**Review of Decision
Methodologies for Evaluating
Regulatory Actions Affecting
Public Health and Safety**

December 1976

**to
Site Designation Standards Branch
Office of Standards Development
U.S. Nuclear Regulatory Commission**

Battelle

Pacific Northwest Laboratories

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REVIEW OF DECISION METHODOLOGIES
FOR EVALUATING REGULATORY
ACTIONS AFFECTING PUBLIC
HEALTH AND SAFETY

Prepared for:

Site Designation Standards Branch
Office of Standards Development
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Washington, DC 20555

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December 1976

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SUMMARY

This report examines several aspects of the problems and choices facing the governmental decision maker who must take regulatory actions with multiple decision objectives and attributes. Particular attention is given to the problems facing the U.S. Nuclear Regulatory Commission (NRC) and to the decision attribute of chief concern to NRC - the protection of human health and safety. The study was undertaken to provide background information for NRC to use in refining its process of value/impact assessment of proposed regulatory actions. A follow-up study with particular emphasis on the application of cost-benefit analysis to NRC regulatory actions is being conducted in 1977 at the Battelle Pacific Northwest Laboratory.

The principal conclusion from this study is that approaches to rationally consider the value and impact of proposed regulatory actions are available. These approaches can potentially improve the decision making process and enable the agency to better explain and defend its decisions. They also permit consistent examination of the impacts, effects of uncertainty and sensitivity to various assumptions of the alternatives being considered. Finally, these approaches can help to assure that affected parties are heard and that technical information is used appropriately and to the extent possible.

The principal aspects of the regulatory decision problem covered in the report are: the legal setting for regulatory decisions which affect human health and safety, elements of the decision making process, conceptual approaches to decision making, current approaches to decision making in several Federal agencies, and the determination of acceptable risk levels.

The most significant feature of the legal setting for health and safety regulations is that both Congress and the courts give the agencies broad discretion in making decisions. With few exceptions (e.g., the Delaney Clause in the Food and Drug Act which prohibits food additives shown to induce cancer in man or animal), Congress has simply told the agencies to protect public health and safety and has not indicated guidelines for acceptable incremental safety expenditures or ways to determine an acceptable

approach. The courts have also generally supported agency decisions affecting public health. This has been true even for cases where a causal relationship between the regulated activity or substance and human health effects cannot be conclusively demonstrated. The case of Ethyl Corporation vs. EPA, regarding the use of lead in gasoline, is probably the best recent example of judicial reluctance to overturn agency decisions on matters affecting public health and safety.

Five elements of the decision making process are identified and discussed in this report: objectives, alternatives, attributes, objective functions, and valuation. Each of these elements is important and should be considered in every regulatory decision.

Four major conceptual approaches to decision making are considered: threshold levels, matrix approaches, cost-benefit analysis, and utility analysis. Advantages and disadvantages of each approach and example applications are discussed. Since the study was designed to provide an overview of the subject, the approaches are not discussed in great detail.

The threshold approach is exemplified by the Delaney Clause. The cost-benefit approach is perhaps most conceptually familiar to government administrators. It involves the quantification of all identifiable costs and benefits associated with a proposed action in dollar equivalents. Matrix approaches are often used because of difficulties in estimating dollar equivalents for many intangible attributes. They involve assembling all relevant criteria, with measurements for each alternative, into a matrix. The "cost-benefit" summation in nuclear power plant environmental impact statements is an illustration. Utility or preference approaches are probably least known and utilized, partly because of their potential complexity. The utility approaches involve assessing relative values for different attribute impact levels and weighing the attributes relative to one another. These operations enable the comparison of alternatives in terms of the common metric of "utils" rather than dollars as in cost-benefit analysis. Conclusions regarding when each of these methodologies might be applied are included in Section 11.0 of this report.

Several Federal agencies were contacted to determine current approaches to regulatory decision making. Approaches vary widely among agencies. The

National Highway Traffic Safety Administration utilizes a cost-benefit approach. The Environmental Protection Agency also utilizes a fairly formal cost-risk approach. More qualitative, matrix-type approaches are used by the Food and Drug Administration and the Occupational Safety and Health Administration.

Typically, the principal objective of NRC is achieving the maximum reduction of health risk for the minimum implementation cost associated with the proposed action. Evaluating the inherent trade-offs in making these decisions is difficult. Qualitative and quantitative approaches to making this decision are explored. Particular attention is given to cost-benefit and utility approaches and their applications as reported in the literature.

REVIEW OF DECISION METHODOLOGIES FOR
EVALUATING REGULATORY ACTIONS AFFECTING
PUBLIC HEALTH AND SAFETY

1.0 INTRODUCTION

Much attention has recently been given to the activities of Federal regulatory agencies. Elected representatives, commentators, and others are asking whether the agencies really act entirely in the public interest and whether the benefits to the public are worth the costs of regulation. Regulatory reform is the term usually applied to this concern.

Examples of recent regulatory reform measures introduced in the U.S. Congress are the Sunset or zero-based budgetary legislation and the Regulatory Cost Impact Act of 1976. The Sunset bill, introduced by Senators Edmund Muskie and William Roth on February 3, 1976, would require review of the total scope of all Federal programs every five years. In another example of concern about regulatory reform, the National Science Foundation recently awarded several million dollars in research contracts to study applied research on "Public Regulation and Economic Productivity" and "The Benefits and Costs of Public Regulation: Case Studies of Selected Commodities and Services."

Impetus to the idea of regulatory reform was provided by President Ford in an address to the Chairmen and Commissioners of the independent regulatory agencies on July 10, 1975. In his remarks the President asked the officials to work toward four objectives: (1) identification and analysis of the costs and benefits of major programs, (2) reduction in regulatory delay, (3) revision of procedures to be responsive to consumer interest, and (4) identification of areas where economic deregulation makes sense. The Office of Management and Budget (OMB) followed the President's remarks by requesting a written report of each Commission's plans to meet the four objectives.

The U.S. Nuclear Regulatory Commission's (NRC) response to the OMB request outlined the Commission's past and continuing efforts to meet the

stated objectives. The effort which is most relevant to this report is NRC's policy, partially in response to the first objective, of making a written assessment of the potential value and impact of all proposed regulations, regulatory guides, and other regulatory actions before their implementation. The process of value/impact assessment is gradually becoming a formalized part of the NRC regulatory decision process.

The study reported in this document was done to provide background information to assist the Commission in making value/impact assessments. The focus of the study is on the elements of the decision process and methodologies for assessing and combining the values and impacts of health and safety related regulation. The study is only intended to provide an overview of alternative decision methodologies; consequently none are examined in great detail. A large amount of additional information is available in the cited references and the additional references at the end of the report. A follow-on study is being conducted at the Pacific Northwest Laboratory during 1977. The study will emphasize the application of cost-benefit analysis to regulatory decision making within NRC.

This report should also be applicable to other agencies concerned with safety regulations such as the Environmental Protection Agency, the Food and Drug Administration, the Occupational Safety and Health Administration, and the Department of Transportation. Issues associated with the value and impact of economic (price and market entry) regulation, such as conducted by the Interstate Commerce Commission and the Civil Aeronautics Board, are not directly addressed in the study.

2.0 THE ROLE OF VALUE/IMPACT ASSESSMENT IN SAFETY REGULATION

This section is intended to identify some of the important issues relating to the process of safety regulation and the role of value/impact analysis in improving the process.⁽¹⁾ More detailed discussions of certain issues are presented later in the report.

2.1 OBJECTIVES OF SAFETY REGULATION

The first step in any type of analytical work to aid in decision making is to identify the objectives of the decision maker. Although the analyst can sometimes help clarify objectives, he cannot select them. In the case of the Federal regulatory agencies, ultimate objectives are set by the Congress and these in turn are implemented through the Chairmen or Secretaries appointed by the President. As discussed further in Section 4.0, however, the Congress generally sets very broad objectives for regulatory agencies responsible for protecting public health and safety. The difficult decisions on how much incremental cost is justified to achieve an incremental reduction in public safety risk are largely left to the agency decision makers. Value/impact assessment can be most useful to the decision maker when it is used to identify and highlight the incremental costs, benefits, risks, and equity considerations associated with particular levels or degrees of a contemplated decision.

As Baram⁽²⁾ has pointed out, there are potential risks when agencies set their own objectives and make individual safety determinations. Each agency may identify risk levels which are acceptable to them individually; however, the cumulative risks may be unacceptable to society. This difficulty, in addition to the more basic problem of agencies attempting to balance costs and risks without specific guidance, suggests that at some time more specific Congressional guidance in this area may be needed.

Government agencies must also be aware that regulation is not the only way to achieve safety objectives. An alternative to regulation, subject to Congressional directives, is to let the common law torts and product liability doctrines, plus workman's compensation, function to encourage safe

practices.⁽³⁾ Although this approach can be at least as valuable as regulation in some instances, it clearly is not always appropriate. It is particularly inappropriate when safety risks are imposed on individuals who do not directly benefit from the activity or may not be aware of their risk because of technical complexities and uncertainties. The recent Kepone⁽⁴⁾ incident in Virginia is an example of an unacceptable health risk to workers who were unaware of the magnitude of the risk.

2.2 WHAT IS VALUE/IMPACT ASSESSMENT?

Although value/impact assessment has not been explicitly defined by NRC, the concept relates to the objective stated by President Ford that the regulatory agencies identify and analyze the costs and benefits of all major programs. Value/impact analysis encompasses traditional cost-benefit analysis,^(a) but should also be considered a broader term, incorporating elements not readily quantifiable in dollars (and consequently normally omitted from cost-benefit analyses) and equity considerations. Under this interpretation value/impact analysis becomes closely analagous to policy analysis. Quade has recently defined policy analysis "as any type of analysis that generates and presents information in such a way as to improve the basis for policy makers to exercise their judgment."⁽⁵⁾ Quade includes within the scope of policy analysis operations research, systems analysis, cost-effectiveness analysis, and cost-benefit analysis. For this report we have taken a somewhat more narrow view and have considered value/impact analysis as a means to aid decision making by systematically exploring implicit trade-offs.

In using decision methodologies, an understanding of the overall decision process is important. For this reason, Section 5.0 discusses the decision process and the role of decision methodologies within the process. We have identified four principal methodologies that can be utilized either singly or in combination to conduct value/impact analyses. These are threshold levels, matrix methods, cost-benefit analysis, and utility or preference methods. Each of these is discussed in Section 6.0.

^(a) Cost-benefit analysis can be interpreted to encompass all positive and negative effects of a proposed action. Such an interpretation is used in the recent National Academy of Sciences publication, Decision Making for Regulating Chemicals in the Environment, 1975.

An important characteristic of any form of value/impact or decision analysis, which should be emphasized, is that the analysis is designed to aid the decision maker. It neither can nor should be used to dictate a final decision by itself.

2.3 WHY CONDUCT VALUE/IMPACT ANALYSES?

Regulatory decision makers must balance conflicting values of different groups, in an environment characterized by uncertainty, inadequate information and time pressures. Their decisions often have relatively easily measured private market costs to weigh against a number of hard to measure social, technical and health impacts. Formalized techniques of decision analysis may appear to be of very little use in making these decisions where value considerations are often overriding and complex tradeoffs between noncommensurate quantities (e.g., reduced SO_x emissions and dollar costs) are made. However, despite the degree of formalization, tradeoffs are made and values are or are not accepted as being important to the decision.

In this report we suggest that some form of formalized value/impact analysis is useful and can improve decision making when it is conducted with care and its limitations are recognized. There are several advantages to conducting a value/impact assessment for a proposed regulatory action. Perhaps the most important aspect is that it can illuminate and expose the many ramifications and trade-offs of the decision for the decision maker and thus improve decisions. Specifically, it can enable consistent examination of the impacts, effects of uncertainty, and sensitivity to various assumptions of the alternatives being considered. Formalized decision procedures can also help to ensure that affected parties are heard, technical information is used to the extent possible, and expert testimony is consistently used. An additional important advantage of the value/impact process is that it can ensure that value judgments are made in a visible and reportable manner, thus providing a framework for the decision which later can be used to defend and explain the decision to others in the government, the affected industry and its employees, and the public. Finally, the analytical process

can reinforce the decision maker's support for the final decision. This will be especially true if the analytical results are consistent with his intuitive judgment. If it is not consistent, it is possible that certain attributes have been omitted or incorrectly valued and a double check of the analytical process is in order.

For each of the advantages to be realized it is important that the decision maker fully understand the analytical process and how the final results are obtained. His involvement during the analytical process will vary depending on the decision methodology chosen. At the least though, the decision maker should participate in identifying the elements of the decision process (Section 5). In the matrix decision method and in most utility decision methods, the decision maker must also be actively involved in the valuation process.

REFERENCES - SECTION 2

1. A good rationale for safety regulation and suggestions for future directions are in Nina Cornell, Roger Noll, and Barry Weingast, "Safety Regulation" in Setting National Priorities, Henry Owen and Charles Schultze, editors, The Brookings Institution, 1976.
2. Michael S. Baram, "Regulation of Environmental Carcinogens: Why Cost-Benefit Analysis May Be Harmful to Your Health," Technology Review, July/August 1976.
3. A historical presentation of common law liability and a discussion of the relative merits of judicial, legislative, and administrative safety standard setting is in Michael J. Wollan, "The Process of Setting Safety Standards in the Courts, Congress, and Administrative Agencies," Staff Discussion Paper 204, Program of Policy Studies in Science and Technology, George Washington University, NTIS No. PB182876, 1968.
4. Cornell, op. cit., p. 462.
5. E. S. Quade, Analysis for Public Decisions, American Elsevier Publishing Co., New York, N.Y., p. 4, 1975.

3.0 WHAT DOES NRC REGULATE?

The NRC is responsible for regulating the nuclear power industry and the use of special nuclear material, source material, and by-product material. Protecting the health and safety of the public and assuring the common defense and security of the country are the statutory objectives of NRC regulatory activities.^(a) Activities and facilities owned by the Department of Defense and the Energy Research and Development Administration are generally exempt from regulation by NRC.

Facilities and activities covered by NRC regulations are:

- 1) Nuclear Fuel Cycle and Waste Storage
 - Nuclear Reactors
 - Power Reactors
 - Test Reactors
 - Research Reactors
 - Critical Facilities
 - Fuel Fabrication Plants
 - Nuclear Fuel Reprocessing Plants
 - Radioactive Waste Storage Facilities
 - Commercial Uranium Enrichment Plants
 - Uranium Mills and Conversion Facilities
- 2) Use of Special Nuclear Material
- 3) Use of Source Material
- 4) Use of By-Product Material
- 5) Packaging of Radioactive Material for Transport
- 6) Radiography Using Sealed Sources
- 7) Use of Radioactive Materials for Medical Purposes

3.1 REGULATORY FORMATS

Regulations, standards, and guides are integral parts of the regulatory and licensing process for nuclear facilities. The regulations published by the NRC in the Code of Federal Regulations provide the rules under which the

^(a) Atomic Energy Act of 1954 as amended, 42 U.S.C. § 2012.

legislation governing the peaceful use of atomic energy are implemented. The regulatory guides are issued to describe and explain methods that are acceptable to the NRC staff for meeting the requirements stated in the NRC regulations. Also, the guides are intended to disclose the "yardstick" used by the NRC staff to determine the adequacy of a nuclear facility design for the protection of the public health and safety.

Nuclear standards are divided into several categories, generally according to scientific and engineering disciplines. Responsibility for drafting the standards in the different categories is assigned to professional societies, e.g, the American Society of Mechanical Engineers (ASME), by the American National Standards Institute, Inc. (ANSI). The purpose of the ANSI nuclear standards is to specify design and operating requirements for nuclear facilities. NRC's Office of Standards Development maintains increase the likelihood that the ANSI nuclear standards will be incorporated by reference in the NRC regulations and regulatory guides without significant changes.

Most of the regulations are in general terms specifying what is to be accomplished. Since the NRC Regulatory Guides specify how the regulatory requirements may be acceptably satisfied, greater detail is presented and they are considerably larger in volume than the regulations. Even greater detail is usually given in the ANSI nuclear standards.

3.2 EXAMPLE REGULATORY REQUIREMENTS

Examples of regulatory requirements are shown in Table 1. This is not an exhaustive list of requirements, but it does illustrate that each requirement may be addressed in regulations, guides, and/or standards.

TABLE 1. Examples of Regulatory Requirements

Area of Regulation	Covered In		
	Regulation	Standard	Guide
<u>Nuclear Reactor Plant</u>			
Containment System	X	X	X
Containment Atmosphere Cleanup System	X	X	X
Missile Protection	X	X	X
Protection Against Natural Phenomena	X	X	X
Reactor Coolant Pressure Boundary	X	X	X
Protection System	X	X	X
Reactivity Control System	X	X	X
Reactor Fuel	X	X	
Inherent Protection	X		
Emergency Core Cooling System	X		X
Electric Power Systems	X	X	X
Effluent Control System	X	X	
Criticality Safety	X	X	X
Quality Assurance	X	X	X
Operating Licensing	X	X	X
Fire Protection	X	X	X
Emergency Plans	X		X
Ultimate Heat Sink			X
<u>Safeguards</u>			
Source and Special Nuclear Material Accountancy	X	X	X
Physical Protection of Nuclear Material	X	X	X
Certification of Nuclear Materials Managers		X	
<u>Site and Environmental</u>			
Population Density		X	X
Seismic Design	X	X	X
Protection from Floods	X	X	X
Exclusion Area Radius	X		X
Population Center Distance	X		X
Tornados		X	X
Proximity to Airports			X
Radioactivity Release Limits	X		X
Thermal Effluents		X	X
Atmospheric Transport of Gaseous and Liquid Effluents			X
<u>Fuel Cycle Facility</u>			
Fuel Reprocessing Plant	X		X
Protection Against Environmental Conditions, Natural Phenomena, and Missiles	X		
Protection Against Fires and Explosion	X		X
Multiple Confinement Barriers and Systems	X		X
Process Safety Features	X	X	X
Nuclear Criticality Safety	X	X	X
Fuel and Radioactive Waste Storage	X	X	X
Fuel Fabrication Plants (Materials License)	X	X	X
<u>Occupational Health</u>			
Radiation Exposure of Operating Personnel	X		
Shielding	X		X
Maximum Permissible Concentrations of Radionuclides	X		
Personnel Monitoring	X	X	X
Environmental Monitoring		X	X
<u>Transportation and Products</u>			
Medical Use of By-Product Material	X	X	
Radiography Using Sealed Sources	X	X	
Packaging of Radioactive Material	X	X	X
Shipping Containers	X	X	

4.0 EXTERNAL GUIDANCE FOR MAKING REGULATORY DECISIONS

In its creation of regulatory agencies and definitions of their mandates, Congress necessarily provides some guidance for making regulatory decisions, as discussed in Section 4.1 below. Both the form and explicitness of such guidance varies greatly; although very general guidance is most common. Typically, Congress enacts a statute with certain broad purposes and grants the regulatory body the powers to define standards and regulations to accomplish those purposes. The agency is therefore ordinarily left to define its own regulatory approaches and to strike its own balance among competing factors in carrying out its mandates.

