, state or local governments under existing regulations often require analyses made by the accused party for defensive purposes after the compliance action takes place.

5.2.2.2 Management Support Analyses

Utilities and industrial organizations, public and private, make analyses to assure adequate safety of operations, increased productivity and cost-effective operation. These are sponsor originated studies aimed at policymakers and risk managers at the strategic level, and may be aimed at technical people at the operational level.

A. MARKETING

Demonstrate that a product or process is safe or harmless on an absolute basis, or that it is relatively safer and less harmful than alternative and competative products or process. Often it is aimed at the general public as the ultimate consumer. There is, of course, no such thing as zero risk, but some try to sell it.

B. PLANNING

1). Research And Development

a. Risk Reduction - Safety Analysis

The purpose is to identify areas of high risk (or relatively high risk) in particular products or processes, and seek means to provide cost-effective solutions to reduce these risks. This is normally done for the following reasons:

1. Safe operation makes good business sense. Outages because of failure can cause loss of production.
2. Fore stall the need for regulation.
3. Reduce exposure to future liability claims.
4. Develop defensive strategies to bound risk liability.
5. Identify new markets for risk control technology.

b. Improved Analysis Capability

Identify areas of high uncertainty in risk analyses, and undertake programs to cost-effectively reduce these uncertainties. This is a particularly necessary strategy for combating overzealous use of margins of safety which have been used in the face of uncertainty. This is also true for new product or process areas, or at least for areas where risk analysis has not been used effectively in the past as a result of such uncertainties.

2). <u>Cost-Effective Use Of Resources</u>

Focus resources on the most risk reduction for a dollar. Can be used by both the private and public sectors. Utilities and industrial organizations can use this approach to best allocate resources addressed to safety. This approach can be used in the public sector, by individual agencies, across agencies, and within other organizations as a means to cost effectively address risk reduction. The idea is to serve the public by spending tax dollars for risk reduction cost-effectively and fairly. The depth of analysis is less than that for regulatory purposes and uses relative risk estimates and the relative cost of reducing risks. This is an area where probabalistic risk assessment techniques can be very effective.

3). <u>Evaluation Of Alternative Systems For Conducting A Process</u>

Evaluation of alternative systems on a relative risk basis to provide perspectives on the types of risk and the magnitude of risks for alternative systems for implementing a specific process or product.

C. <u>RISK MANAGEMENT</u>

Prevent risks from occurring by anticipating and controlling them. This is accomplished by reducing exposure health, safety and financial risks for a given, existing process or product. One can make analyses for:

1). <u>System Safety</u>

Analyze the system for points of possible failure, and provide technological "fixes" for weak points in the system. The use of probabalistic risk analysis, using fault trees and event trees, has met some success in this area. Evaluation of margins of safety in the system is another approach that may be more fruitful.

2). <u>Product Safety and Liability.</u>

The courts begin getting involved when parties are believed to have suffered physical and mental damage or stress from a product that either fails to operate as expected or causes harm. In the United States this has become a major problem, especially in the cases of large jury awards when the courts base liability on ability to pay rather than relating cause and effect.

3). <u>Third Party Assumption Of Risk</u>

Third party assumption of risk is primarily through insurance. The objective is to spread the risk more equitably among subscribers. Of course, insurance companies sell this service with a profit motive in mind. As a result the insurance industry has controls applied to it and is regulated at state level to varying degrees.

a. Insurance

Risk spreading through pooling of risks among suscribers for all types of coverage. Insurance companies operate on a profit basis for both stock and mutual underwriters. Large compensation awards in the United States Courts have led to withdrawal from underwriting in many areas by most insurance companies. For example, at this writing it is impossible to obtain Environmental Liability Insurance for hazardous waste disposal or insurance for vaccine producers of side-effect risks. The latter may soon be underwritten through government action since many pharmaceutical companies have ceased to make certain critical vaccines.

b. Malpractice

Large liability claims and awards for medical malpractice have led to large proportions of effort being directed at preventing malpractice suits rather than for directly reducing risks. Moreover, the cost of malpractice insurance for individual practitioners has become exhorbitant. Essentially the attention given to the third party risks of operating any business with definable risk consequences is becoming greater, and in some instances greater than the need to address the risks themselves directly.

5.2.2.3 Public Education

The public desire for adequate supplies of environmentally safe energy sources at low prices makes it incumbent on public officials to display energy options and their advantages, disadvantages, and problems to their constituents in a manner that promotes better understanding of the issues. However, if such information is biased towards specific applications or energy sources it may become suspect, and its intentions misinterpreted. It is necessary to provide information and commentary on it in an open manner, leaving the reader to draw his own conclusions, if such bias is to be avoided. This does not mean that summaries and commentaries should be avoided, only that they not be slanted.

A. PUBLIC AWARENESS

1) <u>Seek Rational Public Responses</u>

Based on the idea that a knowledgeable public will hopefully act on information rather than preset beliefs. The expectation is that such presentations will be without bias, if they are sponsored and carried out by public or private organizations who are not stakeholders.

2) <u>Fulfill Regulatory Requirements For Public Disclosure</u>

Even though public disclosure may be required by law, a good, simplified and accurate disclosure can also be a useful educational tool, whether or not the sponsor is a stakeholder.

