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COMPARATIVE REVIEW OF RISK ASSESSMENT, SAFETY GOALS AND RELATED CONCEPTS FOR COMMERCIAL NUCLEAR POWER AND ALTERNATIVE SOURCES OF ENERGY

by

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FOREWORD

This contract study on, "Comparative Review of Risk Assessment, Safety Goals and Related Subjects," was conceived as a two-phase effort to review published materials which deal with nuclear and alternative energy sources with the objective of learning the variety and commonalities of treatment of risk assessment and what attention is paid to the subject of safety goal formulation.

In the first phase, reported herewith, the contractor was asked to review seven book-length treatises reflecting on nuclear and alternative energy sources as potential contributors to meeting our national needs for electrical and substitute forms of energy for the next several decades. Other criteria in the selection of these seven treatises is their recency (i.e., published after 1975) and institutional sponsorship, including multiple authorship by a team of researchers.

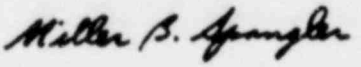
In the second phase, the contractor will perform a similar review of thirty selected journal articles or relatively short treatises. Here the selection criteria will not focus exclusively on institutional sponsorship or recency, nor upon whether risk, cost and benefit comparisons are directed to alternative forms of energy. Rather, their selection will be primarily made regarding the depth of their treatment, or uniqueness of their contribution to, risk assessment methodology, safety goal formulation and related issues which could contribute to a better understanding of alternative approaches in dealing with the question of "how safe is safe enough" for the nuclear option. These criteria do not rule out the selection of articles for review which do not focus specifically, or principally, on the nuclear option provided their conceptual and analytical content are meritorious regarding the above purposes. In view of the hundreds of articles or papers having some merit as candidates, the selection of review articles will not be easy and the possibility of overlooking deserving ones is real.

Because of impending, though tentative, plans and schedules for considering alternative approaches to nuclear safety goal formulation by the Nuclear Regulatory Commission, quite short turnaround times for the two phases of this review effort were decided upon. In this regard, the contract for the Phase I review effort was let with the International Planning Management Corporation on August 15, 1980 and the present draft was delivered to the NRC on September 24, 1980.

Insofar as was practicable, the contractor was requested to be as factual as possible in responding to a review format that was designed to focus on safety goal forms and related criteria and risk assessment issues. The latter are discussed in a reference paper of August 13, 1980 which was co-authored by Roger Mattson, Warren Minners, Malcolm Ernst and Miller Spangler of the Division of Safety Technology of the U.S. Nuclear Regulatory Commission on the subject, "Concepts, Problems and Issues in Developing Safety Goals and Objectives for Commercial Nuclear Power."

However, in recognition that limited attention was focused on the problem of safety goal formulation in the seven selected treatises for the Phase I review effort, the contractor was requested to provide some judgmental interpretations of implicit or indirect information contained in these volumes which could be useful to the purposes set forth above. This was undoubtedly the most difficult part of the review effort and the reliability of the interpretations may be open to challenge. Be that as it may, it is felt that the performance of these review efforts has provided much useful information and a valuable starting point for the long journey of debate that is sure to follow, with or without the contributions of this review, in the quest to formulate safety goals for commercial nuclear power.

Comments on these review efforts are welcomed.



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COMPARATIVE REVIEW OF RISK ASSESSMENT, SAFETY GOALS AND RELATED CONCEPTS FOR COMMERCIAL NUCLEAR POWER AND ALTERNATIVE SOURCES OF ENERGY

INTRODUCTION

This report presents a comparative review of risk assessments, safety goals and related concepts for commercial nuclear power and, where appropriate, alternative sources of energy. More particularly, this report covers the first phase of a planned two-phase literature review. This first phase reviews the following seven books:

(I) Economic and Environmental Impacts of a U.S. Nuclear Moratorium, 1985-2010, A Report of the Institute for Energy Analysis, Oak Ridge Associated Universities, Alvin M. Weinberg, Director (Cambridge, Mass.: The MIT Press, 1979).