As noted in Section 4.2, Congress rarely requires the application of particular techniques in regulatory decisions. This section also examines whether cost-benefit analysis is required by the National Environmental Policy Act (NEPA) and the applicability of that Act to setting standards and other activities by the regulatory agencies concerned with health and safety.

Section 4.3 discusses judicial reaction to administrative decision making involving safety issues. Generally the courts have been reluctant to overturn agency decisions in technical areas involving human safety.

4.1 CONGRESSIONAL GUIDANCE TO AGENCIES MAKING SAFETY DECISIONS

The regulation of health and safety by the Federal Government is a complex process. Virtually every Federal agency takes some regulatory action with respect to safety, although such action is peripheral to the main concerns of many, if not most, agencies. This discussion concerns the guidance given to agencies directly concerned with health and safety regulations. In addition to NRC these include:

Environmental Protection Agency (EPA)

Food and Drug Administration (FDA)

Occupational Safety and Health Administration (OSHA)

Department of Transportation (various subdivisions, each concerned with safety of a particular transportation mode, e.g., the Federal Aeronautics Administration for air, Coast Guard for water)

A single agency may be responsible for safety in a number of areas, with different statutory mandates for each area, and differing legislative instructions for the administration of a given statute. The EPA, for instance, is the regulatory agency responsible for administering the Clean Air Act, the Federal Water Pollution Control Act Amendments of 1972, and the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) as amended by the Federal Environmental Pesticide Control Act of 1972.⁽¹⁾ These statutes differ in both procedural and substantive instructions on standard setting.

Within the Clean Air Act the administrator of EPA has different guidance from different provisions. The broadest example is the difference between primary and secondary ambient air standards. Primary standards are those "the attainment and maintenance of which in the judgment of the administrator, based on such (air quality) criteria and allowing an adequate margin of safety are requisite to protect public health."⁽²⁾ Secondary standards, on the other hand, are those "which in the judgment of the administrator (are) requisite to protect the public welfare from any known or anticipated adverse effects associated with the presence of such air pollutants in the ambient air."⁽³⁾ The distinction between health and welfare effects implies both earlier achievement and more stringent standards for health.⁽⁴⁾ Other sections of the Act demonstrate even more complex legislative instructions. For instance, one section authorizes the administrator to set an emission standard for any pollutant "which in his judgment causes or contributes to or is likely to cause or contribute to air pollution which endangers public health or welfare."⁽⁵⁾ The administrator may also set standards for "hazardous air pollutants" which are those without an ambient air quality standard and "which in the judgment of the administrator may cause or contribute an increase in mortality or an increase in serious or irreversible or incapacitating irreversible illness."⁽⁶⁾

Complexity in setting emissions standards is matched by varying mandates in controlling additives to fuel. The Clean Air Act allows

regulation to control fuel additions "if any emission products of such fuel or fuel additive will endanger the public health or welfare."⁽⁷⁾ However, it also allows such regulation "if emission products of such fuel or fuel additive will impair to a significant degree the performance of any emission control device or system which is in general use ..."⁽⁸⁾

There are important reasons for the differences in instructions for standard setting in various sections of the Clean Air Act, as presumably in all other legislation. The point here is simply that such instructions are likely to vary considerably, even within the relatively limited framework of a single agency's response to a single kind of problem.

The situation is at least as complex when many agencies are given responsibility for control of a particular health and safety problem. For instance, regulation of fluorocarbons is widely scattered. The Consumer Products Safety Commission regulates those used as household refrigerants.⁽⁹⁾ The Occupational Safety and Health Administration regulates them in occupational settings.⁽¹⁰⁾ Since fluorocarbons are used to propel aerosol sprays, many of which are cosmetics, they also fall within the purview of the Food and Drug Administration.⁽¹¹⁾ Finally, they may fall under the control of the EPA in administration of the Clean Air Act.⁽¹²⁾ The same complexity can be found with respect to the regulation of carcinogens. Again, there are important public policy reasons, or at least legislative choices, that result in such dispersions of authority.

4.1.A Types of Congressional Guidance

Rather than attempt to analyze the specific instructions given by Congress to Federal agencies in all the acts affecting health and safety, it is possible after a review of principal acts, to define certain basic kinds of guidance. We have classified these as: broad agency discretion, the balancing approach, technological feasibility, technology forcing, and no discretion. They are discussed below, with examples drawn from legislation.

Broad Agency Discretion

This is probably the most common approach. Congress provides a statute, usually including some statement of policy, and then gives the administering agency broad discretion to fulfill a mandate. An example of this approach is the grant of authority in the Atomic Energy Act to the NRC in the area of licensing. The principal guidance given is to "protect the health and safety of the public."⁽¹³⁾ Another example of this approach is Section 101 of NEPA which requires Federal agencies to do everything possible to comply with the policies of the Act while also complying with all other relevant policies.⁽¹⁴⁾ The range of agency discretion is obviously very broad.

The Balancing Approach

Somewhat more explicit instructions are provided when an agency is told to weigh accomplishment of its specific mandate against other factors. A good example is the Federal Environmental Pesticide Control Act of 1972 which requires the EPA Administrator to balance the economic, social and environmental costs and benefits before cancelling a pesticide registration.⁽¹⁵⁾ NEPA is also an example of this approach since it implicitly requires a balancing of environmental and other policy objectives in Section 101. Another example appears in the OSHA Act:

"The Secretary in promulgating standards dealing with toxic materials or harmful physical agents under this subsection shall set the standards which most adequately assure, to the extent feasible, on the basis of the best available evidence that no employee will suffer material impairments of health or functional capacity even if such employee has regular exposure to the hazard dealt with by the standard for the period of his working life ..."⁽¹⁶⁾

The term feasible in this context has been interpreted to include economic feasibility.⁽¹⁷⁾

Technological Feasibility

Congressional guidance which allows an agency less discretion may require an agency to set standards at the limits of technological feasibility regardless of economic considerations.

4.1.B Procedural Requirements

Instructions for standards setting and the factors to be considered in making regulatory decisions are not the only form of guidance Congress provides. There is a range of procedural requirements in any regulatory statute that form an important source of guidance in their own right. For instance, provisions for judicial review of agency decisions provide some restrictions by setting controls on agency discretion. Usually this is done by incorporating the Administrative Procedure Act⁽²⁴⁾ which gives considerable deference to agency decision making, but other possibilities exist. For instance, the Occupational Safety and Health Act of 1970 allows the Secretary of Labor to promulgate as an OSHA standard any existing standard of any Federal agency relevant to health and safety in the working place.⁽²⁵⁾ This requirement severely limits challenges to such promulgations.

A related procedural constraint on agency discretion is provided in the form of advisory boards. The Occupation Safety and Health Act created the National Institute for Occupational Safety and Health (NIOSH) within HEW to give advice to OSHA, which was lodged in the Labor Department. NIOSH's function is to "develop criteria for dealing with toxic materials ... which will prescribe exposure levels safe for various periods of employment ..."⁽²⁶⁾ While the Industrial Union⁽¹⁷⁾ case held that the NIOSH standards were not mandatory on OSHA, its mere existence provides some constraint on OSHA action.

Other procedural instructions include requirements for public hearings, for inflation impact statements (see Section 10.1), circulation for comment of draft regulations, and requirements of specific findings by the administrator before taking particular regulatory action. NEPA applies generally to regulatory actions; hence the production of environmental impact statements and their circulation for comment is a general authority for such procedures.

The procedural instruction concerning who must participate in regulatory decision making, even if the participation is only advisory, and the findings a public official must make before taking action, may be much more important in the substantive outcome than instructions as to the kinds of factors to consider.

4.2 CONGRESSIONAL GUIDANCE FOR USING PARTICULAR DECISION TECHNIQUES

4.2.A When and Where Cost-Benefit Analysis is Required

While a number of Federal agencies commonly use cost-benefit analysis in making project decisions (e.g., Soil Conservation Service, the Bureau of Reclamation and the Army Corps of Engineers) the practice is not widely mandated by Federal law. Specific legislative requirements for cost-benefit analysis on Federal projects are restricted to water resources development. These evolved in a series of statutes over the years beginning with the Rivers and Harbors Act of 1902 as elaborated in the Flood Control Act of 1936:

The Federal Government should improve or participate in the improvement of navigable waters or their tributaries, including watersheds thereof for flood control purposes if the benefits to whomsoever they may accrue are in excess of the estimated cost and if the lives and social security of these people are not otherwise adversely affected.(27)

The Planning-Programming-Budgeting (PPB) System initiated by President Johnson gave some impetus to the use of cost-benefit analysis. Another recent development has been the uniform standards used in the executive branch.(28) These standards presently appear in 18 Code of Federal Regulations, Section 204.39. The final development was passage of a law in 1974 specifying means for setting the discount rate in such projects.(29)

Beyond the requirements in the water resources area, particularly those applying to projects undertaken by the Corps of Engineers, use of cost-benefit analysis is essentially a matter of agency discretion. The now defunct Atomic Energy Commission (AEC) promulgated formal requirements for such analysis.(30) The adoption of these requirements was in response to the first major litigation seeking to apply NEPA to the AEC practices, Calvert Cliffs' Coordinating Committee, Inc. v. Atomic Energy Commission.(31) The AEC's action was clearly a response to the court's holding about the applicability of NEPA and the statute's requirements for a balancing analysis in decision making. However, as will be shown in Section 4.2.B, Calvert Cliffs does not mandate cost-benefit analysis. More properly, cost-benefit analysis may be viewed as an appropriate response to NEPA's requirement for a balancing of environmental and other factors.

4.2.B Does NEPA Dictate Cost-Benefit Analysis or Some Other Formal Process?

After examining NEPA and the literature we have concluded that NEPA does not dictate formal cost-benefit analyses or any other specific technique for regulating decision making. This means that cost-benefit analysis is available but is not required for value/impact analyses. Some form of systematic approach is however, required by NEPA for environmental decision making. Alternative approaches to decision making are discussed in Section 6.0. In addition to cost-benefit analysis, matrix and utility approaches can be used. Currently most Federal agencies utilize some form of a matrix approach.

There has been considerable discussion about the possibility of NEPA requiring the use of cost-benefit or other formal decision analysis.⁽³²⁾ This discussion in both court decisions and journals has raised a set of issues ranging from a desire by some to see environmental impacts, whether positive or negative, included with economic and technical data in an agency's cost-benefit calculations to a reluctance to quantify environmental impacts or use cost-benefit analysis or other formal decision techniques at all. Adding to the debate, or at least the confusion surrounding it, are explicit provisions of NEPA that seem to point toward the inclusion of environmental impacts in cost-benefit analyses or other quantified decision techniques. These are the requirement in Section 102(A) of the act that Federal agencies "utilize a systematic interdisciplinary approach ... in planning and in decision making which may have an impact on man's environment," and the requirement in Section 102(B) that Federal agencies "identify and develop methods and procedures, in consultation with the Council on Environmental Quality ..., which will insure that presently unquantified environmental amenities and values may be given appropriate consideration in decision making along with economic and technical consideration."⁽³³⁾ The language on its face is susceptible to either of two views. One is that environmental impacts must be quantified, and presumably used in the calculation of benefit/cost ratios. The other is that attention must be given to devising ways to compare previously unquantified environmental impacts to other aspects of a project choice in light of the policy concerns of NEPA. This latter view assumes that the comparison of environmental impacts will somehow be systematically incorporated into agency decision making. The

second view seems to be the correct one. NEPA is designed to insure that environmental impacts are adequately considered in Federal decision making. Adequacy in this context has been interpreted in various ways, from thorough identification of such impacts as a prelude to decision making to placing a very high value on preserving environmental amenities in such decision making.⁽³⁴⁾ Even the latter view, though, is not a requirement for rigorous cost-benefit analysis or any other formal decision technique. Moreover, the Council on Environmental Qualities NEPA guidelines suggest that if a cost-benefit analysis is prepared it be attached to the environmental impact statement, but it does not require the preparation of cost-benefit analyses.⁽³⁵⁾

A systematic, interdisciplinary balancing of environmental impacts with other project effects, as discussed at length in Calvert Cliffs, is clearly required by Section 102(A). Only in this sense is NEPA a cost-benefit stature. It does not require the calculation of a benefit/cost ratio, internal rate of return or even the weighing in dollar amount of all the effects of a project in the environmental impact statement.⁽³⁶⁾

There has, it is true, been considerable comment to the effect that NEPA requires cost-benefit analysis. Frederick R. Anderson of the Environmental Law Institute has called NEPA a cost-benefit statute for agency decisions on all manner of Federal projects.⁽³⁷⁾ There is no indication that Anderson was speaking of cost-benefit analysis in a formal sense though. The law review note, "Cost-Benefit Analysis in the Courts: Initial Review Under NEPA,"⁽³²⁾ describes a number of cases which appear to mandate the performance of cost-benefit analyses. However, the authority is a line of cases concerning dam and other water resource development projects. As mentioned in Section 4.2.A above, such projects require a rigorous cost-benefit analysis independently of NEPA. It seems a mistake to move from such cases to a general requirement under NEPA for cost-benefit analysis.

Part of the reason for such error undoubtedly lies in semantic confusion concerning cost-benefit analysis both in the courts and in the journal literature. Calvert Cliffs, for instance, speaks of environmental costs and their being weighed against other benefits in a number of places. It,

at no point, specifically discusses cost-benefit analysis, but merely the balancing of costs and benefits.⁽³⁸⁾ Apart from the water resources cases in which the calculation of cost-benefit analyses or internal rates of return were found to be mandatory, there is little discussion of a rigorous form of analysis normally associated with cost-benefit analysis.

Outside of the water resources area, no Federal agency appears to require calculation of a comprehensive benefit/cost ratio. NRC, in fact, currently has more formal cost-benefit requirements⁽³⁹⁾ for its licensing activities than nearly all other agencies.⁽⁴⁰⁾

In summary, some form of systematic decision making for activities which affect man's environment is required. Cost-benefit analysis can be used to describe the balancing of environmental and other factors required by Calvert Cliffs. It can also be used in value/impact analyses. NEPA itself, however, does not appear to require it.

4.3 JUDICIAL REACTION TO CURRENT REGULATORY DECISION MAKING

Judicial reactions to regulatory decision making generally support administrative discretion, as they do other forms of administrative action. Particularly in cases like the ones discussed in this section, where both factual uncertainty and a likelihood of disagreement in scientific opinion occur, the courts are apt to favor an administrator's decision (at least so long as he can present some grounds for it).⁽⁴¹⁾

The greatest judicial problem in health and safety regulation is the need to make (and judicially review) decisions made under much greater uncertainty than is normally the case.

Normally, courts review regulatory decisions based on facts. Although uncertainty about facts is nearly always present, the uncertainty is usually small enough that it is not an important decision factor. A regulatory official, operating pursuant to his mandate, makes factual determinations and then defines appropriate regulatory policy. The reviewing court may look to see whether the determination is justifiable on the basis of evidence presented and then consider the relationship between regulations

promulgated and the facts. Ground rules for such analyses are well laid out and understood. While there may be intense dispute over their application in a particular situation, the judicial system is, by and large, adept in this area.

Regulatory safety decision making is typically not based on well proven facts and is a different and newer phenomenon. A recent leading case is Ethyl Corporation v. EPA,⁽⁴²⁾ a challenge to EPA regulation of lead in gasoline. Ethyl is a 5 to 4 decision by the full District of Columbia Circuit Court, upholding the EPA position and reversing an earlier decision made by a panel of that court. The Supreme Court on June 14, 1976, refused to review the decision. Basically, the decision concerns EPA's ability to regulate fuel additives under Section 211 (c)(1)(a) of the Clean Air Act.⁽⁴³⁾ EPA contended that because automobile emissions contribute 90% of the atmospheric lead, because lead is a virulent poison, and because some studies suggested an association between levels of lead in the atmosphere and in the body, it was justified in moving to control lead in motor fuel. The majority of the court agreed with this view on the grounds that the "will endanger" language of the Act is precautionary in nature and does not require proof of actual harm before regulation is appropriate. The opposing line of argument was that a high degree of factual proof, even to the level of demonstrated harm, was necessary to show atmospheric lead actually endangered public health before EPA could move under the provision. There was little strong factual evidence of harm cited in the case. The Ethyl decision has some general force on this issue, in view of the Supreme Court's refusal to review. For NRC the decision suggests that its regulatory decisions can be accepted in the courts even if little or no proof of the potential harm associated with the regulated activity can be shown.

Somewhat similar issues arise in the Reserve Mining Co. case.⁽⁴⁴⁾ While Reserve did not involve a review of regulatory decision by an agency, it turned on questions of judicial decision making under uncertainty. Here the problems were the amount of danger to public health caused by atmospheric emissions from Reserve's plant and from the discharge of a slurry containing asbestos-like fibers into Lake Superior. There was no clear factual showing

of asbestos in the drinking water of Duluth or other nearby cities nor any substantial presence of them in the air. Nonetheless, the court held that any presence of such pollutants in the air and water of itself constituted danger to public health. It then weighed the risks of such danger against the costs of eliminating it to fashion a less severe remedy than the immediate closure ordered by the district court which first heard the case. Nonetheless Reserve clearly suggests that the courts will act to protect public health on some basis other than a clear factual demonstration of harmful effect and strengthens the likelihood that they will uphold agency action taken on the same basis.^(a)

Judicial acceptance of agency decisions in the environmental area is not total, however. Some recent decisions have looked closely at the merits of agency decisions.⁽⁴⁵⁾ A particularly cogent statement of the position for active judicial scrutiny is found in Environmental Defense Fund v. Ruckelshaus,⁽⁴⁶⁾ involving the decision to ban DDT. The judge in the decision advocated the need for agencies to articulate the standards that govern their discretionary decisions and for written findings of fact to support the decisions.