B. ANXIETY FACTORS

1) <u>Bring Perceived Risks More Closely Into Alignment With Objective Risks</u>

Public anxiety can be allayed to some extent by changing the perception of risks by making the objective risk estimates meaningful to people. While anxiety reduction is a worthwhile end in itself, it may also be used as a defensive strategy since an informed public can often be expected to act in a rational manner.

2) Frighten People Into Action Or Agreement

For those seeking attention, premature or overstatement of risks to the public can arouse anxiety. This is an offensive strategy, attempting to stir fear and anxiety.

5.3 Cross Classification Of Uses And Scope Of Application

Table 5.1 provides an initial cross classification of the uses outlined in Table 2.2 and described in the previous section with the scope of application of projects shown in Table 2.1. The objective is to identify where patterns of use may emerge, especially those where incompatibilities may exist among applications. This is an ongoing effort in our research.

So far the primary pattern that we have identified is that projects that address generic issues use risk analysis primarily for planning and for public awareness purposes. Those which are aimed at specific sites for construction and operation primarily use regulatory risk analyses.

TABLE 5.1

A CROSS CLASSIFICATION OF USES OF RISK ANALYSIS FOR DIFFERENT SCOPE OF APPLICATION OF PROJECTS

DIFFERENT USES OF RISK ANALYSIS / SCOPE OF APPLICATION	I. REGULATORY ANALYSES									II. MGMT SUPP ANAL	
	A.CONDUCTED BT REGULATORY AGENCIES				B.MADE BY OTHERS IN RESPONSE TO EXISTING REGULATIONS			C.MADE BY OTHER IN DEFENSE TO REGS.		A.MARKETING	
	1.Screening	2.Reg. Impact	3.Compliance	4.Response	1. Env. Impact St'mnts	2.Permitting	3.Compli-ance Mon.	1.Request For Comments	2.Litaga-tion	1.Absolute Safety	2.Relative Safety
A.Site Specific Projects			X Exist. Systems	X e.g. EIS	X	X	X		X e.g. Siting		
B.Utility Planning Studies										X	
C.Power Grid Planning Studies										X	X
D.National Energy Supply Planning Studies		X			X Generic EIS					X	X
E.Global Planning And Impact Studies											
F.International Energy Planning											
G.Public Information And Dissemination											
Special Purpose Studies											
H. Energy Subsystem Investment	X		X	X	X	X	X	X	X		
I. Evaluation Of Potential New Energy Source Problems	X		X	X	X	X	X	X		X	X

DIFFERENT USES OF RISK ANALYSIS / SCOPE OF APPLICATION	II. MANAGEMENT SUPPORT ANALYSES										
	B. PLANNING				B.MADE BY OTHERS IN RESPONSE TO EXISTING REGULATIONS			C. RISK MANAGEMENT			
	1.Res. & Dev'mt: a. Risk Reduct'n	b.Improved Anal. Cap.	2.Cost Effective Use Of Resources	3. Eval. Of Alt.	1. Env. Impact St'mnts	2.Permitting	3.Compli-ance Mon.	1.Prevent Risks From Occurring	2.Reduction Of Exposure: a.Systems Safety	b.Product Liability	c.3rd Party Risk Ass.
A.Site Specific Projects			X	X	X	X	X		X	X	X
B.Utility Planning Studies	X	X	X	X							
C.Power Grid Planning Studies	X		X					X Outage & Cap. Prob.			
D.National Energy Supply Planning Studies	X	X	X	X	X Generic EIS						
E.Global Planning And Impact Studies	X	X	X	X				X			
F.International Energy Planning	X	X	X	X				X			
G.Public Information And Dissemination											
Special Purpose Studies											
H. Energy Subsystem Investment		X	X		X	X	X				
I. Evaluation Of Potential New Energy Source Problems	X	X	X		X	X	X				

DIFFERENT USES OF RISK ANALYSIS / SCOPE OF APPLICATION	III. PUBLIC EDUCTAION AND PERSUASION			
	A.PUBLIC AWARENESS		B. ANXIETY CONTROL	
	1.Seek Rational Public Response	2.Reg. Req'mt Publ. Discl.	1. Align Pérceived Risks With Actual Risks	2.Frighten People Into Action
A.Site Specific Projects	X	X	X	
B.Utility Planning Studies	X			
C.Power Grid Planning Studies				
D.National Energy Supply Planning Studies	X	X	X	
E.Global Planning And Impact Studies	X		X	X
F.International Energy Planning	X		X	
G.Public Information And Dissemination	X	X	X	X
Special Purpose Studies				
H. Energy Subsystem Investment		X		
I. Evaluation Of Potential New Energy Source Problems	X			

CHAPTER 6

6.0 BENEFITS OF ALTERNATIVE ENERGY SYSTEMS AT AND BEYOND THE BUSS BAR

While a kilowatt of electrical energy at the buss bar appears to be the same at first glance for any energy source, this assumption only holds over a narrow range of alternatives for any given analysis. There are many other aspects of energy production that have benefits which can neither be easily quantified nor measured in a monetary sense. Table 6.1 summarizes these factors.