(II) Nuclear Power: Issues and Choices, Report of the Nuclear Energy Policy Study Group Sponsored by the Ford Foundation and Administered by the Mitre Corp., Spurgeon M. Keeny, Jr., Chairman (Cambridge, Mass.: Ballinger Publishing Co., 1977).

(III) Energy: The Next Twenty Years, Report by a Study Group Sponsored by the Ford Foundation and Administered by Resources for the Future, Hans H. Lansberg, Chairman (Cambridge, Mass.: Ballinger Publishing Co., 1979).

(IV) Energy in America's Future: The Choices Before Us, A study prepared for the Resources for the Future, National Energy Strategies Project, Sam H. Schurr, Project Director (Baltimore: The John Hopkins University Press. 1979).

(V) Energy in Transition, 1985-2010, Final Report of the Committee on Nuclear and Alternative Energy Systems, National Academy of Sciences/ National Research Council (San Francisco: W. H. Freeman and Co., 1980).

(VI) Energy Future, Report of the Energy Project at the Harvard Business School, Robert Stobaugh and Daniel Yergin, eds. (New York: Random House, 1979).

(VII) Jobs and Energy: The Employment and Economic Impacts of Nuclear Power, Conservation and Other Energy Options, Steven Buchsbaum, James W. Benson, et al., (New York: Council on Economic Priorities, 1979).

Each book is reviewed independently of the others in the following sections I through VII. However, each book's review is reported under the same seven headings:

1. Risk Definition

Reporting the explicit definition of risk, if any, employed by the authors of a particular book. If no explicit definition is employed or offered by the authors, an implicit definition is offered which is consistent with the authors' approach to risk assessment.

2. Fuel Cycle Coverage

Presenting those elements of the nuclear or other energy fuel cycle which are given explicit treatment regarding risk assessment by the particular book.

3. Risk Assessments

Presenting quantitative or qualitative statements made by the authors regarding risk assessment for nuclear power and other energy options.

4. Risk Assessment Methodology

Presenting the methodologies employed by the authors in undertaking the book's risk assessment. In addition to methodology, per se, the book's data sources - classified as primary or secondary, recent or dated, and any information gaps - are identified. Basic assumptions are presented which underly any forecast - such as technological, economic, social, and political - or other factors which affect future risks or safety improvements. The authors' views are also registered of factors regarding the range of uncertainty of the risk assessments or of related forecasts.

5. Safety Goal Treatment

Presenting the explicit treatment, if any, given to safety goals and objectives or to supporting standards and guidelines. Where possible, goal forms are identified in terms employed by the draft paper: (Roger Mattson, et al., Concepts, Problems and Issues in Developing Safety Goals and Objectives for

Commercial Nuclear Power, Division of Safety Technology, U. S. Nuclear Regulatory Commission, Washington, D.C., Aug. 13, 1980). The several goal-form options in this treatment include: single vs multiple goals; quantitative vs qualitative goals; ends-oriented vs means-oriented goals; absolute vs relative goals; individual-oriented vs society-oriented goals; site-dependent vs site-independent goals; and time-related vs atemporal goals.

6. Goal Formulation Criteria

Decision criteria, if any, employed in formulating safety goals. Where no such criteria are employed, useful ideas presented by the authors are reported which are relevant to the decision criteria proposed by the NRC draft report by Mattson et al. (ibid.).

7. Risk-Cost-Benefit Considerations

Presenting the scope employed by the authors in their comparison of energy options, including: risk-cost tradeoffs; risk-benefit tradeoffs; risk-cost-benefit tradeoffs; or risk assessments without reference to costs and benefits.

In the following reviews, to help assure accurate reflection of the authors' views, effort has been made to follow as closely as possible the actual wording of the particular report, insofar as their inclusion or close paraphrasing was feasible in the context of this report. It thus is hoped to reduce the possible distortion of the authors' views as presented in this review.