The emergence of substantive review under NEPA, albeit a matter of some disagreement in the courts is another example of decisions being reviewed on their merits. As noted in Section 4.1, NEPA clearly provides a general set of procedural constraints to agency action. What is somewhat less widely recognized is that it also has substantive aspects. That is, not only must agencies prepare environmental impact statements, and consider environmental values in making their decisions, but they must to some extent act to protect those values. This conclusion has ramifications for the criteria weighing process discussed later in the report. The earliest authority for the view of the need to balance environmental considerations along with other aspects

(a) Other cases where courts have accepted agency safety decisions based on limited factual evidence are collected in "In Environmental Cases Involving Scientific Unknowns, Risk Benefit Analysis, Rather than Traditional Standards of Proof, Will Determine Whether Imminent Health Hazard Exists," 25 Catholic University Law Review 167 (1975).

in agency action was the Calvert Cliffs case cited earlier. A more elaborate description of the substantive review standards appears in the Gillam Dam case.⁽⁴⁷⁾ In Sierra Club v. Froelke⁽⁴⁸⁾ the court applied the substantive review standards in detail to the cost-benefit analysis undertaken by the Army Corps of Engineers in the dam project. In Montgomery v. Ellis⁽⁴⁹⁾ the court distinguished between procedural requirements for an adequate environmental impact statement and the validity under the substantive requirements of NEPA Section 101 of the Soil Conservation Services' determination of the benefit/cost ratio for a stream channelization project. The point of both of these is not that NEPA has been applied to cost-benefit analyses, but rather that the broad NEPA policy of protecting the environment requires such analyses and allows serious review of agency decisions.

Despite the emergence of the view of some courts that NEPA creates a substantive body of law, particularly in Sections 101 and 102 (a), to be applied to agency decision making, the issue is unsettled. The Circuit Courts of Appeals are divided on the issue and to date the United States Supreme Court has not clearly ruled on it.⁽⁵⁰⁾

REFERENCES - SECTION 4

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2. 42 USC § 1857c-4(b)(1).
3. 42 USC § 1857c-4(b)(2).
4. See 40 CFR Part 50.
5. 42 USC § 1857f-1(a)(1).
6. 42 USC § 1857c-7(a)(1).
7. 42 USC § 1857f-6(c)(1)(A).
8. 42 USC § 1857f-6(c)(1)(B).
9. 15 USC § 2051 et seq.
10. 29 USC § 651 et seq.
11. 21 USC § 346 et seq.
12. 42 USC § 1857 et seq.
13. 42 USC § 2112.
14. 42 USC § 4331.
15. 7 USC § 136.
16. 29 USC § 655 (b)(5).
17. Industrial Union Department, AFL-CIO v. Hodgson 499 F2d 467 (D.C. Circuit, 1974).
18. 33 USC § 1316 (a)(1).
19. 33 USC § 1311(b)(1)(A).
20. 33 USC § 1311(b)(2)(A).
21. 42 USC § 1857F-1(b)(1)(B).
22. Effects of Chronic Exposure to Low Level Pollutants in the Environment, Congressional Research Service, Library of Congress, p. 348, November 1975.

23. 21 USC § 348 (e)(3)(A).
24. 5 USC § 706.
25. 29 USC § 655.
26. 29 USC § 669 (a)(3).
27. 33 USC § 701 (a)(3).
28. "Policies, Standards and Procedures in the Formulation, Evaluation and Review of Plans for Use and Development of Water and Related Land Resources." Senate Document 97, 87th Congress, 2nd Session.
29. Public Law 93-251, Section 88.
30. 10 CFR 51.23(c).
31. Calvert Cliffs Coordinating Committee, Inc. v. AEC, 449 F.2d 1109 (D.C. Circuit, 1971).
32. See: "Cost-Benefit Analysis and the National Environmental Policy Act of 1969" 24 Stanford Law Review 1092, June 1972.

"Cost-Benefit Analysis in the Courts: Initial Review Under NEPA 9 Georgia Law Review 417, 1975.

"The Least Adverse Approach to Substantive Review Under NEPA 88 Harvard Law Review 735, 1975, and the cases discussed therein, particularly Calvert Cliffs and Sierra Club v. Morton 510 F.2d 813 (Court of Appeals Florida 1975).

"Judicial Review of Cost-Benefit Analysis Under NEPA," 53 Nebraska Law Review 540, 1974.
33. 42 USC § 4332.
34. Sierra Club v. Froehlke, 359 F. Supp. 1289 (D.C. Texas 1973).
35. 40 CFR 1500.8 (a)(4), (8).
36. Sierra Club v. Morton 510 F.2d 818, (Court of Appeals Florida, 1975).
37. Frederick R. Anderson. NEPA in the Courts, Johns Hopkins University Press, Baltimore, MD., 1973, p. 265.
38. See Ibid, p. 256 for a critique at the balancing approach.
39. 10 CFR 51.

40. A discussion of the cost-benefit requirements of Federal agencies is in Ray M. Druley, "Federal Agency NEPA Procedures," Environment Reporter Monograph No. 23, July 9, 1976.
41. See "Substantive Review Under NEPA" 88 Harvard Law Review 735 at 743, Note 58.
42. Ethyl Corporation v. EPA (D.C. Circuit, March 19, 1976) 8 ERC 1785.
43. 42 USC § 1857f-6(c)(1)(A).
44. Reserve Mining Co. v. EPA 514 F.2d 492 (8th Circuit 1975).
45. See Frederick R. Anderson, NEPA in the Courts, Johns Hopkins University Press, Baltimore, 1973, p. 15.
46. Environmental Defense Fund v. Ruckleshaus 439 F.2d 595.
47. Environmental Defense Fund v. Corps. of Engineers 470 F.2d 289, 297 (8th Circuit, 1972).
48. 359 F Supp. 1289 (S.D. Texas 1973).
49. 3 ELR 2845 (N.D. Alabama, 1973).
50. For a summary of opinions on NEPA substantive review, see 88 Harvard Law Review 735, Notes 2 and 3.

5.0 ELEMENTS OF THE DECISION MAKING PROCESS

Decision making can be viewed in a number of ways. A generally useful way is to view it as a process consisting of five elements: 1) objectives, 2) alternatives, 3) attributes, 4) objective function, and 5) valuation.⁽¹⁾ This structure is common to all decisions. The process begins with the identification of objectives which defines the problem and the goals of the best solution. Generation of alternatives is the development of sets of action, one of which will be selected as the best means of achieving the objectives. Objectives for most decisions are broad qualitative statements. Therefore, the decision maker is required to identify a set of indices for each objective which measures the impact of each alternative on each objective. These are called attributes. Each objective must be completely defined by an associated set of attributes. An estimated technical performance score for each attribute for every alternative must also be developed. Trade-offs of the desirability of attribute performances between alternatives are made through the use of an objective function. The objective function represents the desirability of each attribute at different performance levels. Decision methodologies, as used in this study, are types of objective functions. The final element of the decision process is the valuation of desirability of levels of attributes. Measurement of value is different than estimating technical performance scores. Dividing a decision process into the five structural elements of objectives, alternatives, attributes, objective function and valuation does not imply that each element should be considered in isolation. In fact, consideration of one element will be affected by the other elements. For example, the objectives may make a specific objective function most appropriate, which, in turn, will favor the use of a certain type of measures.

There are two reasons for examining the structure of a decision process. First, a decision is no better than its weakest element. Thus, a decision could use an excellent objective function and have well measured attributes, but if the objectives are poorly defined, there is no assurance that a good decision has been made. Second, a proper perspective of the role of decision methodologies (objective functions) in a decision process is gained by

examining the decision structure. The use of a given decision methodology or objective function may influence the types of measurements used. However, a decision methodology is only one element in the overall decision process. The decision maker must supply the other elements of the decision process at a level commensurate with the decision methodology being used.

Table 2 summarizes the decision process in the structural form developed here. Again, the elements of the decision process are interdependent. The ideal decision would entail several iterations of the decision process, using the knowledge and insight gained to modify each of the elements in the process. Each element will be described in more detail below.

TABLE 2. Elements of a Decision Process

	<u>Definition</u>	<u>Properties</u>	<u>Examples</u>
<u>Objectives</u>	Broad statement of the goals of the decision	1. Small Number 2. Complete 3. Independence	Minimize Hazard Minimize Water Effluents
<u>Alternatives</u>	Proposed sets of actions being considered as a means of achieving the goals		Require seat belts Lower speed limits Install air bags
<u>Attributes</u>	Scales, indices, or factors indicating the degree to which alternatives satisfy the objectives	1. Reasonable number 2. Complete 3. Estimable 4. Independence	Radiation exposure Transportation Safety Index, including: a) mode b) distance c) integrity
<u>Objective Function</u>	Method of making trade-offs of desirability of different performance levels of all attributes between alternatives	1. Scaling 2. Linearity 3. Independence 4. Uncertainty 5. Aggregation 6. Interpretability 7. Discounting	Cost-Benefit Multi-Attributed Utility
<u>Valuation</u>	Estimates of desirability of technical performance levels of attributes		Market Comparisons Polls Lottery

5.1 OBJECTIVES

Objectives state the goals of the decision. They tend to be broad generalized statements such as "minimize hazards," "minimize regulatory cost," or "provide adequate service." Often, especially in the regulatory environment, objectives will remain unchanged from one decision to another. Objectives often transcend the immediate decision, forming the basis for a consistent policy.

There are three properties that a set of objectives should satisfy:

- It should be complete, including all of the important considerations which could affect the decision;
- It should be of minimum size to facilitate analysis; and
- Each objective should be independent of the others so that double counting is avoided; i.e., satisfaction of one objective does not depend on the degree of satisfaction of any other objectives.

Each objective may have several levels of subobjectives.^(a) Only at the lowest level of objectives will they be specific enough to be dealt with analytically. Each level of subobjectives should completely describe the objective. For example, the objective "minimize hazard" may have subobjectives of minimize worker exposure, minimize accidental exposure, minimize routine exposure, and minimize exposure from extortion and sabotage efforts. The subobjective of minimizing routine exposure may be further divided into the subobjectives of minimizing air and water effluents. Subobjectives clarify and define the upper level objective, as well as facilitate analytical treatment of the objective. At each level, subobjectives should satisfy the same requirements that objectives must satisfy. That is, they should completely describe the higher level objective, they should be nonoverlapping, and they should be of minimum number.

The number of levels of objectives and breadth of objectives at each level is a judgmental problem. The only requirement is that all subobjectives which may change the results of the analysis must be included.

5.2 ALTERNATIVES

Generation of good alternatives can be one of the most difficult steps in the decision process. Alternative development requires insight and creative imagination. One reason for the difficulty is that it may require conceptualizing something that has not been thought of before.

^(a) Subobjectives are often referred to as decision criteria.

The search for alternatives is a two step process:⁽²⁾

1. Identification of classes of solutions
2. Investigation of solutions in a given class

A class of solutions may represent different approaches to a problem or emphasis on different facets of the problem. The step of developing classes of solutions and solutions within a class requires an attempt to stretch one's mind. The idea at this stage is to generate a wide range of solutions; no effort at evaluating solutions or possible approaches should be made. For example, if the problem being considered is spills from transportation accidents, classes of solutions may include container integrity, transport practices, facility locations, and chemical forms.

Once a broad range of classes of solutions and solutions have been generated, the solutions can be screened to select the best ones for further evaluation. Many solutions will be dominated by other solutions.

Quite often, restating the problem will suggest new alternatives. The way that a problem is stated restricts the types of alternatives that are considered. An example of this situation occurred during a study by Caplan and Nelson⁽³⁾ "designed to improve the employability of black inner city youth adults in Chicago." The punctuality among the trainees was so bad that the program was threatened with failure. Immediately, alternatives were advanced, including:

1. Time perspectives are socialized differently among different socio-economic groups.
2. Black men's time is different from white men's time.
3. Trainees are not future oriented and prefer immediate gratification.

All of these alternatives would require a lengthy study in order to arrive at a solution. Fortunately, someone thought of asking the trainees if they had alarm clocks. Less than 25% did. As a result, the problem was discovered at relatively low cost.

Seeking outside input, important throughout the decision process, can be especially valuable in the process of developing new alternatives. People within different branches of the same organization as well as outside the organization can provide new and different perspectives that may lead to creative alternatives.

5.3 ATTRIBUTES

Objectives and subobjectives are only rarely directly measurable. Attributes are scales or indices which indicate how much an alternative satisfies a given objective or subobjective. The degree of satisfaction is usually referred to as the performance of the alternative on the attribute, or simply as performance. Performance of each alternative on each attribute needs to be estimated; obtaining these estimates is usually the bulk of the technical work in the decision process. Examples of attributes are implementation cost and effluent releases. The estimated implementation cost for an alternative is the performance of the alternative for the attribute of implementation cost. Attributes must be estimable and comprehensive. In addition, desirable properties for attributes are independence and minimum size.

Estimable means that predictions or estimates of attribute performance and measures of desirability are possible. Comprehensive means that the degree of realization of an objective by a given alternative is fully expressed by the set of attributes associated with that objective. Independence means that the value of performance on one attribute is not related to performance on some other attribute. If attributes are independent, then double counting does not occur. Minimum size is desirable in order to keep the analysis tractable.

Great care should be exercised when selecting attributes to assure that the above properties are satisfied and that the objectives are accurately described. Attributes follow directly from the objectives only in a few cases. Thus, a search for or development of attributes may be required. For example, an attribute for the objective of "minimize accidental hazardous material releases during transportation" may require the development of an

index which includes modes of transportation, average trip distance and container integrity. The attributes selected have the potential of affecting the outcome of the analysis. If, in the above example, the attribute included only two of three factors, the analysis could be changed. Thus, the decision maker must be on guard to assure that the attributes fully describe the objective. Also, the sensitivity of the analysis to the attributes selected should be assessed.

Many objectives do not have quantifiable attributes. These objectives may require the use of proxy attributes. Some proxy attributes, e.g., BOD (biological oxygen demand) as an indicator of water quality, are easily quantifiable while others are not. Proxy attributes are used to avoid the problem of use of composite indices such as the one used in the transportation example above. Other reasons for use of a proxy attribute are that data may be more readily available and measurements or monitoring may be easier.

Objectives may not always have associated quantifiable attributes, either because composite indices have not been developed or because the objectives may seem to be inherently nonquantifiable. In such cases subjective attributes may be developed. Two closely related techniques for the use of subjective attributes are commonly used. One method is to have a panel of experts estimate the relative impacts of each alternative for a given attribute. Another is to specify probable scenarios (e.g. artist representations of alternative cooling systems in a given area) and rate the relative desirability of each scenario. The desirability of the attribute for any alternative then depends on the scenario that corresponds the best with the alternative. Use of subjective attributes may be no less precise than the use of objective attributes. Objective attributes, because of the quantification, seem to be very precise, but they can be measures of the wrong quantity or incomplete measures. Also, many objective measures are based on predictions derived from current data and models which typically involve many subjective elements. Thus, in many situations, subjective attributes may provide more meaningful assessments. Furthermore, use of subjective attributes will provide formalized and documented procedure for considering the subjective issues which are often the basis for protracted controversy.

5.4 OBJECTIVE FUNCTIONS

Objective functions are methods for synthesis of the information about attribute performances. Decision methodologies, as used in this discussion, are types of objective functions. A decision methodology enables decision makers to consistently express tradeoffs among desirability of the attribute performances. As such, the methodology will strongly influence which measures of desirability for attribute performances are used. The selection of a decision methodology depends on the objectives, the time and information available. For this reason, a good understanding of the characteristics of each decision methodology is required. Cost-benefit analysis, matrix methods and utility theory methods are decision methodologies which will be discussed in detail. The properties which are useful for comparing decision methodologies will be discussed first. These properties along with definitions are listed in Table 3.

TABLE 3. Properties of Objective Functions

Property	Types	Definition
Scaling	Nominal	Group elements into classes.
	Ordinal	Ranks elements using less than or greater than relationships. First, second, third, ... last is an ordinal scale.
	Interval	Defines a measurement which is an expression of the distance between the elements. Ratings of one to ten comprise an interval scale.
	Ratio or Cardinal	Adds absolute zero to ratio scales so that ratios become meaningful expressions. Money is a ratio scale.
Linearity	Linear	Desirability of an additional increment of a performance does not depend on the performance level.
	Nonlinear	Desirability of an additional increment of a performance depends on the performance level.
Independence	Independent	Desirability of one performance level does not depend on the performance of any other attribute.
	Dependent	Desirability of one performance is related to the performance on some other attribute.
Uncertainty	Deterministic	No uncertainty is assumed to exist.
	Expected Value	Most probable value is used and the analysis is performed as if it were deterministic. The analysis may be repeated using high and low values.
	Explicit Functions	Distribution functions are obtained and carried throughout the analysis. Results are usually in the form of a distribution.
Aggregation		The degree to which different attributes are combined by the decision methodology, ranging from a single dollar figure of cost-benefit to the complete nonaggregation of attributes with some matrix methods.
Discounting		A function which allows performances on attributes occurring at different points in time to be compared on a consistent basis. Usually assumes more distant future impacts to be less important.

5.4.A Scaling

The scale used to measure desirability dictates the kinds of comparisons that can be made.^(a) Nominal and ordinal scales, used with some matrix and preference methods, restrict analytical aggregation. Comparison of deterministic impacts require only ordinal scales. Interval scales allow for aggregation by additive operations, but not by multiplicative operations. This means that ratio comparisons cannot be made. Analytical inclusion of uncertainty requires interval scaling. Ratio scales are required if ratios of adverse to favorable performances are required. If aggregation which is inappropriate for the scales used is attempted, the results will be meaningless. For example, if an ordinal scale is used (alternatives ordered by desirability and numbered: 1 for best, 2 for second best, and on down for each attribute), a score for an alternative made by adding its rankings on the attributes would be meaningless.

5.4.B Linearity

Objective functions may express either linear or nonlinear relationships between impact level and desirability. Linear relationships, where the desirability of an additional increment of performance is independent of the performance level, are most commonly assumed. For many decisions, over the range of expected performance levels, linearity may be an acceptable assumption. In decisions where extremes in performances must be considered, nonlinear relationships should be considered. For example, assuming that the reduction of one man-rem of exposure is worth \$1000 over a small range of radioactivity releases may be valid. Use of such a linear relationship may not be valid, however, for a large range of releases unless a completely linear dose-response curve can be justified.