6.1. FUEL ABUNDANCE

The benefits of a particular energy alternative are very much dependent upon the abundance and source of the fuel supply being considered. Those fuels in abundant supply and readily retrievable and usable are most economically beneficial. Conventional fuels of low quality and small quantity are, at best, only short term sources.

6.2. UNINTERRUPTIBLE FUEL SUPPLIES

Another non-monetary benefit for some fuel supplies are that they are within the nation consuming them. This is particularly important for purposes of maintaining the national security and national economy. A country's security and economic strength is a benefit which directly depends upon the domestic control of the resources used for power production.

6.3. EXHAUSTION OF RESOURCES

Another consideration of relying totally upon the use of domestic supplies of energy is that of the eventual exhaustion of these resources. There is something to be said for using imported sources of energy when domestic sources are still available. However, this option is not without a cost. First, partial control of the economy is now at the discretion of foreign or even corporate powers. Second, with production being shifted to foreign sources, domestic sources will fall into dis-use and, therefore, the time lag and distribution

Table 6.1.

FACTORS AFFECTING THE BENEFIT OF ENERGY AT THE BUSS BAR

1. BENEFITS OF PARTICULAR CHOICES OF ENERGY SOURCES;
   - Continuity of Supply
   - Perservation of National Resources
   - Vulnerability
2. OPPORTUNITIES FOR EFFICIENT USE OF ENERGY MIXES;
   - Distributed and Centralized Energy Source Mixes
   - Matching Needs for Base Loads and Variable Loads
   - Plant Capacity
3. ECONOMICS OF FUEL SUPPLY;
   - Balance of Payments
   - Investment Strategies
   - Economies of Scale
   - Price Elasticity of Demand for Fuel Sources
   - Reliability and Capacity
   - Substitutability
4. INDIRECT BENEFITS OF ENERGY PRODUCTION
   - Employment
   - Separate Supporting Industries
   - By-products of Energy Production
5. FINANCIAL DETERMINANTS OF FUEL SUPPLY
   - Interrelationship of Finance and Economics
   - Financing as a Means to Realization Of Energy Benefits
6. NEGATIVE BENEFITS.
   - Undefined And Diffuse Dysbenefits
   - Opportunities Foregone
   - Hidden Dysbenefits

system necessary for military and commercial consumption may be considerable. A solution to this problem could be subsidies for a system that would respond immediately and satisfactorily in the event of a disruption of supply. However, this alternative may be very economically costly.

6.4. INDIRECT BENEFITS AND RISKS

There is a major question as to whether a number of activities related to energy systems should be considered as risks or benefits from energy systems. Two particular aspects are the mining and construction industries. In most studies, mining of uranium and coal and the construction of power plants have risks and benefits that have been apportioned to particular energy alternatives. There is a strong argument that these should not be included. Each industry, mining and construction, operate on their own cost-risk-benefit balances, independent of energy sources. Alternative energy sources are considered as market opportunities for expanding the industry. A coal miner does not particularly care whether the coal he mines is used to make steel, for space heating, for electrical energy production, etc., as long as the market ensuring his job remains available. In the same manner, a construction worker may differentiate among contracts involving bridges and tunnels, buildings, power plants, etc. as being different types of jobs, but the benefits of being employed on any of these risky undertakings outweighs the risks. Each of these industries must make its own balance of risks and benefits, and the degree of regulation involved will depend upon the risk level in each industry and the regulatory bodies involved, e.g. Department of Labor.

6.4. FINANCIAL DETERMINANTS OF FUEL SUPPLY

The means of financing fuel supplies can have significant affect on the economic viabilty of particular alternative energy sources. This interrelationship of the finance and economics of fuel supply must not only be explicitly recognized, but can be considered as a means to the realization of benefits from particular alternative energy systems. Some of the factors to be considered in this light are:

a. Efficiency Of Financing Measures - Leading to relatively expeditious, low-cost energy at a particular site.

b. Evaluation Of Alternative Financing Sources - Yielding corresponding trade-offs as to savings schedules for what volume consumed for what source, and when.

c. Characterization Of Financing Strategies - Estimates of the business, social and technological outcomes of different financial approaches.

d. Impact Of The Financing Methods Selected As Indirect Benefits or Detriments - To providers, end users and specified third parties.

6.5. NEGATIVE BENEFITS

Negative benefits are defined here as those undesirable aspects of energy alternatives not associated with direct costs or environmental impact. They can be considered as dysbenefits rather than costs or risks. Most studies address these in only a general fashion and either specifically omit them from discussion, or treat them superficially. In particular, these have to do with alternative energy sources vulnerability to sabotage, terrorism, or to incapacitation due to war. Moreover, the problem of weapon development at the national level is peculiar to some nuclear options. Vulnerability of large centralized plants to military or paramilitary activities is one consideration. Use of stored energy such as the thermal energy in nuclear power plants or potential energy of water behind dams can make such facilities prime targets.

Another aspect of negative benefits are opportunities forgone. These cannot be considered costs, but opportunities lost. Failure to become energy independent is an example.