I. ECONOMIC AND ENVIRONMENTAL IMPACTS OF A U. S. NUCLEAR MORATORIUM

1. Risk Definition - Nuclear Moratorium does not explicitly define risk. It employs the term more in an economic sense as a hazard to the economy of the United States or of the world. In those places where Nuclear Moratorium does in fact consider effects on health and safety, the term "risk" is used in the sense of a threat. This use is secondary to the economic connotation.

2. Fuel Cycle Coverage - Nuclear Moratorium states explicitly that "the ever-present possibility of coal mining accidents suggests that an evaluation of the impacts of a U. S. nuclear moratorium should include the entire fuel cycle risks in each scenario considered (p. 272). It is their view that

the indictment of the coal mining industry as "hazardous and hostile" appears justified when coal mining's safety record is compared with that of other mining activities, although the fatal accidents are lower (p. 275).

Noting that radionuclides are encountered in each step of the nuclear fuel cycle, exposure to the population resulting from planned or unavoidable releases results primarily from the electrical power generation and fuel processing steps (p. 279).

Nuclear Moratorium espouses the position that the future of nuclear energy in the United States should be based upon Liquid Metal Fast Breeder Reactors (LMFBRs) and that those reactors will require less uranium than the current light-water reactors. Thus, in considering the effect on mine wastes and tailings, Nuclear Moratorium states,"the radioactivity of the mill tailings (in the future) will be less than the radioactivity now involved in the mining and milling of uranium, in the ratio of the amount of uranium now extracted to the amount extracted in the future cases (that is for the LMFBRs) (p. 319).

Nuclear Moratorium also makes the assumption that the disposal of radioactive wastes will be satisfactory in the future. The rationale for this assumption is quite simple: "Unless self-disposal or some equivalent system is proven acceptable, nuclear energy will not be a long-term energy option " (p. 319).

Nuclear Moratorium treats separately the disposal of high-level and low-level wastes. They conclude that "one cannot escape the impression that one thousand square miles of high level waste disposal area might be sufficient to take care of the entire nuclear energy system for tens of thousands of years " (p. 320).

Each breeder reactor creates about 7 thousand(55-gallon)drums of low-level waste per year. These low-level wastes emit about the same specific radioactivity as natural uranium and present a correspondingly small hazard (p. 321).

Also, no problem is foreseen with regard to retiring used reactors of which 20 would be retired each year under the foreseen nuclear future using breeder reactors.

Nuclear Moratorium suggests that an evaluation of the impacts of a U. S. nuclear moratorium should include the entire fuel cycle risks in each scenario. For example, the increased possibility of a nuclear reactor accident resulting from high dependence from nuclear power should be compared in the alternative to the increased possibility of a major mining tradgedy accompanying increased dependence on coal. Nuclear Moratorium suggests the need for considering the entire fuel cycles but leaves the implementation to a footnote: Lave and Freeburg, "Health Effects of Electricity Generation from Coal, Oil and Nuclear Fuel," Nuclear Safety, Vol. 14, No. 5 (1973).

3. Risk Assessments - In his introduction to Nuclear Moratorium, Alvin Weinberg, Director of the Institute for Energy Analysis of the Oak Ridge Association of Universities, notes that the study was, when published, already out of date in many particulars, having been first issued some two years earlier as an IEA report. Nevertheless, he states that the major findings held up rather well (p. xxiii).

The study concludes that a domestic moratorium on nuclear energy would have little effect on the risks of nuclear weapon proliferation, unless the rest of the world abandons nuclear power (p. xxv).

Employing the Rasmussen WASH-1400 accident probabilities, Nuclear Moratorium concludes that the number of expected reactor meltdowns that will release a significant amount of radioactivity occurring by the year 2010 would be about 0.6 without the moratorium and 0.2 with the moratorium. Of those meltdowns, about one-third would be expected to actually breach above-ground containment (p. xxxv).

Insofar as coal mining is concerned, injuries and fatalities from coal mining accidents per year in 2010 are estimated without the moratorium to be about half of what they would be with the moratorium (p. xxxvi).