5.4.C Separability

The desirability of one attribute may be independent of performances of other attributes. For these cases, the desirability of an alternative is the sum of the desirabilities of each attribute. Some decisions may involve a functional relationship between the desirability of several attributes. For

^(a) See Reference 1 for a more detailed discussion of scaling.

example, the desirability of a particular level of air effluent may depend on the level of water releases. Usually, separable or independent attribute desirabilities are assumed, since they are easier to compute. Again, this assumption may be good only for certain ranges of impact levels.

The properties of linearity and separability combine to give relationships of preferential substitution between alternatives. This is the rate at which the decision maker is willing to trade off performances of one attribute for performances of other attributes. The usual assumptions of linearity and independence of desirabilities yield a linear rate of preferential substitution. An example of a function with a linear rate of preferential substitution is the \$1000 per man-rem guideline. Many decisions involving safety and health issues use nonlinear preferential substitution functions. For example, situations involving threshold levels for toxic chemicals are nonlinear functions, since exposure to chemicals above threshold levels is extremely undesirable, while below threshold levels, one may be indifferent to exposure.

5.4.D Uncertainty

Uncertainty arises at many points in the decision process: in models used in predicting future events, estimation of attribute performances, and measurement of desirability. The distribution of likelihood of performances for attributes, embodied in uncertainty, is information that may be very important to the decision. Very rarely is uncertainty carried through the analysis in explicit form. Usually, the expected value (the most likely) is used and the analysis is performed as if no uncertainty existed. Under these conditions, sensitivity analysis should be performed by repeating the analysis using high and low values. Variations of cost-benefit and utility methodologies have been used which explicitly incorporate uncertainty. However, these approaches usually require simulation to aggregate the attributes. Uncertainty should be explicitly treated, whether analytically or through sensitivity analysis, in the decision process.

5.4.E Aggregation

Decision makers must aggregate attributes either explicitly or implicitly. Some decision methodologies will aggregate the desirabilities of

attributes into a single number for each alternative. Other methodologies only aggregate groups of attributes, while some do no explicit aggregation. Supporters of explicit aggregation argue that such a process documents the assumptions and values of the decision maker. Debate over a decision is then focused towards values and assumptions. Others argue that analytical schemes cannot do justice to the complex judgmental processes of humans. One difficulty with this latter approach, however, is that experimental evidence suggests that humans often do a poor job of aggregating in situations involving several attributes⁽⁴⁾ or where the uncertainty is large.⁽⁵⁾ If the decision makers have extensively participated in all phases of a decision process, then analytical results will be very close to the judgmental results. A common situation, however, is that the decision makers, without an explicit statement of objectives, are presented with performances for some set of attributes developed by a research group. In such cases, explicit aggregation could be misleading and is probably a disservice, since the decision maker may not have a full understanding of the assumptions and bases for the aggregated number.

5.4.F Discounting

Discounting is a technique developed to enable comparisons of different time streams of income and expenditures. The process is based on the assumption that current consumption is more desirable than future consumption. Discounting is often applied to monetary income streams. Its use for nonmonetary attributes is a matter of current debate.

There is also considerable debate over what discount rate should be used for particular applications. Arguments are made that the discount rate of government projects should be the cost of money to the government, the market cost of money, and numerous other rates. Government financed projects will usually use the cost of money to the government. Privately financed projects should be analyzed using the rate of return required by the companies. Some argue a societal discount rate should be applied to government projects, since benefits and costs really accrue to everyone through secondary effects and other indirect mechanisms. Whatever discount rate is used, the reason for selection must be clearly stated. Sensitivity analyses with different discount rates should also be performed.

The use of discount rates for nonmonetary attributes is quite controversial. Some argue for positive discount rates saying that future impacts are too uncertain. They argue that technology developments will tend to mitigate the nonmonetary attributes, e.g., new technology will make it easier to control air pollution, or that war will intervene and the impacts won't matter anyway. Others argue that negative discount rates should be applied (putting a premium on future resource commitment) since the environment has only a limited capacity to cope with the effects of man's activities. Frequently a zero discount rate is used for nonmonetary attributes while the debate continues.

5.5 VALUATION

Techniques of valuation infer desirability from observations of behavior. This requires making inferences about desirability from empirical data. Matrix decision methods utilize a subjective, implicit approach to valuation. The decision maker is presented with attribute performance scores for each alternative and subjectively values performances in comparing alternatives. In cost-benefit and utility methodologies, the valuation process is made explicit. A "documented trail" leads from attribute performance to alternative comparison. This "trail" is significant because it provides a much greater opportunity for groups directly affected by the decision and the public to critique a regulatory decision and to understand the basis for the decision.

Two approaches to valuation are commonly used, a market approach and a direct approach. Examples of market approaches include inferring the value of:

- a) recreation - by determining amounts that people spend on lodging, travel and meals;
- b) health - by surveying expenditures to get well or surveying court awards;
- c) risk - by examining pay for risky jobs or examining activities with accepted risk.

Examples of direct approaches include bidding games, delphi techniques, paired comparison techniques (see Section 7.4) and questionnaires or surveys. Either approach may be used to measure values in terms of utility or dollars.

The market approaches are more commonly used, because the units of measurement are usually dollars, extensive data bases exist, there is considerable experience with the models, and the techniques are more readily understandable. Difficulty with market approaches occur when intangible factors must be considered in public decision making. Since good statistics indicating societal value of these intangible attributes do not exist, schemes for measuring the value have been developed which use related activities as a surrogate for the attribute being considered. Examples include the value of recreation and health mentioned above.

Imputation of monetary values for intangible factors sometimes seems inappropriate. This has led to a limited although increasing use of utility models. Utility models are based on axioms of rational behavior and assess preference functions through a series of questions, although market approaches can also be used. A principal advantage of utility units is that there is no interaction between the value of the attribute and the units to express that value. In addition, utility can be measured on ordinal or interval scales, requiring weaker assumptions than use of a ratio scale such as money.

Valuation techniques have many limitations. The problem is to measure values which are inadequately expressed by the activities of diverse groups of people, who choose among competing goods with many social and institutional constraints. Such measurements of value usually require a large data base and many computations. Market approaches generally utilize economic data to make inferences about values. Thus, values are inferred from observations of behavior. Market approaches are not restricted to use of economic data. For example, much recent work on the value of different types of risks is based on observations of public behavior.⁽⁶⁾ Direct approaches infer preferences from the responses of people directly questioned. The questioning may take the form of a poll, questionnaire, series of gambles or be an interactive session with a number of peers.

With the use of any valuation approach, several difficult problems are encountered. These should be recognized at the outset and provide an additional incentive for sensitivity analysis. These problems are:

1. Interdependencies between attributes should be explicitly specified and measured if possible. This is rarely done because of the large number of possible interactions. For small changes in attribute levels, the interaction effects may be assumed to be small.
2. People do not easily perceive and evaluate probability of events consistently and have difficulty differentiating between probabilities.⁽⁷⁾
3. The questions of whose values should be used and what weight to give each person or group when combining the values have not been answered. For some applications, the decision makers' values have been selected as the most relevant.
4. Any measurement is static, reflecting the values of the population at only one point in time.
5. The value of an incremental change in attribute performance may depend on the attribute performance level, i.e., a nonlinear preference function.

To illustrate the fifth point, consider the example with the following data:

	<u>Value of Impact (\$)</u>		<u>Total Value (\$)</u>
	<u>Impact 1</u>	<u>Impact 2</u>	
Alternative 1	12	100	112
Alternative 2	10	105	115

By just examining the total values, Alternative 2 seems to be the best. However, for many people an additional \$5 (\$105-\$100) when they already have \$100 is less valuable than an additional \$2 when they have only \$10. If such a relation holds, then Alternative 1 is better than Alternative 2. This means that knowledge of the value of additional dollars at different levels of

dollars is required. This concept is usually referred to as decreasing marginal utility. That is, each additional unit adds less to one's overall utility than the previous unit.

In addition to these general problems, each approach has operational and generic difficulties which are specific to the approach. These difficulties are summarized in Table 4. The operational difficulties can be overcome if enough time, money and care are expended in making the measurements. However, time and money are scarce commodities.

TABLE 4. Specific Difficulties of Valuation Techniques

<u>Market Approaches</u>	<u>Direct Approaches</u>
<p><u>Operational</u></p> <ol style="list-style-type: none"> 1. Money, with a value in itself, is often used as a measure of value. This usually results in the assumptions of linearity and independence being implicitly made which implies a constant rate of preferential substitution 2. Attributes not traded in a market may result in distortions from actual desirabilities because of the methods used for deriving the value. 3. Hard to separate components of market data. 4. Measurement of an activity often reflects only opportunity, not demand. 5. Incomplete formulations of demand functions may be very misleading. 6. Market costs do not always reflect value, especially where affected by regulations, tax structure or limited alternatives. <p><u>Generic</u></p> <ol style="list-style-type: none"> 1. Market equilibrium is assumed. 2. Nonmarket effects, e.g., equity flexibility, quality, balanced growth and reversibility remain external to the analysis. 3. Assumptions of free markets are required, specifically no transaction costs and perfect information. 	<p><u>Operational</u></p> <ol style="list-style-type: none"> 1. Wording, sequence and type of questions asked can introduce an unknown bias. 2. People may be unwilling or unable to verbalize preferences, particularly within the structure or terms that the analyst provides. 3. Techniques using hypothetical gambles depend on subjective probabilities as well as subjective preference. There is evidence that subjective probabilities do not correspond to calculated probabilities. 4. Damage functions must be specified in comprehensive terms. 5. Limitations on the number of people interviewed in each group may lead to sampling errors. 6. Expert interpretation of results of questions may be required. 7. Determining whose values to be measured. 8. Development of a good, understandable questioning format for eliciting values. <p><u>Generic</u></p> <ol style="list-style-type: none"> 1. It is difficult to combine utility functioning of different groups and individuals. 2. Verbalized preferences are often inconsistent with behavior. 3. Individuals may exaggerate preferences in order to mislead decision makers.

Despite the many difficulties in valuation approaches, measurements of value still need to be made. It is better to have some measurements, even with restrictive assumptions that at least indicate general first order preference for attributes at one performance level, than to have an expert or a decision maker postulate (without measurements) public preferences.

5.6 SUMMARY

This discussion has examined the decision making process from a structural perspective involving the elements of objectives, attributes, alternatives, objective functions and measurement. This enabled the development of a perspective on the role of decision methodologies within the decision process. However, the role of the decision maker in the process has been underplayed in the above discussion. The participation of the decision maker or his delegate throughout the decision process is vital if formalization of the process is to be of any use. Formalization, if accomplished within the framework of the decision process, can provide the documented basis for decisions. This may enable focusing debate about a decision on questions of objectives, state of knowledge, uncertainty and values. Decisions from a formalized process are more amenable to revision as the result of new information. It is also easier to monitor the effects of the decisions because objectives and attributes are documented and feedback from the actual performances of a decision can be incorporated in a straightforward manner in refining the decision.

The difficulties of measuring values suggest the need for public input throughout the decision process, so that the most extreme values and objections of those most affected will be heard. Possibly the format of the public hearings might be expanded from hearing scientific testimony (which sometimes can be presented in a value-laden nonscientific manner) to include work sessions for establishing objectives and discussions of values.

Formalization of the decision process offers many advantages for public decision making and is increasingly necessary in order to treat consistently the many factors that impact on complex decisions.

REFERENCES - SECTION 5

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6.0 DECISION METHODOLOGIES FOR REGULATORY DECISION MAKING

Decision methodologies have been developed to provide a framework for evaluating the performances of different alternatives in a manner consistent with the decision makers' objectives. The need for developing these methodologies arises from the complex interactions of today's socio-technical systems, making the consideration of a wide number of attributes a necessary element of decision making. The role of a decision methodology is to provide a consistent means to make trade-offs between performances of alternatives. As such, implementation of decision methodologies can point out areas of weakness in the decision, i.e., gaps in knowledge, or performance levels with large uncertainty. The methodologies range from rules of rational behavior to assessment and combination of probability distributions of attributes and utility. Each method is useful in some situations. The following discussion is focused on the relative merits of three broad classes of decision methodologies: matrix, cost-benefit, and utility methods. Use of threshold levels and sequential elimination is also discussed. The purpose of this discussion is to develop an understanding of the implicit assumptions and the applicability of the different methodologies.

It is useful to begin by discussing the classical decision model. The model considers two dimensions: alternatives and attributes (illustrated in Table 5). These dimensions can be set up as the rows and columns of a matrix where the rows correspond to alternatives and the columns correspond to attributes. The entries in the matrix represent the performance level of the alternative "i" on the attribute "j".

The classical decision model assumes independence between attributes, that desirability is linear with impact levels, and uncertainty is not explicitly represented. Extensions to the model which overcome some of these limitations are available.^(a) The important point is to understand the common structure that underlies the various decision methodologies.

^(a) Example extensions of decision methodologies include:

- 1) Treatment of interdependent attributes by use of interaction matrices by D.W. York.⁽¹⁾
- 2) Incorporation of probability distribution of attribute performance in a utility approach by Litchfield, et al.⁽²⁾
- 3) Consideration of equity in a matrix technique by Hill.⁽³⁾
- 4) Incorporation of uncertainty in cost-benefit analysis by Stacey, et al.⁽⁴⁾

TABLE 5. The Classical Decision Model

Attributes	1	2	3	.	.	.	n
Weight	W_1	W_2	W_3	.	.	.	W_n
Alternative							
1	P_{11}	P_{12}	P_{13}	.	.	.	P_{1n}
2	P_{21}	P_{22}	P_{23}	.	.	.	P_{2n}
3	P_{31}	P_{32}	P_{33}	.	.	.	P_{3n}
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.
m	P_{m1}	P_{m2}	P_{m3}	.	.	.	P_{mn}

W_j = weight of attribute j in the decision

P_{ij} = performance of alternative i for attribute j

Difficulties of the Classical Decision Model

1. Implicit assumptions of linearity of desirability of impact over all levels of impacts.
2. Implicit assumption of independence of value of attribute performance levels.
3. Uncertainty is left out of the analysis.

Decision methodologies differ primarily in their use of measures of performance and whether or not attributes are weighted and aggregated.

These differences are summarized below.

Matrix Methods

1. Performances may not be in mathematically comparable units.
2. Weights may be supplied judgmentally.
3. Alternatives are usually compared by sequential comparison and elimination.

Cost-Benefit

1. All performances, P_{ij} 's, measured in dollars, costs will be $-P_{ij}$.
2. All weights, W_j 's, equal one.
3. Alternative i score $\sum_j P_{ij}$ = net benefit.

Preference Methods

1. Performances are values, in utiles, or attribute performance level.
2. Weights represent relative weights of attributes.
3. Alternative score is $\sum_i P_{ij} W_i$.

The following discussion will examine the use of sequential comparisons, threshold levels, matrix methods, cost-benefit analysis, and utility analysis with the aim of defining what each technique is, and the limitations of each. Again, the discussion is directed at the possibilities of use for each decision methodology, and not at the details of applying the technique.

6.1 SEQUENTIAL ELIMINATION

One of the oldest decision techniques used is sequential elimination. The method, really a very qualitative matrix technique, requires the decision maker to make trade-offs among subsets of attributes. This method is described by Benjamin Franklin in the following letter to Joseph Priestley.⁽⁵⁾

Approaches similar to this are applicable to public decision making, when it is difficult to get agreement on making quantified trade-offs, and consensus may be obtainable with a qualitative, judgmental approach.

6.2 THRESHOLD LEVELS

The threshold level methodology contemplates the establishment of a specific attribute performance level which, if exceeded, will automatically trigger a regulatory response. They can be established by the Congress and be regulatory agencies. Threshold levels used by the Food and Drug Administration, for example, are discussed in Section 10.0. Population dose standards (e.g. the standards for protection against radiation in

London, September 19, 1772

Dear Sir,

In the affair of so much importance to you, wherein you ask my advice, I cannot, for want of sufficient premises, advise you what to determine, but if you please I will tell you how. When those difficult cases occur, they are difficult, chiefly because while we have them under consideration, all the reasons pro and con are not present to the mind at the same time; but sometimes one set present themselves, and at other times another, the first being out of sight. Hence the various purposes or inclinations that alternately prevail, and the uncertainty that perplexes us. To get over this, my way is to divide half a sheet of paper by a line into two columns; writing over the one Pro, and over the other Con. Then, during three or four days consideration, I put down under the different heads short hints of the different motives, that at different times occur to me, for or against the measure. When I have thus got them all together in one view, I endeavor to estimate their respective weights; and where I find two, one on each side, that seem equal, I strike them both out. If I find a reason pro equal to some two reasons con, I strike out the three. If I judge some two reasons con, equal to some three reasons pro, I strike out the five; and thus proceeding I find at length where the balance lies; and if, after a day or two of further consideration, nothing new that is of importance occurs on either side, I come to a determination accordingly. And, though the weight of reasons cannot be taken with the precision of algebraic quantities, yet when each is thus considered, separately and comparatively, and the whole lies before me, I think I can judge better, and am less liable to make a rash step, and in fact, I have found great advantage from this kind of equation, in what may be called moral or prudential algebra.

Wishing sincerely that you may determine for the best, I am ever, my dear friend, yours most affectionately.

B. Franklin

10 C.F.R. 20) should be distinguished from the threshold level decision methodology. Standards should result from a decision methodology. As used here, the threshold approach is a decision methodology.

The major difficulty with this methodology is that it provides no guidance to select an appropriate threshold level. A second difficulty with this technique is that it may allow the implementation of many decisions, none of which exceed the threshold levels, but cumulatively the decisions may have an unacceptable impact. The cumulative effect of a series of decisions can be unacceptable regardless of the decision methodology. However, the problem can be worse with threshold levels since alternatives satisfying the threshold levels are not critically reviewed. A third difficulty with threshold levels is that poor alternatives may be accepted just because the threshold levels are met, while better alternatives are rejected.

Threshold levels can be used for screening alternatives, or for determining the level of analysis that should be performed in the decision making process. Constraints such as minimum performance requirements or maximum emissions can be expressed as threshold levels. Thus, "threshold" should be an expression of constraints on the decision.^(a) However, threshold levels are really an inappropriate device for making the final decision since satisfying alternatives can be accepted without considering better alternatives.