CHAPTER 7

7.0 APPLICATION TO ALTERNATE ENERGY SYSTEMS

There are a number of issues to be addressed as we attempt to use the framework described previously to alternate energy systems. These include the following as a minimum:

1. Differences in analysis for different parts of the energy cycle
   - A. Separation of fuel production from the rest of the energy system.
   - B. Waste disposal as a special problem
   - C. Life cycle costs
2. De minimis concepts and uses
   - A. For determining significance of issues
   - B. For determining when cost effectiveness of risk reduction has reached an end point
3. Cost-effectiveness of risk reduction under different concepts:
   - A. Systems Safety Resource Allocation
   - B. Value of a life
   - C. End point considerations
   - D. Role of finance and different finance methods

7.1 DIFFERENCES IN ANALYSIS FOR DIFFERENT PARTS OF THE ENERGY CYCLE

There are a number of issues that must also be addressed in the application of the framework.

7.1.1. Fuel Preparation

The risks from the production and preparation of fuel can be arguably separated from the rest of the fuel cycles. We are only considering the raw production which includes exploration, mining and transporation to fuel preparation facilities in this case; fuel preparation is a separate consideration that may also be separable for some of the reasons cited below. First, in nearly all cases, the fuel produced is only partially used in the electrical energy production cycle. Coal is used for steel making, chemical feedstock, and central heating. Oil is used for transportation, chemical feedstock and space heating. Natural gas is used for space heating, cooking and hot water heating. Uranium and thorium production is somewhat unique in that fuels are used primarily for electrical energy production and to some extent for weapons production. One can argue for fossil fuels that a prorated proportion of risks can be assigned for energy production. This may be improper for several reasons. First, any formula for prorating risks based solely on proportion of fuel used will be arbitrary and incorrect. It may well be that the marginal demand for fuel affects risk more than the actual amount used. At low prices, reducing amount of resources committed to safety is one means of lowering competative production costs. At high demand, more risky operations may be used as additional supplies. How does one allocate marginal changes in demand among the competing uses of fuels? Certainly not by simple allocation formula based upon static usage.

The allocation of such costs puts nuclear energy at an advantage, since nearly all mining risks will be allocated to energy production. However, this is not an argument for separation of fuel preparation, only an observation. The major argument for separation is that the risks from fuel acquisition are nearly all to workers, whether from mine and transportation accidents, black lung disease or lung cancer, or to the environment from excavation and waste disposal. The production and sale of fuel is one of the major industries in the world, and jobs created are considered opportunities by workers. Mine safety is a regulated activity in many countries; and safety and the cost-effectiveness of risk reduction are not balanced against the use of the fuel, but rather versus the value of the fuel and the job opportunities created. Thus, there are major justifications for separating fuel production from the rest of the energy cycle for most of the uses addressed in Chapter 5. Perhaps separation might not be appropriate in the most general risk analysis, but a good case can be made for it in all other analyses. The risk analysis of fuel production for any cycle should be contained in a separate analysis, aimed at allocating resources to improve production safety.

In any case the choice of whether to allocate fuel preparation costs or not will depend upon the specific situation and the requirements of the analysis.

7.1.2 Other Parts Of The Fuel Cycle

For the remaining fuel cycle components, the cost-effectiveness of risk reduction must be addressed in terms of both short term costs and life cycle costs. This includes the disposition of wastes and decommissioning of facilities by acceptable means. Short term costs may be used for parts of the cycle for allocation of health and safety resources. Life cycle costs are used for overall system performance assessment.

7.2 THE DE MINIMIS CONCEPT AND ITS APPLICATION

For different magntudes and types of risk there are de minimis levels of probability where the probabilities are so low as to be below reasonable thresholds of concern or even to have meaning. This concept is different from that of "acceptable risk" which occurs at a much higher level. The concern here is with risks so small as not to be considered significant. If they are significant, then they must be addressed and an acceptable risk level adopted formally or informally.

The question of an "acceptable" level of risk is a concept left for the analysis itself. What we are concerned with here is the concept of "de minimis risk". This concept is adapted from common law where a matter that is considered to be too trivial to be considered by the court is cited as de minimis.

For purposes here we mean the case when there is some combination of probability and consequence levels that are small enough to be below the threshold of concern. This threshold of concern is a changing target, a value judgement that is well below levels established for acceptable risk. Some large magnitude risks such as the sun exploding in the next few years and the earth being hit by a large meteorite have extremely low, but finite probabilities. We go about our business without giving them much concern nor in the latter case becoming troglodytes. The probabilities are below our threshold of concern, due to, perhaps, a built in response to anxiety over events that are only remotely possible, beyond our control, or a combination of these.

The International Atomic Energy Agency (IAEA) has been addressing this issue for radiation for both individual and population risk. They have proposed 1 millirem for individuals and 100 man rems for population exposure as de minimis levels. No such levels exist for other fuel cycles as far as we know. These levels for radiation may be lower than others in society. We have, however, been involved in establishing such levels for the United States Forest Service for pesticide application in Environmental Impact Statements. These have been set in the order of a lifetime risk of 1 in 100,000,000.