With the moratorium, the estimated annual whole-body radiation dose per person from energy technologies in 2010 is estimated as about 0.12 millirems (mrems) per person; without the moratorium the number would be between 0.5 and 0.7, depending on the particular scenario employed. These figures

are small compared to the average annual exposure of 120 mrems per person from natural background radiation.

Contrasting emissions from coal plants, U. S. air pollution from sulfur dioxide, nitrogen oxide, carbon monoxide and hydro-carbons would all be higher with the moratorium than without it.

Considering the impact on land use, the report concludes that with the moratorium the land disturbed from uranium would only be about one-third as much as it would be in the nuclear supply case by the year 2000 (p. xxxvii).

Some attention is given the solar option, speculating that solar energy, though very useful as a supplement to other energy systems, becomes especially awkward and expensive if it is itself the prime source of energy (p. xxxviii). The report concludes that an all-solar society would be almost surely a low-energy society, but one that would not require the vigilance and care demanded by a nuclear society (ibid.).

The report concludes that a U. S. nuclear moratorium would not affect significantly in the near term atmospheric levels of carbon dioxide, but loss of the nuclear option throughout the world would accentuate the carbon dioxide problem in the next century (p. xxxix). "Even the most conservative world energy scenarios indicate increases in carbon dioxide which approach a doubling of atmospheric concentration by the year 2050 " (p. 60).

In its consideration of proliferation and the use of nuclear weapons, Nuclear Moratorium concludes that "we are unable to determine the effects of a U.S. nuclear moratorium on the international proliferation of nuclear weapons " (p. 56).

The less quantifiable hazards of nuclear energy -- diversion, sabotage, possibility of reactor accident -- become impediments to the use of nuclear breeders over the very long future. The study proposes a "fix" that they think might enable man to live comfortably with fission: confine all reactors, processing plants and waste disposal in the United States to some 100 sites occupying 50 square miles each (p. xxxviii).

The report asserts that radiation exposure from activities associated with power generation results primarily from the power generation and fuel reprocessing steps (p. 64).

Finally, Nuclear Moratorium also emphasizes the problems posed by social constraints: "the primary obstacles to the wide spread permanent use of nuclear energy are probably institutional and social, not technological" (p. 322).

4. Risk Assessment Methodology - Nuclear Moratorium was the work of 14 authors, 8 contributors and more than 30 consultants, some of national and even international renown. As the full title suggests, the work is primarily concerned with the potential impacts of the U. S. nuclear moratorium upon economic and environmental conditions in the period 1985 to 2010. The principal methodology is economic modeling employing a variety of alternative scenarios reflected by parametric economic analysis, supplemented by argument and, to a limited degree, by physical analysis where appropriate. The physical analysis involves projections of such things as radioactivity levels and waste disposal site areas envisioned in the future.

Although published in book form in 1979, the study was completed and presented to CONAES in 1976. The moratorium which formed the basis of the analysis was presumed to begin in 1980 with practical effects first felt in 1985.

The specific methodology employed in the analysis was to present a plausible range of future economic growth and energy demand scenarios extending over the period of consideration, 1985 to 2010 (p. xxv). Five possible economic impacts of the moratorium are treated: future costs of electricity; regional dislocations; nuclear industry impacts; effects on the coal industry; and international implications. Four levels of environmental trade-offs were considered as possibly resulting from a shifting of the additional fuel requirement from nuclear to coal after 1985. Details of the economic model involved are presented in the appendix (p. 339 et seq.).

The report adopts what it considers the simplest method of projecting future injury rates by extrapolating historic trends or by making assumptions about the future energy demand and use (p. 63).

Potential impacts on the health of large segments of the U.S. population were examined on the basis of various scenarios developed originally for their economic implications.

The report assumes that the risk of injury from radioactive release from nuclear power sources is proportional to dose. The relevant dose is the average per capita dose to the tissue of interest. The annual dose in millirems per person is obtained by multiplying the dose commitment per unit of electricity generated by the estimated total nuclear capacity in place during the period considered (p. 65).