6.3 MATRIX METHODS

Matrix methods are a large class of methods which have been developed as an aid in multi-attributed decisions. These methods provide a consistent means of considering attribute performances for all alternatives. The philosophy behind matrix methods is that quantitative methods of making trade-offs among attribute performances cannot reflect or do justice to the complex judgmental processes of human decision making. Furthermore, many important

(a) Threshold levels have been particularly useful as a model describing past decisions made by individuals, corporations, and governments. Thus, it can be a model of behavior but not necessarily a model of a good procedure.

attributes are nonquantifiable and, consequently, are often ignored in quantitative analyses. Thus, matrix methods differ from other decision methodologies in that they attempt to assure full consideration of attributes and alternatives, but they are non-aggregative methods.

The basic function of a matrix method is to present information relevant to a decision in a concise, easy-to-process manner. The matrix summarization of information closely parallels the structure of the decision process as developed earlier. Attributes, derived from objectives, head columns. Each row represents an alternative. The estimated performance for each alternative on each attribute is entered into the respective cell. At this point the matrix is a bookkeeping device which may aid in assuring complete consideration of attributes and alternatives.

To further aid decision makers, explicit weights for attributes may be derived and subsets of attributes may be aggregated. For many decisions the full set of attributes may be very large and difficult for a person to fully consider. Subsets of attributes can often be readily aggregated, thus making it easier for a decision maker to consider differences between alternatives.

The following example illustrates how a matrix technique might be used. Imagine that installation of an air pollution control device is being considered. Four alternative devices are available, each with different costs and efficiencies, relative to various air contaminants. This results in differing mixes of air pollution-aggravated health effects. These devices are noisy, thus causing some hearing difficulties. Each device also improves burner efficiency resulting in some savings. Below is a sample matrix with attribute performances for each alternative.

Alternative	Capital Cost	Operating Cost	Savings	Reduced Asthmas	Reduced Colds	Reduced Sight Problems	Increased Hearing Problems	Aesthetics of Residual Effluent
1	100	20	20	20	20	4	8	2nd best
2	150	20	40	40	14	6	6	3rd best
3	200	10	50	40	18	8	6	4th best
4	170	40	60	40	5	2	4	best
Status Quo	0	0	0	0	0	0	0	worst

With only five alternatives and eight attributes, it is difficult to consider all of the information. When possible it is desirable to condense several attributes into a single unit. Some of the attributes can be aggregated fairly easily; e.g., the financial ones into a net present value (NPV). Others such as health effects can be aggregated, although with less ease, into a health improvement index (HII). It should be possible to eventually reduce the matrix as follows:

Alternative	NPV	HII	Aesthetics
1	-10	2.3	2nd
2	-27	5.4	3rd
3	-26	5.7	4th
4	-47	5.3	1st
Status Quo	0	0	5th

With the reduced matrix it is easier to consider the differences between the alternatives. Of course the reduced matrix must embody a number of assumptions; e.g., a 10% discount rate, a 10-year life for the equipment, and that colds are 1/10 as serious as any other of the health effects. Thus, it is necessary that the decision maker participate in any aggregation of attributes in order to insure that he understands the meaning of such aggregated attributes, and the value judgments that must be made.

Two problems still remain in dealing with all of the information in the matrix. The first is that the health improvement index has no units. This can be rectified by specifying an illness, which if prevented would result in a health improvement comparable to the magnitude of the index numbers being considered. For example, one case of loss of hearing prevented might be equivalent to an HII value of 4. The second problem is realizing the relative importance of each attribute in the final decision. Several schemes for assessing relative importance have been applied.⁽⁷⁾ Estimates of relative importance can be listed as weights on the attributes. The final matrix is below.

Alternative	Weight	NPV ^(a) 3	HII ^(b) 6	Aesthetics 1
1		-10	2.3	2nd
2		-27	5.4	3rd
3		-26	5.7	4th
4		-47	5.3	1st
Status Quo		0	0	5th

(a) Net present value (NPV) is in units of thousands of dollars.

(b) One case of hearing loss prevented equals an HII value of 4.

The philosophy behind matrix methods is that this is as far as quantification and collapsing of attributes should be carried.

From the above example two principal problems emerge: valuation and aggregation. As discussed previously, valuation (estimating desirabilities of attribute performance of alternatives) is a problem of the decision process. Matrix methods are more flexible than other decision methodologies in the types of valuation measurements that can be used. Attribute desirability can be measured with any scale (nominal, ordinal, interval or ratio), or verbal descriptions can be used. Such variety of scales, when mixed in one matrix, can be difficult to use. In the above example an ordinal scale is used for aesthetics. While this simplifies the measurement process, it is difficult to use in making decisions. How much worse than the second best alternative, for example, is the third best alternative?

Aggregation of subsets of attributes must be done very carefully with matrix methods since such a variety of scales are often used. Aggregation schemes for some matrix methods have been proposed which are meaningless because they combine nominal and ordinal scales.⁽⁸⁾

A variety of matrix methods have been used. Variations principally use different scales appropriate to special applications. Hill⁽⁹⁾ has expanded the matrix to include equity and distributional data. Most applications of matrix methods seem to have two goals. The first is to ensure

that every attribute is considered for every alternative. The second is to have attribute performances presented in a concise way to facilitate critical review of the alternatives.

Principal advantages of using matrix approaches are that they allow the inclusion of nonquantifiable objectives, they present information in an easy to understand format, different scales can be used for different impacts, and consideration of all attributes for all alternatives is insured. Disadvantages include: limited consideration of uncertainty; a number of attributes with different scales can be very confusing; and invalid aggregation is often attempted, implicitly assuming independence and linearity, and performing invalid operations on the attribute scales used. An additional disadvantage is that the subjective valuation process inhibits the possibility of dialogue about the decision with individuals not participating in the decision.

6.4 COST-BENEFIT ANALYSIS

Cost-benefit analysis has been widely used by government agencies. Entire books have been written on cost-benefit techniques.^(a) The purpose of this discussion is only to present a summary overview of the subject.

There are two principal advantages of cost-benefit analysis. First, the basis of cost-benefit analysis and the common metric used for valuation, dollars, are understandable and familiar to both expert and layman. Second, data and methods to convert many attribute levels to dollars are available.

Simply stated, cost-benefit analysis involves translating the attribute performances of alternatives into dollar quantities. The favorable attribute performances are added together to become the benefits. The sum of the unfavorable attribute performances is the cost. Thus, the cost-benefit analysis can be viewed as a process of deriving dollar values for each entry in a performance matrix and aggregating all of the performances into one attribute, either net benefits (benefits minus cost) or a benefit to cost ratio.

(a) An excellent discussion of the basis and techniques of cost-benefit with special application to the protection of public health appears in J. Hirshleifer.⁽¹⁰⁾ An overall treatment of cost-benefit analysis is in E.J. Mishan's book.⁽¹¹⁾

When available resources are limited and only a few projects can be undertaken, the benefit/cost ratio should be used as the decision criterion maximizing net return. If only one project is to be undertaken, the benefit-cost difference should be the decision criterion, thereby maximizing benefits.

Capturing the full value of all attribute performances for each alternative can be difficult, often requiring considerable ingenuity. Particular care is needed to measure the value of attributes (such as aesthetics) which do not have a market price. Both direct and indirect effects must be assessed in monetary terms.

To fully capture the value of the benefits, the demand curve should be estimated. The demand curve relates the quantity of a good that will be purchased to the price. A good that is being supplied at a fixed price is being bought by a number of people who would be willing to buy that good at a higher price. The difference between the price being paid and the price people are willing to pay is called consumer surplus. Benefits of an action should include the consumer surplus.

A problem with many cost-benefit studies, especially as performed for environmental impact statements (EIS), is double counting.⁽¹²⁾ For example, a power plant produces power which valued at its selling price plus the consumer surplus will be a benefit of the project. In many studies (including the old AEC guidelines for EIS), the value of the jobs created and the taxes paid are counted as benefits. Including jobs and taxes as benefits is double counting since the price of power must include the revenue needed for taxes and salaries.

Methods for estimating the monetary value of some seemingly non quantifiable attributes have been developed. Procedures for estimating the value of recreation, time lost, injury, life, and pollution have been applied. In general two different methods are used in evaluating these impacts for which there is no market. The first is the use of surrogate factors. For example, the value of a recreational area is often estimated by the travel and lodging expenses incurred by visitors to that area. The second method is to measure willingness to pay for some incremental change in conditions, e.g., reduced water pollution.

There are several difficulties in using cost-benefit analysis for public decisions.^(a) Social objectives such as equity, flexibility or balanced development cannot easily be included in a cost-benefit analysis. This means that cost-benefit analysis does not recognize that benefits often go to people who are not bearing the cost. The requirement of monetary units is restrictive on the preference structure and can result in excluding certain group's values. In theory, market values represent societal values (the average of all groups). However, when market imperfections exist it is difficult to obtain monetary values that accurately reflect societal values. The approaches used for valuing impacts often involve complex schemes which may or may not capture the true desirability of the attribute performance.

In addition to the difficulties mentioned above, there are several operational problems in using a cost-benefit analysis. The assumptions that desirability of performance is linear with the performance level and independent of other performance levels are almost always implicitly made. Uncertainty is usually excluded from the analysis. Future health and environmental effects are sometimes discounted. Such practice is controversial and unacceptable to some. Also getting agreement on the proper discount rate for purely financial costs and benefits can be a major problem. The difficulties mentioned in this paragraph can be overcome with proper modifications of the cost-benefit methodologies at the price of greater complexity.

The use of cost-benefit analysis to make decisions which affect human health or the environment is not universally accepted. Its use has been rather severely criticized in several recent publications. Green,⁽¹³⁾ for example, sees the possibility that quantification of the costs and benefits associated with a decision that will affect public health may be "nothing more than a 'numbers game' through which the subjective judgments of the

(a) Additional discussion of these difficulties is in National Academy of Sciences, Decision Making for Regulating Chemicals in the Environment, Washington, DC, 1975.

public are to be subordinated to the judgments of experts as to what the public wants and what the public is willing to pay, in dollars and risk, for the presumed benefits." Levodie⁽¹⁴⁾ has recently argued in regard to environmental protection programs that the uncertainties associated with cost-benefit analysis are sufficiently great to preclude its usefulness in decision making. He concludes with the thought that "the issues are of conscience and morality, not economics." Kneese⁽¹⁵⁾ argues that cost-benefit analysis cannot be used to effectively evaluate policy issues associated with nuclear energy. He states that the questions are of an ethical character and that cost-benefit analysis may actually obscure the issues. Finally, a University of Oklahoma research team has called the reduction of environmental or health effects into dollars or any other single index a disservice to policy makers.⁽¹⁶⁾ To some extent, these comments seem to reflect dissatisfaction with poorly done analyses. For carefully done analyses, these criticisms seem unduly harsh.

6.5 UTILITY METHODS

Recently a class of methodologies, which provides a means for establishing and comparing subjective feelings of values for attribute performances, has been developed and applied. These methods are referred to as utility methods.^(a) Through the use of utility methods it is possible to rigorously compare subjective preferences, to consider interdependencies between attributes, to include uncertainty and incorporate the preferences of several different groups in the analysis. However, to take full advantage of all the advantages of utility methods, considerable operational and computational complexity is required. Also there is a gulf between the factors that can be considered theoretically and the factors that can be incorporated in practice. Thus, for applications reported to date, only some of the possibilities allowed by utility methods have been used.

(a) A comprehensive recent source of information on utility analysis is Ralph L. Keeney and Howard Raiffa, Decisions With Multiple Objectives: Preferences and Value Trade-Offs, John Wiley & Sons, New York, NY, 1976. This book also contains an extensive bibliography.

The general framework for utility methods calls for a two-step process. In the first step, the relative values of various impact levels for each attribute are assessed. The second step is to assess the relative importance of each of the attributes. A wide variety of methods have been used in assessing both the values of performance levels⁽¹⁷⁾ and the relative importance of the attributes.⁽¹⁸⁾

The process of assessing relative values for performance levels defines the utility function. If the attributes are independent, then the utility function can be defined without considering the other attributes. When the criteria are interdependent, the utility function for an attribute must be assessed with several different values of the other attributes. Hence, there is considerable incentive to define the attributes so that they are independent. Utility functions may be nonlinear and may include the decision maker's attitude toward uncertainty. However, because the procedure for assessing a utility function which includes uncertainty requires the use of hypothetical gambles, most applications have not included uncertainty. Hypothetical gambles seem to be appropriate only with attributes readily measured in monetary units. Thus, utility functions incorporating uncertainty have nearly always been limited to business situations where the single attribute of money is considered.

Most of the methods for assessing utility functions that have been applied are variations of paired comparisons or direct rating techniques.⁽¹⁷⁾ In general, the assessment procedure requires extensive questioning of the person whose utility is being measured. The questioning may take the form of games, filling out questionnaires, or interacting with an analyst or computer. The task of assessing a utility function can be time consuming and tedious. If more than one person's utility is to be used, utility functions for each individual (or group) can be measured and combined. It is also possible to derive a societal utility function by examination of social statistics. This approach has been advocated by Rowe⁽¹⁹⁾ as a means to make decisions about acceptable risks. His approach is discussed in Section 7.4.

Once utility functions for each attribute are assessed, the relative weights of the criteria must be determined. Those weights are used to compare the utility functions for the attributes on the same scale. The most common methods used are variations of paired comparisons. Trade-off methods for determining relative importance have also been utilized allowing the attribute importance to depend on the performance level.⁽²⁰⁾ The total utility of an alternative is the sum of the utility for each attribute times the attribute weight. Uncertainty can be included by deriving the distribution of utility based on the distribution of attribute performance levels. Incorporation of uncertainty by this method will usually require computer simulation methods.

Preference methods overcome many of the shortcomings of other decision methodologies at the price of increased complexity. Most of the disadvantages or preference methods are related to the complexity; it is difficult for many people to understand these methods. Assessing utility functions, often a tedious task in itself, can be more difficult because respondents do not understand the methodology and, consequently, full cooperation may not be realized. In addition, the interrogative methods used for defining utility functions must be very carefully designed to obtain good results. For example, results may be affected by the wording and order of the questions. Also, utility assessment is vulnerable to misstatement of preferences, either intentionally to influence the outcome or because of misperceptions. That is, people sometimes do not act as they think they would. Another problem is determining whose utility should be measured and the number of people to measure in order to get a representative sample. This is a particularly severe problem when there are multiple decision makers. An additional problem with using utility methods, also due to the complexity, is that all of the possibilities of the methods are rarely used in applications. Thus, even though there is the potential for considering interdependencies, importance as a function of performance level, and uncertainty in utility analysis, one or more of these are usually not considered in order to make the analysis easier. In summary, utility assessment is often a difficult process involving problems of determining the sample, explaining the methods, gaining cooperation, developing a reliable interrogative technique, and assuring that the responses are consistent with behavior.

6.6 SUMMARY

Each of the classes of decision methodologies reviewed provide a systematic method for considering differences in alternatives. The relative merits of each methodology are summarized in Table 6. Modifications to cost-benefit and utility analysis are available which make both methodologies quite comparable. However, all of these possible modifications have not been used in applications due to the increased complexity. Items listed in Table 6 as pros, are advantages that arise from almost any application of the given methodology. Disadvantages, listed as cons in Table 6, seem to be inherent in the application of the methodology. The operational difficulties are problems with a methodology which have been overcome in applications by use of appropriate modifications.

The choice of methodology depends on time and resources available, the importance of the decision, and salient properties of the particular decision. For example, if an important decision is characterized by a small number of attributes with large uncertainty, a utility approach may be preferred over a matrix approach. By considering the relative merits of each methodology, the best methodology for the particular situation can be chosen. It should be remembered that the decision methodology is only one part of the decision process. Consequently, the decision methodology should complement the other steps in the process. With poorly defined objectives, an incomplete set of attributes or poor estimates of performance, the rigorous use of a good decision methodology will not insure a good decision. Additional concluding comments on the selection of an appropriate methodology are in Section 11.0.

TABLE 6. Comparison of Decision Methodologies

Cost-Benefit	Matrix Methods	Preference Methods
Pros		
1. Conceptually easy to understand.	1. Allows non-efficiency objectives.	1. Rigorously handles non-linear desirabilities.
2. Theoretical basis from general welfare theory.	2. Provides a good summary of data.	2. Uncertainty is included in analysis.
3. Reduces multi-dimensional impacts to scalar values, allowing easy comparison.	3. Can use a variety of measures for desirability of attribute performance.	3. Allows non-efficiency objectives.
4. Measurement methods limit analysts influence on results.	4. Assures all criteria are considered for each alternative.	4. Allows consideration of interdependent attributes.
5. Extensive data bases available.	5. Relatively less time required.	5. Allows inclusion of preferences of several groups.
6. Explicit valuation facilitates dialogue and critiques by outsiders.		6. Explicit valuation facilitates dialogue and critiques by outsiders.
Cons		
1. Monetary units restrictive on preference structure, and inclusion of different groups' values.	1. Uncertainty is not considered.	1. Utility assessment is difficult.
2. Excludes social objectives such as balanced growth, flexibility and equity.	2. No systematic method for comparing alternatives.	2. Mathematics can be complicated.
3. Market like approaches can involve complex schemes that do not capture true desirability for qualitative attributes.	3. Large number of attributes can be confusing.	3. Conceptual complexity.
	4. Tendency to mentally consider quantified attributes more than qualitative attributes.	4. Whose utility should be used?
	5. Subjective valuation diminishes possibility of constructive dialogue with outsiders.	
Operational Difficulties		
1. Uncertainty is rarely included.	1. Usually independence is assured.	1. Stated preferences are not consistent with behavior.
2. Implicit assumptions of linearity of desirability and independence of attributes are usually made.	2. Often attributes are aggregated by wrong mathematical methods.	2. Expert interpretation of responses needed.
3. Discounting of health and environmental effects.		3. Procedures to reduce the complexity have prevented the realization of all of the advantages of the methods.
4. Some tendency to double count.		

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7.0 EXAMPLE APPLICATIONS

Applications of the four principal decision methodologies - threshold levels, cost-benefit, matrix methods, and utility methods - are presented in this section. The purpose of the presentation is to illustrate the use of the methodologies. The details of the applications are not discussed but can be obtained in the references. By considering applications, the appropriateness of the methodologies for particular situations may be better understood.