7.3. COST-EFFECTIVENESS OF RISK REDUCTION UNDER DIFFERENT CONCEPTS:

We will address three different uses for the cost-effectiveness of risk reduction for alternate energy systems as a minimum in subsequent research. The first is the cost-effectiveness of relative risk reduction for allocating safety resources within a fuel cycle. In this case risks are relative to each other, and absolute risk estimates are only important when the results are pegged to benchmark risk level. The major difficulty in analysis is the differences in uncertainties about risks and to a lesser extent about cost estimates for different fuel cycles and parts of fuel cycles. The separation of risks into normal, abnormal and the several rare event categories provides a very useful means for grouping and addressing the uncertainties. The major difficulty in implementing such strategies is the partitioned nature of the fuel cycle operations. As Cohen points out; one can hardly imagine shifting safety resources from the mining of coal to control of sulfur dioxide emmision. Those allocating the resources will have to make the value judgement of allocating resources across the categories. Those actions that reduce rare events may increase normal or abnormal risks and vice versa. This interaction can become clear by analyses using this classification.

The question of when to stop spending resources for risk reduction is another matter. It requires an absolute risk assignment, if only by pegging relative risks to a single benchmark risk analysis. The end point for spending is based upon the resultant absolute risk estimates for each category. There are several ways to address the end points.

The first is to use established de minimis levels for each category of risk. This has already been addressed.

A second approach is to use the value of a life. However, the value of a life may very well be different for the different risk categories addressed. The consequences of an event involving accidents and chronic effects, such as exposure to toxic materials or radiation, involve morbidity, premature injury and death, and property damage. However, the cause of death, the manner of dying and injury, and the type of gamble involved all influence the subjective evaluation of these consequences. The causes and manner of injury or dying fall into four general classes:

1. Immediate Acute Effects - Immediate death or injury from an accident involving explosion, fire, suffocation, action of corrosives and poisons, etc., resulting from a specific incident.

2. <u>Delayed Acute Effects</u> - Delayed death or injury resulting from massive toxic exposure as a result of a specific event or set of events.

3. <u>Observable Chronic Effects</u> - Premature death and increased morbidity resulting from exposure to identified substances over a long period. The effects are often cumulative such as in metal and pesticide poisoning or latent such as in carcinogenesis.

4. <u>Unobservable Chronic Effects</u> - Contribution to premature death and increased morbidity by the hypothesized synergistic or contributing action of a particular substance. Some substances indicate toxicity at high levels of exposure, but action at low levels cannot be established. Others operate synergistically such as exposure to asbestos for smokers.

Society treats these consequences in different ways and reacts to them differently, and not necessarily by the categories above. Such factors as the ability or willingness to pay indemnities, the extent of pain and disability are just a few of the confounding factors. However, the categorization above does explain to some extent why accidents are treated differently than disease.

This valuation of consequences is, primarily, a subjective evaluation. Values of life, as well as de mimimis and acceptable risk levels, used to judge one kind of consequence may not be suitable to judge other kinds.

A third approach uses the "limits of knowledge" as a criterion. There are practical, and perhaps, theoretical limits to measurement. This approach can only be used when risk magnitudes are small enough to represent only a fraction of the uncertainty band, then these limits may be used as end points. One must recognize that as measurements can improve, the end points may also be tightened.

Finally one must not ignore the role that finance and specific financing methods play in establishing the cost-effectiveness of risk reduction by particular alternatives. The integrality of finance and insurance is one example. The cost of insurance and the spreading of risk through the insurance mechanisms directly affect the cost-effectiveness ratio. If underwriters will provide premium reduction for proven safety features at specific sites as is presently not the case, then increased safety can be highly cost-effective. Additionally the capacity of finance providers to be able to invest in technological innovation may well be the key factor in whether innovative alternatives may survive.

CHAPTER 8

8.0 CONCLUSIONS

The use of the framework we have developed provides a number of advantages for analyzing the risks and benefits of alternative energy systems:

- Combines both policy analysis needs and technical analysis in one process without confusing the two aspects. Lets the policy aspect govern the technical analyses in an effective manner.
- Provides direct assessment of the differences in analyses needed for different uses and different situations.
- Fits the analysis to the use intended. Not the other way around.
- Makes clear the implications of intended usage.
- Makes apparent value conflicts visible; and, if not resolvable, indicates the political realities of the choice among alternative systems.
- Demonstrates that quantitative analysis by itself can seldom directly resolve major value conflicts.
- Provides information for policy and decision makers and the general public in an easily understandable fashion, but also provides the technical community with visible, traceable, and repeatable means for addressing the details of the technical estimates.
- Separates value judgements from technical content.
- Provides a perspective of what is most likely going to occur during the lifetime of a system, rather than focusing on only the adverse aspect of risks (Normal Operation).
- Shows what the system is designed to cope with and the associated risks in a balanced fashion (Abnormal Operation).
- Treats different aspects of rare events separately in a meaningful fashion for decision making and policy analysis as well as public concerns.
- The use of interval estimates shows both the level of risk and the uncertainty in estimates at the same time. The width of the interval is a direct measure of the uncertainty in the estimate.
- Does not aggregate beyond meaning. Provides a small number of key results which are easily addressed by all target audiences. This does not mean that the results will still not be subject to value

conflicts among the major results, but that such value conflicts are accentuated and made visible.

- Does not attempt to acquire and quantify information beyond that which is useful to the use and objectives of the analysis.

- Assures that needed information acquisition is cost-effective.

- Takes into account that energy at the buss bar is not independent of beneficial choices.

- Provides a logical framework for addressing risk issues. The framework has been used effectively in a number of other applications, but has not yet been applied to an actual case of comparing alternative energy systems.