In estimating the emission of various air pollutants, Nuclear Moratorium drew heavily on the accounting system developed by Brookhaven National Laboratory for the Council on Environmental Quality and upon ERDA (p. 70).

Environmental impacts were determined by contrasting the implications of proceeding with further nuclear energy development with the alternative of shifting to coal. Basic data was drawn from a variety of sources, for example, from Keeling and Rotty (p. 296) and Hansen, Keeling and Machta (ibid.).

It is assumed that the probability of a major reactor accident increases in proportion to the number of reactors operating and the length of time of operation.

Radiation impacts are determined by employing atmospheric diffusion models using Gaussian laws, modified by atmospheric stability and other meterological parameters. Similar approaches were used in estimating the deposition of nuclides on the earth; transfer from soil to food and water; and distribution via ingestion (p. 279). Nuclear Moratorium was unable quantitatively to relate the emission of pollutants from coal combustion to resultant ambient levels, and fell back on gross estimates of total emission from the energy sector as a crude indicator of environmental impacts (p. 283).

The basic data employed by Nuclear Moratorium are secondary, being drawn from other sources. For example, in its consideration of energy conservation studies data were drawn from studies by the National Petroleum Council, the Dow Chemical Co., the Council on Environmental Quality, the American Center of Physics, the Energy Policy Project, the Energy Research and Development Administration, and the Federal Energy Administration (p. 17).

Nuclear Moratorium uses the Rasmussen study as the basis for its analysis of reactor accident probabilities and implications. More particularly, the study employs pressurized water-reactor accident modes 1 through 7, and boiling-water reactor modes 1 through 4 (p. 62).

The study employs a number of rather important assumptions. For example, one important assumption is the rate at which energy services that can be supplied either by liquid or gaseous fuels or by electricity are captured by the latter. The study acknowledges use of optimistic rates of market penetration by electricity as well as by conservation. Nevertheless, those projections are considered reasonable, though increased coal gasification and the use of technologies based on gas may prevent electricity from capturing as much of the market as estimated in the study (p. viii). Another far reaching assumption is that risks of geologic waste disposal are acceptable.

The study projections also assume: that the historic rate of improvement in coal mining safety will continue; that the mix of surface mining and underground mining for the period will remain the same as it is today; and that the rate of coal consumption follows from the energy scenarios adopted by the study (p. 63).

A major assumption pertains to sulfate pollution from coal burning. The increase in health problems from power plant generated sulfate pollution is highly dependent on siting policy. Certain sites were chosen as representative and the resulting conclusions depend upon how representative those sites really are (p. 68).

The public health impact of radioactive releases from the nuclear power industry isevaluated by adopting the following three assumptions: (i) the environmental impact is directly related to the total quantity of radio-nuclides released to the environment; (ii) the risk of injury to man is proportional to dose (the relevant exposure being the average per capita dose to the tissue of interest); and, (iii) since the half-lives of the important nuclides are no longer than 1 year, dose estimates are in terms of dose commitment: the total dose deliverable during the decay of the nuclides (p. 280).

In determining the difference between the impacts of a nuclear and non-nuclear future for each energy demand scenario, the study relates changes in emissions to changes in energy strategy, changes in ambient levels, and changes in health effects. The study observes that this is a complex task; an accurate inventory of current anthropogenic emissions apparently does not exist (p. 283).

In its consideration of mine tailings and radioactive waste disposal, the study assumes that the effects of the mine tailings do not persist over many years, which implies some sequestering or covering of the tailings. As noted before, it is assumed that disposal of radioactive wastes is satisfactory. Their rationale for the latter assumption is particularly interesting. "Unless disposal or some equivalent system is proven acceptable, nuclear energy will not be a long-term energy option" (p. 319).

A basic assumption relating to breeder reactor retirement is that each reactor will last 50 years (p. 321).

In order to be rid of the plutonium diversion problem, the study (ibid.) adopts the principle proposed by H. G. MacPherson: no plutonium or other weapons-grade fissile material will be transported.