7.1 THRESHOLD LEVELS

The best known example of a threshold level set by Congress is the Delaney Clause in the Pure Food and Drug Act regarding cancer causing chemicals in food. The clause states: "Provided, that no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal." This clause mandates the banning of any food additive that is shown to be cancer causing. However, below the threshold level of being cancer causing, decisions regarding food additives can be based on other decision methodologies.

Threshold levels can be used to trigger a response, and hence are appropriate for emergencies or imminent danger situations. However, threshold levels provide no guidance when the threshold is not exceeded, nor do they specify what degree of action is appropriate when it is exceeded.

Appropriate threshold levels should result from a decision process established before the need arises, so that the appropriate response is undertaken without delay. Prior consideration should help to ensure well considered responses and avoid crisis atmosphere decision making.

7.2 MATRIX METHOD

Many environmental impact statements (EIS) present the cost and impact data in a matrix format. The best alternative is selected on the basis of the information presented. The table used in the EIS for the Oyster Creek Nuclear Generating Station⁽¹⁾ is presented in Table 7. Performance levels are listed in noncomparable units. Comparison of alternatives is difficult but still feasible even with over 30 attributes. The matrix could be reduced to make it less cumbersome by aggregating some of the attributes. Also, attribute levels which are the same for all alternatives could be omitted, such as shoreline use and transmission lines. Note, that to compare alternatives the decision maker is required to make implicit judgments about the relative importance of each impact.

A different type of matrix method is shown in Table 8. This matrix was assembled by Warner and Preston for the U.S. EPA.⁽²⁾ Each of the 17 alternatives is an environmental impact assessment methodology. The matrix rates each methodology as to whether it satisfies certain desirable properties. At first glance this matrix seems to be difficult to use, but simplification is possible if there are one or more properties that a methodology must satisfy for a particular application. For example, if NEPA compliance is required, then Dee (1973) is the only methodology that can be selected. Similarly, if uncertainty is of a paramount importance for a particular application, then only five methodologies are acceptable. Final selection may be based on other attributes.

7.3 COST-BENEFIT

Many cost-benefit analyses have been performed in conjunction with government programs. Many of these suffer from problems of incompleteness, double counting, or poor treatment of uncertainty. An example of a good cost-benefit study is presented in Air Quality and Stationary Source Emission Control⁽³⁾ which evaluates alternative sulfur emission control strategies for different coal plants. The analytical work in the study is briefly summarized below.

TABLE 7. Oyster Creek Alternatives Matrix
Source: EIS-Oyster Creek, 1974 (Ref. 1)

SIGNIFICANT COSTS OR ENVIRONMENTAL IMPACTS	ENERGY SOURCES				EXISTING PLANT						
	OYSTER CREEK (BASE CASE)	OIL FIRED STATION WITH ONCE THROUGH COOLING	COAL FIRED STATION WITH ONCE THROUGH COOLING	MODIFIED RAD WASTE SYSTEM WITH ONCE THROUGH COOLING	OCEAN INTAKE AND DISCHARGE SYSTEM	DILUTION	ALTERNATE COOLING METHODS			FRESHWATER LAKE	
							COOLING TOWER, 23° APPROACH			700 ACRE POND SEWAGE EFFLUENT	SPRAY POND SEWAGE EFFLUENT
COSTS (ALL COSTS IN \$ MILLIONS)											
CAPITAL COSTS	89.9	398	474	94	311	90.6	126	128	128	153	139
DESIRED RETURN ON INVESTMENT (%/YR)	13.5	13.25	13.25	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
RETURN ON INVESTMENT	12.1	53	63	12.7	42	12.2	17.1	17.2	17.2	20.7	18.8
ANNUAL OPERATING COST ^(a)	2.7	2.5	3.2	2.9	3.3	2.8	4.8	4.8	5.5	a	7.2
ANNUAL FUELING COST	5.6	9.5	39	5.6	5.6	5.6	5.6	5.6	5.6	5.6	5.6
LAND USE											
SHORELINE USE	NONE	NONE	NONE	NONE	NONE EXCEPT DURING CONSTRUCTION	NONE	NONE	NONE	NONE	NONE	NONE
LAND REQUIREMENT	352 ACRES	452 ACRES	752 ACRES	352 ACRES	352 ACRES	352 ACRES	362 ACRES	362 ACRES	362 ACRES	1082 ACRES	652 ACRES
REDUCTION IN WILDLIFE HABITAT	25 ACRES	100 ACRES	400 ACRES	25 ACRES	25 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER 300 ACRES	25 ACRES	35 ACRES	35 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER ADDITIONAL 400 ACRES	35 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER ADDITIONAL 800 ACRES	735 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER ADDITIONAL 800 ACRES	200 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER ADDITIONAL 800 ACRES
EFFECT ON TERRESTRIAL BIOTA	NO EFFECT	NO CHANGE FROM BASE CASE	POSSIBLE EFFECT DUE TO ACERAGE LOST	NO CHANGE FROM BASE CASE	NO SIGNIFICANT CHANGE AFTER REVEGETATION	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	NO SIGNIFICANT CHANGE AFTER REVEGETATION	NO SIGNIFICANT CHANGE AFTER REVEGETATION	PROBABLE EFFECTS DUE TO ACERAGE LOST	POSSIBLE EFFECTS DUE TO ACERAGE LOST
WATER USE											
EFFECT ON AQUATIC BIOTA											
WINTER FLOUNDER	24,000 INDIVIDUALS/YR	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	SIGNIFICANT REDUCTION	SAME AS BASE CASE	1400 INDIVIDUALS/YR	0	0	0	0
OTHER FISH	110,000 INDIVIDUALS/YR						6000 INDIVIDUALS/YR	0	0	0	0
CRABS	32,000 INDIVIDUALS/YR						2000 INDIVIDUALS/YR	0	0	0	0
MENHADEN	10 ³ -10 ⁴ INDIVIDUALS/YR						0	0	0	0	0
ZOOPLANKTON											
KILLED BY CHLORINE	150 TONS/YR										
KILLED BY TEMPERATURE	300 TONS/YR										
BAY PRODUCTIVITY	500 TONS/YR				90 TONS/YR ^(b)	0	50 TONS/YR ^(b)	0	0	0	0
HEAT ADDITION TO BAY	1310 MW	1080 MW	1080 MW	1310 MW	NONE - 1310 MW TO OCEAN	1310 MW	~91 MW	~23 MW	~23 MW	~23 MW	~23 MW
ARTIFICIAL RADIOACTIVITY RELEASED TO BAY	0.55 MAN-REMS/YR	0	0	0.55 MAN-REMS/YR	NONE - 0.05 MAN- REMS/YR TO OCEAN	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR
RELEASES TO THE BAY, Na ₂ SO ₄	18 TONS/YR	18 TONS/YR	18 TONS/YR	18 TONS/YR	NONE 18 TONS/YR TO OCEAN	18 TONS/YR	18 TONS/YR	18 TONS/YR	18 TONS/YR	18 TONS/YR	18 TONS/YR
AIR USE											
ARTIFICIAL RADIOACTIVITY RELEASED IN THE AIR	410 MAN-REM/YR			4.4 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR
PARTICULATE RELEASES	2.5 TONS/YR	1,700 TONS/YR	1,700 TONS/YR ^(c)	5.0 TONS/YR	2.5 TONS/YR	10 TONS/YR	40 TONS/YR	40 TONS/YR	40 TONS/YR	40 TONS/YR	40 TONS/YR
CHEMICAL RELEASES - SO ₂	13.2 TONS/YR	13,600 TONS/YR	20,500 TONS/YR	22.0 TONS/YR	13.2 TONS/YR	20 TONS/YR	330 TONS/YR	330 TONS/YR	330 TONS/YR	330 TONS/YR	330 TONS/YR
NO _x	32.9 TONS/YR	5,200 TONS/YR	11,800 TONS/YR	66.0 TONS/YR	32.9 TONS/YR	40 TONS/YR	120 TONS/YR	120 TONS/YR	120 TONS/YR	120 TONS/YR	120 TONS/YR
ATMOSPHERIC EFFECTS - FOGGING ICING	NONE	NONE	NONE	NONE	NONE	NONE	~10% INCREASE IN FREQUENCY	~10% INCREASE IN FREQUENCY	~10% INCREASE IN FREQUENCY	~10% INCREASE IN FREQUENCY	~10% INCREASE IN FREQUENCY
EFFECT ON COMMUNITY AESTHETIC	MINOR IMPACT	MINOR IMPACT	MAJOR IMPACT FROM COAL HANDLING FACILITIES	MINOR IMPACT AFTER CONSTRUCTION	MINOR IMPACT AFTER CONSTRUCTION	MINOR IMPACT	MEDIUM IMPACT	MEDIUM IMPACT	MEDIUM IMPACT	MINOR IMPACT	MINOR IMPACT
RECREATIONAL IMPACT	SHIPWORM DAMAGE TO RECREATIONAL FACILITIES AND EQUIPMENT	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION	NO CHANGE FROM BASE CASE	PARTIAL ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT THERMAL DISCHARGE	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION
NOISE	QUIET	QUIET	NOISY	QUIET	QUIET	QUIET	QUIET	QUIET	QUIET	QUIET	QUIET
TRANSMISSION LINES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES

^(a) INCLUDES COSTS RESULTING FROM ADDITIONAL POWER REQUIREMENTS AT \$90K/W/YR

^(b) INCLUDED WITH TEMPERATURE EFFECT

^(c) COAL FIRED STATION EMISSIONS ARE BASED ON EPA LIMITS⁵

TABLE 8. Environmental Impact Methodologies Matrix
Source: Wamer and Preston, 1974 (Ref. 2).

TYPE	COMPREHENSIVENESS	ISOLATE PROJECT IMPACTS	TIMING AND DURATION	DATA SOURCES	MAGNITUDE	OBJECTIVITY	SIGNIFICANCE	EXPLICIT CRITERIA	UNCERTAINTY	RISK	ALTERNATIVES COMPARISON	PUBLIC INVOLVEMENT	AFFECTED PARTIES	SUMMARY DESCRIPTION	KEY ISSUES	NEPA COMPLIANCE	RESOURCE REQUIREMENTS	REPLICABILITY	FLEXIBILITY
ADKINS	C	P	S	N	N	N	N	N	N	N	S	N	N	S	N	S	N	S	S
DEE (1972)	C	P	S	S	S	S	S	N	N	N	S	N	P	S	S	P	N	S	P
DEE (1973)	C-M	P	S	S	S	P	N	S	N	N	S	P	S	S	S	P	S	N	P
GEORGIA	C	P	S	S	S	S	P	S	N	N	P	N	N	P	N	N	N	P	P
JAIN/URBAN (73)	CO	S	S	S	S	S	P	P	P	S	P	S	S	S	S	S	S	S	S
JAIN (74)	M	P	S	P	P	P	P	P	P	P	P	P	P	S	S	S	P	P	P
KRAUSKOPF	O	P	S	N	S	P	N	N	N	N	S	N	N	P	S	N	N	P	N
LEOPOLD	M	P	S	N	S	N	P	N	N	N	S	N	S	S	S	P	S	N	S
LITTLE	C	S	S	N	P	P	N	N	N	N	N	N	S	S	N	P	P	P	P
MCHARG	O	P	S	N	P	N	P	N	N	N	S	N	S	S	S	P	N	P	N
MOORE	M	S	S	N	S	N	P	N	N	N	S	N	N	S	P	N	S	N	S
NEW YORK	M	P	S	N	N	P	N	N	N	N	N	N	N	S	P	N	S	N	P
SMITH	C	P	S	N	P	P	N	S	N	N	S	N	N	N	N	N	N	N	P
SORENSEN	NW	S	P	N	P	N	N	P	N	N	N	N	N	N	N	N	P	N	N
STOVER	C	S	S	N	P	P	N	P	N	N	S	N	S	S	N	P	N	N	S
TASK FORCE	C	P	P	S	S	P	P	N	N	N	S	N	S	S	P	P	S	N	S
TULSA	C	P	S	P	P	P	P	P	N	N	S	N	N	S	N	N	P	P	P
WALTON	C	P	S	N	P	S	P	N	N	N	S	P	N	S	N	N	N	N	P
WSCC	A	P	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

KEY TO TYPES:

- A = AD HOC
- O = OVERLAY
- C = CHECKLIST
- M = MATRIX
- NW = NETWORK
- CO = COMBINATION COMPUTER-AIDED

KEY TO EVALUATION SYMBOLS:

- S = SUBSTANTIAL COMPLIANCE, LOW RESOURCE NEEDS, OR FEW REPLICABILITY-FLEXIBILITY LIMITATIONS
- P = PARTIAL COMPLIANCE, MODERATE RESOURCE NEEDS, OR MODERATE LIMITATIONS
- N = NO OR MINIMAL COMPLIANCE, HIGH RESOURCE NEEDS, OR MAJOR LIMITATIONS
- = AGGREGATION NOT ATTEMPTED

Sulfur emission controls increase the cost of electricity. The benefits of control include averted health effects, less material damage, improved aesthetics, and decreased acid rainfall. The cost of health effects includes the sum of medical care costs and lost productivity. The values of cleaner air and reduced property damage are derived from a study by Waddell and are summarized in Table 9 for a plant in an urban location. The sum of the costs are expressed in terms of dollars per pound of sulfur emitted. Knowing the amount of sulfur emitted and the cost of electricity for each control option, the total social cost of electricity can be computed. The graph in Figure 1 shows total production, emission control, and damage costs of electricity (on the ordinate) for each control option as a function of sulfur emission damage costs. The ordinate intercepts represent the production and emission control cost of electricity using the specified control option (17.5 mills for high sulfur coal, 21 mills for low sulfur eastern coal, etc.). The lines, representing the total social cost of electricity, depend on the quantity of sulfur emissions for each control option. In addition, the graph presents the probability distribution of likely values for sulfur emission damage costs. The probability distribution is based on the judgment of experts for the distribution of health effects and distribution of increased ambient sulfur levels. The estimated cost of sulfur emission derived in Table 9 is conservative and, thus, is higher than the most likely value in the probability distribution.

Presenting the information in the form of the graph in Figure 1 is a useful way of dealing with uncertainty in cost-benefit analysis. It can be readily observed that high sulfur coal is almost certainly an unacceptable option. Low sulfur eastern coal seems to be the best option for the range of most likely values of sulfur emissions (19 to 59¢/lb of sulfur emitted). On the basis of the value of sulfur emissions, flue gas desulfurization (FGD) is most likely unjustifiable.

TABLE 9. Cost of Sulfur Oxide Emissions Representative Calculation for Urban Plant Emitting 10,000 kg of SO_x/hr (96.5×10^6 lb of sulfur/yr)(a)

Health Effects from Increase (computed at ambient level of $16 \mu\text{g}/\text{m}^3$):

75,500 cases of chronic respiratory disease x \$250 per case	\$ 18.9 million
755,000 person-days of aggravated heart-lung disease symptom x \$20 per day	15.1
156,000 asthma attacks at \$10 each	1.6
18,400 cases of children's lower respiratory disease at \$75	1.4
42 premature deaths at \$30,000	1.3
Total Health Costs	\$ 38.3 million

Materials Damage

2.6 million per $\mu\text{g}/\text{m}^3$ of SO_4 x 1.86	\$ 4.8 million
0.7 million per $\mu\text{g}/\text{m}^3$ of SO_2 x 7.5	5.3
Aesthetics ($\$0.034 \times 96.5 \times 10^6$ lb)	3.3
Acid Rain etc. ($\$0.015 \times 96.5 \times 10^6$ lb)	1.4
Total Emissions Costs	\$ 53.1 million
Emissions Costs Per Pound of Sulfur	55¢

(a) Costs computed based on $1.86 \mu\text{g}/\text{m}^3$ increase in sulfate and $7.5 \mu\text{g}/\text{m}^3$ increase in sulfur dioxide concentrations in metropolitan areas with population 11.5 million.

FIGURE 1. Total Social Cost Versus Pollution Cost, Old Coal-Fired Plant Reconverted to Coal (Urban), Showing Probability Distribution on Pollution Cost/lb of Sulfur

7.4 PREFERENCE METHODS

A wide variety of preference methods have been proposed. The most widely applied method is probably utility theory for making risky financial decisions. This method has been used in many business environments.⁽⁴⁾ As discussed earlier, the assessment of utility functions incorporating attitudes towards risk for nonfinancial attributes often does not seem appropriate. The example applications discussed here include a method that does not incorporate uncertainty, a method that incorporates uncertainty, and a method that uses utility theory to develop estimates of acceptable risk.

To evaluate alternative waste management systems for military camps, Drobny, et al.,⁽⁵⁾ used a cost-effectiveness technique with all of the non-financial criteria aggregated by utility methods. The total utility for each system was then plotted against the cost to determine the most cost-effective system; i.e., the system which maximizes the utility per dollar cost. The eight attributes used for this analysis are presented in Table 10 and the matrix of performances of each alternative for each attribute in Table 11. Using the relative weights for each attribute, the attribute performances for each alternative are collapsed into a single effectiveness score for the alternative.

Relative attribute weights and attribute performances for each alternative were assessed by the technique of paired comparisons. For attribute weights, this method lists the attributes and assesses the relative importance of the attribute to the attribute below it. If the attributes are independent, the normalized relative weights (weights sum to one) can be computed. For alternative scores on the attributes, the procedure is similar. In this case, the degree of satisfaction of the attribute for one alternative is compared to the next alternative. Normalized scores can be computed from this information.

TABLE 10. Effectiveness Attributes and Adjusted Relative Weights. Source: Drobny, et al., 1971 (Ref. 5)

Effectiveness Measures		Adjusted Relative Weights
M_1	Simplicity of Operation	0.37
M_2	Simplicity of Installation	0.25
M_3	Operational Flexibility and Reliability	0.13
M_4	Environmental Quality Control	0.10
M_5	Manpower Requirements	0.06
M_6	Space Requirements	0.04
M_7	Power Requirements	0.03
M_8	Relocatability	0.02
		1.00

TABLE 11. Summary of Cost-Effectiveness Analysis - Alternative Treatment Processes for 500-Man Camps. Source: Drobny, et al., 1971 (Ref. 5).