In spite of laying out a step by step methodology in Part I., the particular steps in the methodology are not fixed or static. They are more in the form of a checklist than a prescriptive methodology. Moreover, these are guidelines of how to use both top-down and bottom-up analyses in a combined manner to cost-effectively resolve policy decisions.

The generic approach described has been used effectively in a number of other areas. In each case the application required emphasis on particular steps in the methodology, omitting some as appropriate. As long as the reason for omitting steps is clear, such omission is proper. The adaptation to analysis of the risks and benefits of alternative energy systems is new here. The success of its use will only be ascertained by actually carrying out some authentic analyses and determining whether the analysis aids in resolving the policy decisions involved. Under these conditions, actual scenarios for critical variables can be developed and subject to policy evaluation and specific rules for addressing uncertainty can be addressed.

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APPENDIX A.

SAMPLE SCENARIOS

CONDITIONAL VARIABLES FOR SITUATION #26

#1	Fuel Cost Esculation	High
	Expectation Of Disruption	High
	Degree Of Anti-Nuclear Sentiment	High

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, with sabotage attempts and civil disobedience highly probable. A major nuclear event likely to occur - may or may not involve loss of life, but has high coverage by the media.

#2	Fuel Cost Esculation	Moderate
	Expectation Of Disruption	High
	Degree Of Anti-Nuclear Sentiment	High

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. Difficulty of delivery more of a problem for coal than nuclear. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, with sabotage attempts and civil disobedience highly probable. A major nuclear event likely to occur - may or may not involve loss of life, but has high coverage by the media.

#3	Fuel Cost Esculation	Low
	Expectation Of Disruption	High
	Degree Of Anti-Nuclear Sentiment	High

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, with sabotage attempts and civil disobedience highly probable. A major nuclear event likely to occur in country if nuclear option selected. May or may not involve loss of life, but has high coverage by the media.

#4	Fuel Cost Esculation	High
	Expectation Of Disruption	Moderate
	Degree Of Anti-Nuclear Sentiment	High

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, but sabotage attempts and civil disobedience are unlikely. Political settlement sought. Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#5 Fuel Cost Esculation Moderate
Expectation Of Disruption Moderate
Degree Of Anti-Nuclear Sentiment High

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. Difficulty of delivery more of a problem for coal than nuclear. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, but sabotage attempts and civil disobedience unlikely.Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#6 Fuel Cost Esculation Low
Expectation Of Disruption Moderate
Degree Of Anti-Nuclear Sentiment High

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, but sabotage attempts and civil disobedience unlikely. Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#7 Fuel Cost Esculation High
Expectation Of Disruption Low
Degree Of Anti-Nuclear Sentiment High

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, but sabotage attempts and civil disobedience are unlikely. Political settlement sought. Nuclear accidents will not occur if nuclear option is taken.

#8 Fuel Cost Esculation Moderate
Expectation Of Disruption Low
Degree Of Anti-Nuclear Sentiment High

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, but sabotage attempts and civil disobedience are unlikely. Political settlement sought. Nuclear accidents will not occur if nuclear option is taken.

#9 Fuel Cost Esculation Low
Expectation Of Disruption Low
Degree Of Anti-Nuclear Sentiment High

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. Very heavy anti-nuclear sentiment with a "Green Party" coalition possible, but sabotage attempts and civil disobedience are unlikely. Political settlement sought. Nuclear accidents will not occur if nuclear option is taken.

#10 Fuel Cost Esculation High
Expectation Of Disruption High
Degree Of Anti-Nuclear Sentiment Moderate

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. Organized opposition to nuclear energy exists, but does not become a political issue. Sabotage attempts and civil disobedience highly probable. A major nuclear event likely to occur in country if nuclear option selected. May or may not involve loss of life, but has high coverage by the media.

#11 Fuel Cost Esculation Moderate
Expectation Of Disruption High
Degree Of Anti-Nuclear Sentiment Moderate

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. Organized opposition to nuclear energy exists, but does not become a political issue. Sabotage attempts and civil disobedience highly probable. A major nuclear event likely to occur in country if nuclear option selected. May or may not involve loss of life, but has high coverage by the media.

#12 Fuel Cost Esculation Low
Expectation Of Disruption High
Degree Of Anti-Nuclear Sentiment Moderate

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. Organized opposition to nuclear energy exists, but does not become a political issue. Sabotage attempts and civil disobedience highly probable. A major nuclear event likely to occur in country if nuclear option selected. May or may not involve loss of life, but has high coverage by the media.

#13 Fuel Cost Esculation High
Expectation Of Disruption Moderate
Degree Of Anti-Nuclear Sentiment Moderate

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. Organized opposition to nuclear energy exists, but does not become a political issue. Sabotage attempts and civil disobedience unlikely. Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#14 Fuel Cost Esculation Moderate
Expectation Of Disruption Moderate
Degree Of Anti-Nuclear Sentiment Moderate

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. Organized opposition to nuclear energy exists, but does not become a political issue. Sabotage attempts and civil disobedience unlikely. Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#15 Fuel Cost Esculation — Low
Expectation Of Disruption — Moderate
Degree Of Anti-Nuclear Sentiment — Moderate

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. Organized opposition to nuclear energy exists, but does not become a political issue. Sabotage attempts and civil disobedience unlikely. Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#16 Fuel Cost Esculation — High
Expectation Of Disruption — Low
Degree Of Anti-Nuclear Sentiment — Moderate

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. Organized opposition to nuclear energy exists, but does not become a political issue. Sabotage attempts and civil disobedience will not occur. Nuclear accident like Chenobyl unlikely in another country. Only very minor incidents if nuclear is selected in country.