Alternative Systems A_i	Measure of Effectiveness, (M_i), and Relative Weight, (w_i) ^a								Total Effectiveness, $E(A_i)$	Total Unit Treatment Cost, \$/1000 gal
	M_1 (0.37)	M_2 (0.25)	M_3 (0.13)	M_4 (0.10)	M_5 (0.06)	M_6 (0.04)	M_7 (0.03)	M_8 (0.02)		
A_1	0.0303 ^b	0.0133	0.0109	0.0010	0.0034	0.0004	0.0040	0.0010	0.0643	0.53
A_2	0.0303	0.0133	0.0109	0.0010	0.0034	0.0004	0.0024	0.0010	0.0627	0.60
A_3	0.0228	0.0140	0.0077	0.0097	0.0026	0.0035	0.0013	0.0011	0.0627	1.05
A_4	0.0228	0.0140	0.0077	0.0097	0.0023	0.0035	0.0007	0.0011	0.0618	1.70
A_5	0.0228	0.0140	0.0077	0.0097	0.0033	0.0035	0.0011	0.0011	0.0632	1.05
A_6	0.0228	0.0140	0.0077	0.0097	0.0030	0.0035	0.0016	0.0012	0.0635	1.03
A_7	0.0251	0.0140	0.0090	0.0097	0.0047	0.0035	0.0016	0.0012	0.0687	0.85
A_8	0.0251	0.0182	0.0090	0.0065	0.0037	0.0035	0.0031	0.0018	0.0709	0.60
A_9	0.0313	0.0111	0.0105	0.0020	0.0055	0.0069	0.0024	0.0009	0.0706	0.70
A_{10}	0.0331	0.0127	0.0114	0.0003	0.0035	0.0001	0.0050	0.0009	0.0670	0.39
A_{11}	0.0289	0.0191	0.0077	0.0015	0.0064	0.0035	0.0046	0.0014	0.0731	1.09
A_{12}	0.0207	0.0241	0.0081	0.0097	0.0049	0.0035	0.0004	0.0020	0.0734	1.30
A_{13}	0.0178	0.0202	0.0067	0.0097	0.0040	0.0035	0.0003	0.0014	0.0636	2.90
A_{14}	0.0187	0.0241	0.0070	0.0097	0.0058	0.0035	0.0013	0.0020	0.0721	0.93
A_{15}	0.0178	0.0241	0.0067	0.0097	0.0040	0.0035	0.0003	0.0020	0.0681	2.48

(a) Relative weights are given in parentheses and are obtained from Table 1, Ref. 5.

(b) All matrix entries are products of respective ratings and averaged relative weights.

The most cost-effective system is the one with the largest effectiveness to cost ratio. For this example, alternative 8 is the best. Another way of selecting the best alternative is to plot effectiveness versus cost, and construct a line joining the points on the upper left part of the graph as in Figure 2. The slope of the line will decrease sharply at the most cost-effective alternative (A_8) meaning that extra effectiveness must be purchased at a higher unit price than paid in alternative 8.

FIGURE 2. Relationship Between Total Unit Cost and Total Relative Effectiveness of Various Alternative Treatment Systems

A different utility approach has been applied to rank alternative nuclear waste management schemes for research funding. This method, developed by Litchfield et al⁽⁶⁾ incorporates values of several social groups and technical performance estimates made by experts which include uncertainty. This method is illustrated in Figure 3. Experts in the field estimate the performance of each alternative for each of the four attributes shown below.

Attribute	Metric
Present Value Costs	Dollars
Long-Term Risks	Number of Times the Risk of Lightning
Short-Term Risks	Number of Times the Risk of Lightning
Accident Detection and Recovery	Percent Reduction in Consequences

Estimation is accomplished by asking the expert for the most likely value or range of values, and the highest and lowest possible values. These points are then placed on a graph of attribute performance versus probability and the expert is asked to connect the points to reflect the probability distribution.

FIGURE 3. Decision Model Algorithm

Utility is assessed by giving people (selected to represent different social groups) a graph with a utility of one for the ideal level of the attribute. The graph has four other attribute levels marked on it. Respondants then are to mark the utility for each of these levels relative to the ideal level. For example, the following graph may be presented.

Relative to the ideal level, utilities for impact levels of L_1 , L_2 , L_3 and L_4 are shown below.

Connecting the indicated level with lines defines the utility function.

The utility function is merged with the probability distribution for the attribute to obtain the probability distribution of utility for each attribute (Figure 3). Attribute importance weights are assessed by the technique of paired comparisons. The distribution of attribute weights, i.e., the number of people weighting the attribute at each level (Figure 3d) is used to aggregate the utility distribution for each alternative. The final result is a distribution of total utility for each alternative (Figure 3e). The best alternative can be selected from this final graph.

The two previous examples used direct approaches for assessing utilities. A market approach to assess a societal utility function has been used by Rowe⁽⁷⁾ to develop estimates of acceptable risk. Acceptance of a given risk depends on subjective attitudes towards that risk. These can include the

probability, the consequence, the degree of avoidability and control, and the benefits of the activity. All of these factors are interrelated as illustrated in Table 12a. Rather than deal with the dependencies between the attributes (or risk factors), Rowe developed risk categories (Table 12b). The numbers in the table are the risk levels considered to be accepted by society for that particular type of risk. Risks can only be compared to risks in the same category. Two risk factors or attributes are identified as being independent, benefits and controllability. By examining historical data, Rowe derived the rate at which benefits and controllability are traded off for increased risk. These trade-off rates can be represented as factors (Table 12c). To determine whether a given risk is acceptable, the risk (R) is multiplied by the benefit factor (B) and the controllability factor (C). For most situations the risk will consist of three component risks; fatality (R_f), injury (R_i), and property damage (R_p). The value of risk for a given situation is calculated as follows:

$$\begin{array}{ll} V_f = R_f * B * C & \text{Value of risk of a fatality} \\ V_i = R_i * B * C & \text{Value of risk of an injury} \\ V_p = R_p * B * C & \text{Value of risk of property damage} \end{array}$$

If these values are smaller than the numbers for appropriate risk category in Table 12b, then the risk is considered acceptable.

As implemented in this example, the approach used by Rowe is weak in that the transition from the multi-attributed risk model that is developed, to the use of multiplier factors for risk categories is sketchy. Much of the potential usefulness of the original model is lost. However, the approach is important because it estimates a societal utility function on the basis of social statistics.

TABLE 12a. Relationship Between Risk Structure and Risk Factors (How Risk Factors Can Alter Risk Evaluation). Source: Rowe, 1975 (Ref. 7).

<u>Risk Factor</u>	<u>Consequence Description</u>	<u>Probability of Occurrence of the Consequence</u>	<u>Value of the Consequence to the Risk Taker (Evaluator)</u>
Voluntary - Involuntary	X		X
Avoidability and Alternatives	X	X	X
Time Discount			X
Spatial Distribution		X	X
Controllability	X	X	X
Propensity to Take Risks			X

TABLE 12b. Societal Experience Risk Numbers for Different Types of Risk

<u>Type of Risk</u>	<u>Involuntary</u>			<u>Voluntary</u>		
	<u>fat/yr/ind</u>	<u>inj/yr/ind</u>	<u>\$/yr/ind</u>	<u>fat/yr/ind</u>	<u>inj/yr/ind</u>	<u>\$/yr/ind</u>
Man-Made Catastrophic	1×10^{-7}	5×10^{-7}	2×10^{-2}	2.1×10^{-6}	2.3×10^{-6}	3.5×10^{-1}
Man-Made Ordinary	5×10^{-6}	2.5×10^{-5}	1	5.7×10^{-4}	3.0×10^{-1}	1.6×10^2
Natural Catastrophic	1×10^{-6}	5×10^{-6}	2×10^{-1}	*		
Natural Ordinary	6.7×10^{-6}	3.6×10^{-5}	3	*		

*Naturally imposed risk is by definition involuntary.

fat = fatalities
inj = injuries
ind = incident

TABLE 12c. Risk Trade-Off Multipliers

<u>Degree of Control</u>	<u>Range of G</u>	<u>Benefit-Cost Balance</u>	<u>Range of P</u>
Demonstrated Positive Control	1.0	Favorable	$10^{-1} - 10^{-2}$
Proposed Positive Control	$5 \times 10^{-1} - 1 \times 10^{-1}$	Marginal	$10^{-2} - 10^{-3}$
Demonstrated Level Control	$10^{-1} - 10^{-2}$	Unfavorable	$10^{-4} - 10^{-5}$
Proposed Level Control	$10^{-2} - 10^{-3}$		
Uncontrolled	$10^{-4} - 10^{-5}$	Unacceptable	0

REFERENCES - SECTION 7

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8.0 ESTIMATING ATTRIBUTE PERFORMANCE LEVELS

Identification of appropriate objectives (criteria) and attributes, estimating attribute performance and conversion (if desired) to common metrics are all difficult parts of the decision process. Appropriate attributes must be selected to be comprehensive, yet, independence of attributes is highly desirable. Estimates of attribute performance of each alternative also present difficult problems. This report does not discuss estimation difficulties in detail; however, brief remarks on health and safety estimation and cost estimation are made in this section.

Nine potential criteria (sometimes called subobjectives) and selected attributes under each which NRC might utilize in making regulatory decisions are shown in Table 13. The list is not intended to be comprehensive. It does suggest, however, criteria which could be considered in decision making. Each criterion will naturally not be relevant for every decision. Before any list of criteria is used in decision making, it should be closely examined to maximize independence. The attributes in the list as it appears are not fully independent if all are considered. For example, the impact on cost of power could be a surrogate for the three preceding attributes.

A detailed discussion of each criterion is outside the scope of this study. Brief comments on two of the criteria--impact on safety and health and cost to industry--are made in the following subsections, however. These were chosen because of our belief that they will frequently be the most important criteria. Further discussion on approaches to analyzing the safety-cost trade-off is in Section 9.0.

8.1 IMPACT ON SAFETY AND HEALTH

This criterion is perhaps the most important which NRC considers. A principal objective of the Commission is the protection of public health and safety. Thus, in many if not most instances, the major objective of proposed NRC regulations or regulatory guides will be the enhancement of public health and safety in some manner. If a cost-benefit analysis is being performed in the value/impact assessment, this criteria will be the principal term on the benefit side of the equation.

TABLE 13. Sample Criteria and Attributes for New NRC Regulations, Guides, and Position Papers

OBJECTIVES

- A. Assure Reasonable Cost
 - 1. Cost to NRC
 - a. preparation time
 - b. review time
 - c. publication cost
 - d. monitoring for compliance cost
 - 2. Cost to Industry
 - a. evaluating and interpreting time
 - b. labor cost
 - c. annualized equipment (purchase and maintenance) cost
 - d. impact on cost of power
 - 3. Impact on the Length of the Licensing Process
 - a. expected length of licensing process
 - b. barrels of equivalent foreign oil to supply power during delays
- B. Minimize Risks
 - 1. Impact on Safety and Health
 - a. expected occupational radiation exposure
 - b. expected chronic nonoccupational radiation exposure
 - c. expected accidental radiation exposure
 - d. expected occupational accidents
 - 2. Impact on Security Systems
 - a. likelihood of theft of nuclear material
 - b. likelihood of weapons proliferation
- C. Consistent with Social Objectives
 - 1. Changes in Public Awareness of Decision Making
 - 2. Possible Anti-Competitive Effects
 - 3. Environmental Impacts
 - a. land use
 - b. gaseous effluents
 - c. liquid effluents
 - d. plant, animal and fish impacts
 - e. aesthetic impacts
 - 4. Use of Strategically Short Supply Resources

Estimation of the incremental health and safety effects associated with contemplated regulatory actions is unquestionably a difficult task with many associated uncertainties. For example, it may be necessary for a given proposed action to estimate the incremental probability of radiation release, the possible pathways for the release, the incremental exposure to human beings, and the response of those exposed to the dose they received. Each of these steps is complicated and will likely involve a wide error band. Considerable attention is now being given to each of the steps in this chain. The best known recent work is the Reactor Safety Study, WASH-1400, which utilized event and fault trees to estimate the likelihood of a reactor accident. Another recent study⁽¹⁾ proposed the use of a "to/through" approach where an undesired event is first postulated and the analyst then traces back in reverse sequence possible paths leading to the event.

Clearly the techniques applied in WASH-1400 will be prohibitively time consuming and expensive for estimating the safety risks associated with all regulatory actions. The value of the information to be gained must be traded off against the cost of analysis in choosing an appropriate risk estimating technique. For actions which involve major changes in health risks and/or where the cost of obtaining risk information is relatively small, the rigor of the analysis should be correspondingly high. Similarly, when the incremental health risk to be caused by the regulatory action is small and/or the cost of obtaining information is high, relatively less rigorous analysis may be acceptable. Once an estimate of risk is obtained, it can be converted to dollars (as the National Highway Traffic Safety Administration might do, Section 11.3), or perhaps to a health severity index which collapses various health effects into a single index.

8.2 COST TO INDUSTRY

The cost to industry to implement proposed regulations and guides will clearly be a relevant and important attribute in nearly all regulatory decisions. Usually NRC must decide whether a given safety improvement is worth this incremental cost increase. Accurate identification of implementation cost is consequently important. All costs which industry incurs are likely

to be eventually passed on to the consumer, and in the case of nuclear power plants will ultimately be reflected in the consumer's power bill. There are several detailed sources on the subject of cost estimating.^(a) Consequently, in this subsection only certain important principals are mentioned. Also included is a discussion of potential industry-NRC interaction to improve cost estimating.

Strictly speaking, the cost of any proposed regulatory action is the benefits lost by not putting the dollars to a more productive alternative use. In practice, identification of the alternatives and measurement of the benefits lost, i.e., the opportunity cost, is quite difficult (especially when the government must estimate industry's opportunity cost) and consequently the money cost of a proposed action will usually serve as a reasonable proxy.

The relevant cost to estimate is always the incremental cost that will result from implementation of the proposed action. Past or sunk costs are not relevant because the opportunity to use that money in alternative ways is not available.

Costs should be projected into the future to the extent the analyst is able to do so. Whether or not future costs should be discounted must be decided after considering other relevant attributes. If environmental and health effects of the proposed action are not to be converted to dollar equivalents, the monetary costs can generally be discounted. If environmental and health costs are to be converted, the analyst must first decide whether these costs are to be discounted. As discussed elsewhere in this report, this is a controversial issue that has not yet been resolved. If those costs are not to be discounted, it is not clear that monetary costs should be discounted. If the monetary costs to industry are to be discounted, the appropriate discount rate is the industry's weighted average cost of capital.

The uncertainty associated with cost estimates should be included in the analysis if possible and made available to the decision maker. This is especially important when, for example, industry and government estimates of implementation costs substantially differ.

^(a)One of the best is Fisher's book.⁽²⁾

The analyst should make a concerted effort to comprehensively include all costs to industry in making cost estimates. Industry's greatest criticism of early value/impact statements seems to be the omission of certain cost items such as retrofit requirements. Sample costs which should be included are: evaluating and interpreting time, labor cost, equipment cost, maintenance cost, operating cost, interest cost (if any), and the value of lost production during extra shutdown times.

The difficulty of comprehensively including all relevant costs raises the issue of how an agency such as NRC should estimate industrial implementation costs. Four principal alternatives are available.

1. Government Estimation

One alternative is for government analysts to estimate the implementation costs exclusively. The difficulty with this approach is that the analyst must be thoroughly familiar with existing industry practices and the cost and effects of the proposed changes in order to make reliable estimates. Often the analyst will not be sufficiently familiar, and under-estimated costs are likely to result.

2. Industry Estimation

Exclusive implementation cost estimates by industry would relieve the familiarity difficulty, but would be suspect because of their natural bias. Moreover, it would likely be an unlawful delegation of authority by NRC.

3. Estimation by a Third Party

If a disinterested and knowledgeable third party could be found, an unbiased cost estimate could conceivably be made. Finding such a party would be difficult, though, and the party would almost certainly have an irresistible tendency to approach industry to verify cost estimates in any case.

4. A Hybrid Approach

A hybrid approach to cost estimating incorporating elements of the three previous approaches seems most satisfactory. Such an approach might call for NRC to make the initial cost estimates. Industry input could then be solicited possibly through the Atomic Industrial Forum, Inc., as a check on NRC estimates prior to publication of the proposed action. If industry input is

not solicited until after publication of the value/impact assessment, the regulatory process may be unnecessarily delayed, if there is significant disagreement. A third party could perhaps be utilized when differences between industry and government estimates are large and the dollar magnitude is sufficiently high to warrant an additional opinion. The final judgment on implementation cost should, of course, be made by the government decision makers.

REFERENCES - SECTION 8

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9.0 DETERMINATION OF RISK ACCEPTABILITY

As noted earlier, the principal objective of NRC is the regulation of the nuclear industry for the protection of human health and safety. Of all the attributes listed in Table 13, the most significant for many NRC decisions will consequently be implementation cost and health and safety effects. The crucial question facing the decision maker will then likely be whether a given safety improvement is worth the necessary implementation cost.

The final decision on a proposed safety improvement is appropriately made by the NRC Commissioners appointed by the President. Making the safety determinations is clearly a difficult task. Moreover, the Commissioners must rely primarily on their own instincts for an appropriate decision rule because they have little specific guidance from the Congress.

9.1 FACTORS AFFECTING ACCEPTABILITY

A number of factors influence the acceptability of a public health risk. The following list is representative of the relevant factors which have been suggested. More detailed discussion of many of the factors is in Lowrance.⁽¹⁾

1. The difference between technical and perceived risk
2. Whether the risk is from a common or a "dread" hazard
3. Whether the risks are assumed voluntarily
4. The time span between exposure and effect
5. The available alternatives
6. The degree of uncertainty about the risk
7. Whether the risks are occupational
8. Whether the health effects occur to identifiable or statistical people
9. The degree of controllability, and
10. To whom the benefits accrue.

There are numerous complications associated with these factors. One difficulty is that as risks decrease and standards of living increase, the acceptable level of risk changes. Historically, the level of risk generally considered acceptable has been declining. In some cases, though, reducing

general risk can increase occupational risks. Workers are not always compensated for their increased risk. Also, for many technologies, those who incur the risks do not receive the benefits. Managing these risk transfer and distributional problems could take the form of technological risk reduction or compensation to the risk bearers. Compensation schemes require the identification of the risk bearers and the determination of appropriate compensation and transfer mechanisms.

The issue of whether regulation should be aimed at technical (real) risk, societal valuation of the risk, or the societal valuation of perceived risk is a difficult problem which is particularly relevant to regulation of the nuclear industry. Regulating technical risk will potentially reduce societal risk levels by eliminating disparate risks, e.g., the risk differences between driving and flying. However, such policies could cause much social unrest because of the differences in value as influenced by the factors mentioned above. The problem is compounded when the technical risks are misperceived due to either lack of information or incorrect information. This question interacts with the issue of when government intervention is appropriate. Regulating the societal value of perceived risk may cause complaints of unfairness from the industry. These differences can be reduced by the development of credible informational methods, although it conceivably may be cheaper to reduce technical risk than to engage in a public education program.

9.2 ANALYTICAL APPROACHES FOR DETERMINING ACCEPTABLE RISK

Development of analytical procedures for determining acceptable risk would have all the advantages discussed in Section 2.3. In addition, it could lead to more consistency across government agencies so that limited safety resource dollars are allocated to achieve the greatest health improvement.

An analytical method for determining acceptable risk must use some measure to value risks and determine acceptability. To some degree the technique used to measure risk values depends upon which method of determining acceptability is used. Risk assessment should include general population

exposure, occupational exposure, routine risks and nonroutine risks. Obtaining an ultimate value of acceptable risk is not the goal of any approach. Acceptability depends on a number of social, economic and technical factors, and it changes over time. A key issue in risk evaluation is the means of comparing different types of risks, e.g., death, injury and genetic damage. Often no analytical attempt is made to compare these types. However, at some point decision makers must make these comparisons. Methods could be purely judgmental, trading off one health effect for another, or the more quantitative methods of attaching monetary or utility equivalents to health effects. Better resolution of this issue of comparing types of risks could ease the burden on decision makers.

One method for determining acceptable risks would be to ask for a guideline from Congress. This method should reflect the social value of the risk. However, it would also require each Congressman to undertake the same analysis that the agency would perform, often with poorer data and methods. Some interaction with Congress may be desirable, though, to get an idea of the social valuation of various risks.

Another method sometimes used in establishing acceptable risk levels is to examine social and economic statistics or legislative actions to determine past reactions to risk. Difficulties with this approach are that the rationale for past decisions is often obscure and risk acceptability may change over time. If factors influencing the valuation of risk and the magnitude of their effects could be isolated, then use of past behavior has great potential for determining acceptability.

Surveys or polls conducted to determine risk acceptability is another alternative. This method can be expensive and is subject to several methodological issues. Results of surveys depend on who is questioned and the composition of the surveys, e.g., wording and order of questions. Guidelines for performing surveys need to be developed to prevent improper surveys. A further issue with surveys is whether or not and how to communicate the full array of technical information about risk to someone unfamiliar with a new technology. Can the public meaningfully assess probabilities and their

relationships with a new technology in expressing their values of the risk? There is also a question as to whether the public's behavior is consistent with the opinions that they give.

The three prior approaches are relatively qualitative in nature. Two quantitative approaches are available: cost-benefit analysis and utility analysis; both were discussed in Section 6.0. Cost-benefit analysis, perhaps most familiar to government agencies, attaches dollar values to health effects. Initially such data would be used in cost-effectiveness studies, e.g., where should resources be allocated to achieve the largest benefit? Cost-benefit data would ultimately be conceptually used to reduce risks until the point is reached where marginal benefits equal marginal costs across all government agencies. Although the technique has some appeal, considerable controversy surrounds the use of dollar values for health effects. Also, there are several methodological problems such as the fact that uncertainty is usually not included, distribution of effects are not included, and difficulties exist in measuring the monetary value of health effects. These difficulties relate to the problem of separating the value of the risk (e.g., the dollar value attached to a voluntary risk would likely be less than an involuntary risk) from the value of the health effects and obtaining reasonable estimates where no markets exist. Factors affecting the valuation of risk should be reflected in the dollar value of health effects. This is very rarely done, partly because the way that these factors affect risk has not been determined.

The question of whether or not to assign a dollar value and if so, what value to assign has generated a relatively large quantity of recent literature.⁽²⁾ Most commentators who have suggested a value that society should appropriately spend to prevent a statistical death have suggested values in the \$200,000 to \$1,000,000 range.

Utility analysis overcomes many of the shortcomings of risk-benefit analysis but because of its technical complexity it takes considerable time and effort to apply. As discussed earlier, utility is a measure of personal value incorporating uncertainty and may include qualitative as well as quantitative contributions of value. Rowe⁽³⁾ has developed a utility-based risk

methodology for determining risk acceptability (Section 6.5). By examining historical data, accepted risk levels are established. A number of multipliers reflecting the influence of the social factors mentioned earlier are proposed. The technical risk estimates are adjusted by the multipliers before being compared with the historically accepted risk figure. This approach has the promise of avoiding the major problems of utility analysis of assessing values and determining whose values to assess. However, the methods for developing the multipliers, reflecting social valuation of each factor, need to be developed. Litchfield's⁽⁴⁾ utility model can assess risk when there is large technological uncertainty. This model confronts the issue of measuring the utility of low probability events and shortens the time consuming method usually used to assess utility. However, much work in value assessment methods is still required. For example applications of these utility methods, see Section 7.4.

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10.0 SURVEY OF SAFETY REGULATION PROCEDURES IN SELECTED FEDERAL AGENCIES

Several Federal agencies whose prime responsibility is the protection of public health and safety were contacted to learn how new and proposed regulations affecting human health and safety are currently being evaluated. The agencies were the Food and Drug Administration (FDA), the Occupational Health and Safety Administration (OSHA), the National Highway Traffic Safety Administration (NHTSA), the Environmental Protection Agency (EPA), and the Council on Wage and Price Stability. Although the Council does not have a regulatory function it does play an important role by encouraging analytical consideration of new regulations. This list is clearly not comprehensive. Components of the Department of Transportation other than NHTSA, the Consumer Product Safety Commission, as well as NRC are other Federal agencies which must make decisions affecting public safety.

Each agency reported the need for some kind of justification document to accompany every proposed regulatory action. Usually, some items are specified which must be considered in the justification document. These items can be regarded as decision criteria. However, for some agencies, the full set of decision criteria are not specified. Most agency employees felt that the most difficult step of regulatory decision making is developing alternatives.

None of the agencies contacted use a complete formalized decision methodology. In fact, there is almost universal agreement with a conclusion presented in a recent National Academy of Sciences Publication.⁽¹⁾

"Highly formalized methods of benefit-cost analysis can seldom be used for making decisions about regulating chemicals in the environment. ...However, the benefit-cost and decision frameworks described in this report can be useful in organizing and summarizing relevant data on regulatory alternatives which the decision maker must review."

A short summary of the procedures for regulatory decision making for each of the agencies contacted is presented below. It is not possible to say exactly how a decision is made in each agency, but it is possible to summarize the level of consideration and documentation required for different decisions and criteria.

10.1 FOOD AND DRUG ADMINISTRATION

Employees contacted at the Food and Drug Administration mentioned three areas which seem to be the most difficult:

- 1) Relating results of animal studies to man
- 2) Estimating the value of health effects
- 3) Developing feasible alternative actions to solve a problem.

Cost-benefit analysis is not used by the FDA because it is believed that economic data about health costs do not accurately reflect the value of health.

Occasionally, e.g., when the Delaney clause is invoked, the FDA has little discretion in making decisions. More often though, a number of attributes are considered for any action. The attributes are used as threshold levels. If a specified level of the attribute is not exceeded, an Inflation Impact Assessment (IIA) is made publicly available. Essentially the IIA states why none of the attribute levels are exceeded. If any of the attribute levels are exceeded, then an Inflation Impact Statement (IIS) must be prepared. (An IIS is required for major executive branch actions by presidential order.) The IIS must present a cost-benefit analysis of all alternatives considered. The analysis required is not truly a costbenefit analysis, but is a listing of relative benefits and costs for every alternative considered. However, FDA believes that in most cases there are very few alternatives that are left open within their legislative mandate.

The attributes and threshold levels used by FDA are:

1. Cost (or price) increases to industry, government, and consumers where the total impact exceeds \$100 million per year; or where the impact on any one industry equals or exceeds \$80 million per year.
2. Substantial changes in the competitive structure of an industry with value of shipments exceeding \$100 million annually.
3. Decreases in productivity requiring a net additional 10,000 employees in public and private sectors to sustain current levels of production.
4. Shortages of supply of important services and/or materials where the annual dollar value of the change exceeds \$100 million.

5. Increases in usage or decreases in availability of energy (i.e., electricity, fuel oil, gasoline, coal, or natural gas) by one-tenth of one percent or more of annual domestic usage within a two year period.

10.2 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

The procedures used at OSHA for developing regulations obviates the need for making decisions among complex alternatives from OSHA's point of view. That is, the systematic procedure of developing a regulation consistent with OSHA's objectives assures that the regulation is better than other alternatives. Data on cost, reduced health effects classified by seriousness, and age groups affected are generated as part of the regulation development process. These data are then used to consider the proposed action against the status quo.

OSHA's regulation development process consists of the following steps:

1. Identify problem area.
2. Try to quantify problem by establishing:
 - a. Mortality effects by age groups
 - b. Morbidity by age group and seriousness.
3. Establish an action level considering frequency of exposure, duration and concentration. An action level is a threshold level below which no demonstrable health effects occur.
4. Establish a maximum level. For some chemicals the maximum level may take the form of a peak exposure and a maximum yearly dose.
5. Develop appropriate control methods consistent with the following considerations:
 - a. Monitoring is required for exposure that has the potential of exceeding the action level.
 - b. Engineered controls should be employed wherever needed to minimize exposure to hazards.
 - c. Personal protective measures may be substituted for engineered controls, but must be justified on the basis of:

1. savings
2. infrequent, short duration exposure
3. exposure voluntarily undertaken by people aware of the hazards.

6. Take action only when health effects can be established.

This process embodies both the legislative mandate and the objectives of OSHA. A difficulty with the process is that potentially better alternatives may never be considered or generated by its rigid application. For example, the establishment of performance standards may be less costly than the specification of engineered controls.

OSHA has also devoted considerable effort to establishing dollar values of health effects. Approaches that have been tried include:

1. Willingness to pay
2. Court settlements
3. Examination of social statistics
4. Economic cost.

Several conclusions have been drawn from these efforts.

1. Too many factors are involved that affect the valuation of a health effect to obtain one generally applicable number.
2. The range of numbers obtained is too large to provide meaningful input for the decision.
3. The loss of information from health effect statistics to dollar values makes the decision harder.
4. The dollar values derived do not seem to adequately reflect the value to the people affected.

For these reasons, health effects of proposed actions are presented by seriousness and age groups affected rather than in dollar equivalents. No attempt at aggregation is made.

OSHA sees only a limited potential for quantified methods to aid its decision making. The proper role for such methodology is to assure consideration of the many factors (attributes) at a level appropriate for the decision.

Particular care must be taken to insure that the boundaries for analysis are not too narrowly defined. Also, OSHA is wary of trying to quantify many factors on the basis of their experience with quantification of the value of health effects.

10.3 NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION (NHTSA)

The benefit/cost ratio is the primary means of evaluating proposed standards at NHTSA. Benefits are measured by estimating the cost to society of accidents, fatalities, injuries and property damage and by evaluating a proposed standard's effectiveness in reducing such costs. Costs are the estimated costs to the consumer of the safety standard. Preliminary benefit/cost ratios are estimated to prioritize consideration of proposed safety standards. Before the final benefit/cost ratio is established, a proposed standard is evaluated to assure compliance with technical feasibility and legislative mandate.

The two major problems for NHTSA are estimating the effectiveness of a proposed standard in reducing accident costs and estimating the consumer cost of the standard. It is felt that benefits are fairly well captured by the dollar estimates of health effects as developed in their "Societal Costs of Motor Vehicle Accidents" study,⁽²⁾ which is currently undergoing revision. This study classifies accident costs by seriousness, and by considering a large number of factors including health care costs, lost productivity, lost consumption, and pain and suffering costs (detailed in Tables 14 and 15).

Social, political and other noncost criteria are considered together with cost-benefit analysis in making the final decision about a proposed standard. For example, stricter standards are applied when the standard is aimed at an identifiable group of people, e.g., handicapped, school age children, or bus riders, than when the standard applies to the statistical average. Other considerations may include the relative timing of the costs and benefits and the public acceptance of the standard.

TABLE 14. Societal Cost Components for Fatalities. Source: U.S. Department of Transportation (Ref. 2).

<u>Component</u>	<u>1971 Costs</u>
Future Productivity Losses	
Direct	\$ 132,000
Indirect	41,300
Medical Costs	
Hospital	700
Other	425
Property Damage	1,500
Insurance Administration	4,700
Legal and Court	3,000
Employer Losses	1,000
Victim's Pain and Suffering	10,000
Funeral	900
Assets (Lost Consumption)	5,000
Miscellaneous Accident Cost	200
TOTAL PER FATALITY	\$ 200,725

TABLE 15. Injury Severity Classes in the 1972 Societal Cost Study. Source: U.S. Department of Transportation, 1972 (Ref. 2).

	<u>Permanent Total Disability</u>	<u>Permanent Partial Disability & Permanent Disfigurement</u>	<u>No Permanent Disability</u>
Percent Distribution of Injuries	0.2	6.5	93.3
<u>Costs</u>			
Productivity	\$ 191,000	\$ 48,000	\$ 350
Medical	7,800	2,800	315
Property Damage	1,000	900	700
Legal and Court	3,000	1,000	150
Insurance Administration	4,300	4,300	800
Pain and Suffering	50,000	10,000	100
All Other	3,200	100	50
TOTAL COST PER INJURY	\$ 260,300	\$ 67,100	\$ 2,465

10.4 ENVIRONMENTAL PROTECTION AGENCY (EPA)

The EPA is a relatively young agency with responsibility in many areas. Each branch has a slightly different procedure for regulatory decision making. In addition, the decision making procedures seem to be evolving rather rapidly, with risk-benefit analyses used most often. In general, this approach requires a risk assessment and an economic impact analysis. The risk assessment involves a judgment that an agent is a potential hazard and an estimate of the magnitude of the impact on public health. Economic impact analyses involve estimating the cost of control options. The cost may be costs of control or the costs of using a substitute.⁽²⁾

The method of making trade-offs between health risks, environmental impacts, and financial costs is not specified. Russel Train, EPA Administrator, has stated that he will weigh the risks and benefits estimated in the risk-benefit assessment to arrive at the appropriate level of control.⁽³⁾

10.5 COUNCIL ON WAGE AND PRICE STABILITY (CWPS)

The CWPS, created by Congress in 1974, has a responsibility to monitor the inflationary impact of activities in the public and private sectors of the economy. The Council has two responsibilities relevant to regulatory decision making. The first is to intervene in agency rule making proceedings and hearings to present views on inflation and productivity impacts. The second is to review impact statements which must accompany "major" proposed actions from any Executive branch agency. In fulfilling these responsibilities, CWPS has been working with some agencies to define "major" and develop methodologies for measuring costs and benefits.

The CWPS evaluates proposed actions using cost-benefit analysis. Often, proposed actions are found to be unjustified when evaluated by the CWPS. Certain of the affected regulatory agencies expressed the view that the cost-benefit approach used by CWPS does not consider some important non-economic effects. For example, OSHA employees noted that CWPS' criticism of OSHA's proposed standards for coke oven emissions does not consider the benefit of reduced emissions in the surrounding community and criticism of OSHA's

proposed standards on industrial noise levels considered only cases of hearing loss and not cases of hearing impairment. A NHTSA employee noted that the CWPS criticism of NHTSA's proposed brake standard did not account for pain and suffering.

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11.0 CONCLUDING COMMENTS REGARDING THE SELECTION OF A DECISION METHODOLOGY

When faced with a regulatory decision, the decision maker must first decide which decision methodology is most appropriate to conduct a value/impact analysis. The preceding sections have described some of the options available. We cannot offer any formula which will determine the most appropriate methodology in each case, but we do have some concluding comments that might be considered.

Initially it can be noted that the sophistication of the decision methodology should be comparable to the complexity of the problem at hand. A complex problem with many uncertain elements and multiple objectives and decision criteria calls for a more sophisticated approach than one which does not have these characteristics.

Application of the matrix methodology might be appropriate as a first step in any value/impact analysis for several reasons. Compared to other methods this approach requires relatively less time. It should help the analyst or decision maker to organize his thoughts and become more fully aware of the ramifications associated with the decision. For certain problems the matrix approach may be sufficient to reach a final decision. A threshold approach could be applied to the collected attribute impacts as a decision rule or the decision maker can subjectively make trade-offs among the attributes. If a more sophisticated decision approach is deemed advisable, nothing is lost since the attribute measurements for each alternative are required for any other approach.

The cost-benefit approach for value/impact analysis will be the most desirable choice if the analyst is confident he can quantify all relevant benefits and costs in dollars. One example where it seems especially appropriate is when the objective of the proposed regulatory action is entirely to mitigate property damage. Quantification of the benefits in dollar terms in this case is relatively straight-forward and is probably the best approach. When health effects are also an objective of the proposed regulations, a more difficult problem is presented. Use of a constant dollar equivalent (e.g.,

\$1000/man-rem) facilitates the decision process, both for NRC and industry, but raises certain questions discussed previously. For example, is \$1000/man-rem the most appropriate figure in all cases? What about equity and risk transfer issues? Questions such as these merit future attention.

The analyst can consider some form of a utility approach if he wishes to aggregate all decision criteria but does not necessarily want to use dollars as his index. Like other approaches, utility methods have been applied at various levels of complexity. The combination utility-matrix approach utilized by Drobny et al.,⁽¹⁾ and discussed earlier, is an attractive method that could be adapted to a number of decision problems including those involving health effects. The approach suggested by Rowe⁽²⁾ is not unduly time consuming and is especially relevant to the problem of choosing an acceptable risk level. For especially complex and/or important decisions, a complete utility analysis incorporating uncertainty can be performed in the manner suggested by Keeney and Raiffa⁽³⁾ or Litchfield.⁽⁴⁾

Finally, the analyst may elect to pursue more than one approach if time or the complexity of the problem justify it. More than one approach permits comparison of the results and allows the analyst to be aware of the influence of the approaches themselves on the decisions that are reached.

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