#17 Fuel Cost Esculation — Moderate
Expectation Of Disruption — Low
Degree Of Anti-Nuclear Sentiment — Moderate

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. Organized opposition to nuclear energy exists, but does not become a political issue. Sabotage attempts and civil disobedience will not occur. Nuclear accident like Chenobyl unlikely in another country. Only very minor incidents if nuclear is selected in country.

#18 Fuel Cost Esculation — Low
Expectation Of Disruption — Low
Degree Of Anti-Nuclear Sentiment — Moderate

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. Organized opposition to nuclear energy exists, and does not become a political issue. Sabotage attempts and civil disobedience will not occur. Nuclear accident like Chenobyl unlikely in another country. Only very minor incidents if nuclear is selected in country.

#19 Fuel Cost Esculation — High
Expectation Of Disruption — High
Degree Of Anti-Nuclear Sentiment — Low

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. No organized opposition to nuclear energy exists, and does not become an issue. Sabotage attempts highly probable. A major nuclear event likely to occur in country if nuclear option selected. May or may not involve loss of life, but has high coverage by the media.

#20	Fuel Cost Esculation	Moderate
	Expectation Of Disruption	High
	Degree Of Anti-Nuclear Sentiment	Low

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. No organized opposition to nuclear energy exists, and does not become an issue. Sabotage attempts highly probable. A major nuclear event likely to occur in country if nuclear option selected. May or may not involve loss of life, but has high coverage by the media.

#21	Fuel Cost Esculation	Low
	Expectation Of Disruption	High
	Degree Of Anti-Nuclear Sentiment	Low

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. No organized opposition to nuclear energy exists, and does not become an issue. Sabotage attempts highly probable. A major nuclear event likely to occur in country if nuclear option selected. May or may not involve loss of life, but has high coverage by the media.

#22	Fuel Cost Esculation	High
	Expectation Of Disruption	Moderate
	Degree Of Anti-Nuclear Sentiment	Low

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. No organized opposition to nuclear energy exists, and does not become an issue. Sabotage attempts and civil disobedience unlikely. Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#23	Fuel Cost Esculation	Moderate
	Expectation Of Disruption	Moderate
	Degree Of Anti-Nuclear Sentiment	Low

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. Organized opposition to nuclear energy exists, and does not become a political issue. Sabotage attempts and civil disobedience unlikely. Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#24	Fuel Cost Esculation	Low
	Expectation Of Disruption	Moderate
	Degree Of Anti-Nuclear Sentiment	Low

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. No organized opposition to nuclear energy exists, and does not become an issue. Sabotage attempts and civil disobedience unlikely. Nuclear accident like Chenobyl likely in another country. Only small accidents if nuclear is selected in country.

#25	Fuel Cost Esculation	High
	Expectation Of Disruption	Low
	Degree Of Anti-Nuclear Sentiment	Low

OPEC members agree on production quotas and fuel prices soar. Coal and uranium costs rise very sharply. No organized opposition to nuclear energy exists, and does not become an issue.Sabotage attempts and civil disobedience will not occur. Nuclear accident like Chenobyl unlikely in another country. Only very minor incidents if nuclear is selected in country.

#26	Fuel Cost Esculation	Moderate
	Expectation Of Disruption	Low
	Degree Of Anti-Nuclear Sentiment	Low

OPEC members don't agree on production quotas, but world crisis make shipments of fuel difficult. Cost rise with scarcity, but at reasonable levels. No organized opposition to nuclear energy exists, and does not become an issue.Sabotage attempts and civil disobedience will not occur. Nuclear accident like Chenobyl unlikely in another country. Only very minor incidents if nuclear is selected in country.

#27	Fuel Cost Esculation	Low
	Expectation Of Disruption	Low
	Degree Of Anti-Nuclear Sentiment	Low

OPEC members don't agree on production quotas, and present prices and availability of fuels are maintained indefinitely. No organized opposition to nuclear energy exists, and does not become an issue.Sabotage attempts and civil disobedience will not occur. Nuclear accident like Chenobyl unlikely in another country. Only very minor incidents if nuclear is selected in country.

GLOSSARY

Acceptable Level Of Risk - A level of involuntary risk designated to be low enough to be acceptable in a regulatory sense. This concept is NOT used in these criteria.

Accident Risks - Risks caused by accidents resulting in direct trauma or death. Recovery from injury in non-fatal accidents occurs, but not always.

Annual Risk - Risk to an individual or population in a calendar year of 365 days, for example, the probability of .001 per year that an individual will be injured in an autmobile accident. An example for populations is 10 automobile fatalities per year per 100,000 people exposed.

Average Exposed Individual - An individual whose received exposure (dose) represents the average exposure (dose) to an exposed population.

Consequence - A possible undesirable outcome of an event.

Consequence Magnitude - The measured size of the consequences: an objective measure.

Consequence Value - The value of a consequence to those impacted by it: a subjective measure.

Conservative Assumptions - Assumptions made which overstate the most likely risk estimate.

Defined Consequence - A particular consequence whose description is precise and delineated. For example, a non-fatal cancer.

De minimis - A legal term designating a transgression that is so trivial as to be below the concern of the courts.

De minimis Level Of Risk - A level of risk so small as to be below the threshold of concern by general agreement.

Disease Risks - Risks caused by acute or chronic exposure to a disease vector or a toxic substance or an environmental stress. The cause-effect relationship may be direct or indirect, and often involves a latency period. Cures may or may not be possible.

Exposure - The condition of being vulnerable to a threat.

Exposure Pathways - The temporal and spatial pathways by which individuals are threatened by risky events.

Exposure Potential - The number of people who could possibly be exposed by a postulated event in contrast to what the expected exposed number of people might actually be.

Individual Risk - Risk to a single individual who is exposed. Expressed in terms of annual risk, that is, probability of a given consequence per year, e.g., fatalities/yr, or lifetime risk, that is, the probability of the given consequence occurring in a persons lifetime. The individual may be subject to maximum exposure (see Maximum Exposed Individual) or an average representation of all those exposed (see Average Exposed Individual).

Involuntary Risk - Risks for which the gamble is inequitably imposed on the risk taker (i.e., the recipients of the risks and benefits are not the same), or knowledge about the risks are purposely withheld, or no alternatives are available. Risks to the general public from Forest Service actions are of an involuntary nature. Those who naively or carelessly ignore prudent precautions may have to be classified as involuntary risk to cover Forest Service responsibility to protect the public.

Lifetime Risk - Risk to an individual or population for exposure over a 70 year lifetime for the general public and for 47 years (18-65 years of age) of exposure to workers during employment.

Maximum Exposed Individual - A hypothetical individual who represents the maximum possible exposure (dose) that an individual can receive from a given event.

Most Likely Risk - The risk estimate that attempts to neither overstate nor understate the estimated risks based upon available data. It is the realistic risk estimate, i.e., the best estimate of what the actual risks may be.

Population Risk - Risk to the collective population exposed by an event. Expressed as the number of effects in the total population, e.g. number of cancers per year for one million potentially exposed people. If the number is less than one it is interpreted as the probability of one effect in the total population exposed.

Probability Of Effect - (p_{ef}) - Given that an event leading to exposure takes place, the probability that the defined consequence occurs. For example, given that a truck carrying hazardous materials has an accident, the probability that a rupture occurs leading to release to potable drinking water is the probability of effect for an accident. For disease, given that exposure to a pesticide occurs, the probability of an exposed person of getting cancer is the probability of effect. (see probability of an outcome)

Probability Of Exposure - (p_{ex}) - Probability that an event occurs, leading to exposure of the target populations. For example, the probability that a truck carrying hazardous materials has an accident or the probability that a person may be exposed to a dose of a pesticide are probabilities of exposure. (see probability of an outcome)

Probabilty Of An Outcome - (p_{oc}) - The joint probability that an event occurs and the probability that the defined consequence takes place:

$$p_{oc} = p_{ex} \times p_{ef}$$

For example, the probabilty that an accident takes place AND the particular consequence occurs. Also the probability that a person is exposed to a dose of a pesticide AND that person actually gets cancer as a result of the exposure.

Realistic Assumptions - Assumptions supporting the most likely risk estimate.

Risk - Risk is the downside of a gamble. It is the potential for the unwanted, negative consequences on an event (1). The formulation of a quantitative risk description involves a functional relationship between two parameters: the probability of occurrence of a particular consequence of an event and the magnitude of the event.

Risk Analysis - Risk analysis is the process of estimating the magnitude of risks and displaying these risks for decision making. The probabilities and magnitudes of outcomes of the risk factors occurring as a result of a proposed action are determined, based upon available data. A realistic estimate of the risks is sought; but, in the absence of complete data, conservative and worst case assumptions are used in place of such data.

Risk Factor - An exposure situation that may lead to a risk. Many such risk factors are examined in a risk analysis.

Voluntary Risk - Risks for which the risk taker knowingly takes the gamble involving the risks, believes the gamble is equitable, and that possible alternatives were available. Risks to workers and to those who purposefully and outrageously disregard prudent precautions might be considered of a voluntary nature, in terms of Forest Service responsibility to protect the public and workers.

Worst Case Assumptions - Assumptions made using extreme conservatism, such that one may be sure that the actual risk will be below the worst case estimate.

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The purpose of this report is to provide guidelines for conducting analyses of the risks and benefits of alternative energy systems in an effective manner. There are considerable difficulties in carrying out such analyses as described in our previous study for the European Atomic Energy Community entitled 'Assessment of comparative and non-comparative factors in alternative energy systems'. The objective of the present study is to carry out several of these recommendations made in the initial study, leading to rational and effective approaches for analysing risks and benefits in alternative energy systems and meaningful presentation of the results to the user community. The result will be guidelines and methods that can be directly employed in such analyses and presentations. Except for examples illustrating the methodologies described in the guidelines, no actual analyses are carried out in this report.