Perhaps the most important statement on uncertainties is the conclusion: "Nuclear energy based on breeders is much less beset by uncertainties related to our energy demand, our ore reserve, or our separative work capacity than is nuclear energy based on burners " (pp. 332 - 333).

5. Safety Goal Treatment - Although few specific safety goals per se are specified by Nuclear Moratorium, a number are implied, particularly in its conclusions and recommendations.

Thus, in protecting the public in the event of serious reactor accident, "the first priority, of course, is to prevent any actual exposures that could cause accute injury (i.e., external gama radiation leading to whole-body irradiation in a range approaching 100 rads or more)." A similar priority should be given to the short-lived iodine-nuclides 134 and 131, since the quantities present could result in thyroid dose levels in the therapeutic range" (p. 273).

Two institutional goals related to safety are emphasized by Nuclear Moratorium: (1) the gradual replacement of scatter siting of nuclear reactors by cluster siting, with further strengthening of containment, including the possibility of undergrounding; and (2) strengthening of the Nuclear Regulatory Commission. The latter goal is important, for only if that agency possesses true trust and confidence of the public greater than is demanded of most regulatory bodies, can NRC do its job adequately. This second objective may mean conferring on NRC more the aspect of an appellate judiciary, rather than regulatory, body (p. 325).

Considering the possibility of a future major melt-down accident, the Rasmussen probability of one chance in 20,000 per year, which might result in perhaps one such accident every 2 years, would be unacceptable to the public, in the estimate of the study (p. 326). The legislated melt-down probability for liquid metal fast breeder reactors of 10^{-6} per reactor year would relieve much of the study's concern about large breeder accidents (p. 327).

The study reportedly recommends the use of only a relatively small number of concentrated or committed sites for combined nuclear systems, say, 1,000 reactors at 100 sites (p. 327). A firm national commitment to the principle that the nuclear enterprise should be confined to as few sites as possible is specified as a minimum goal together with a more far reaching policy that all breeders and their supporting facilities should be co-located (p. 328).

To counter terrorism, the study believes that the United States probably will have to impose on its nuclear plants the same kind of security imposed on them during the war. It will thus be necessary to buy order at the expense of freedom (p. 328).

In the (study's) final analysis, the safety and integrity of the nuclear system will depend on the caliber of the staff that mans the system. A high degree of professionalism of the staff is recommended (p. 329).

Concerned that a nuclear plant might simply be abandoned after a serious accident, the study recommends that some means be found of preventing responsibility from lapsing in the event of an accident, possibly leading to

bankruptcy (p. 330). The institutional arrangements must be part of any anti-proliferation system. The recommended siting policy, which confines nuclear energy to relatively few large sites with a minimum of transport of fissile material, is thus a major safety goal recommended by the study.

In terms of the draft paper by Mattson et al., these goals have been characterized by the present authors as follows: they are multiple rather than single; more qualitative than quantitative; both ends and means oriented; more absolute than relative; more society-oriented than individual-oriented; highly site dependent; and, perhaps strangely, more atemporal than time-related.

6. Goal Formulation Criteria - Since Nuclear Moratorium really does not emphasize risk assessment, it pays even less attention to decision criteria for risk assessment.

Nevertheless, the study does recommend three mechanisms which it states are essential if the projected nuclear system of the future is ever to be acceptable. These are: to minimize the likelihood of physical disaster; to minimize the consequences of such a disaster; and to insure institutional responsibility. To meet these ends, which might be recognized as safety goals and perhaps should be included in the prior section, Nuclear Moratorium notes that any future nuclear system will inevitably be self-limiting: it will expand only to a size with which society is comfortable and this size will depend primarily upon the state of the technology...We shall have to exercise nontechnical ingenuity to reduce the risks, even though they cannot be quantified" (p. 327). The implication is that any future decision must be social and political rather than technical and that social decision criteria will predominate.

The study emphasizes that a so-called "consensual climate" on the part of society will be essential to any future nuclear energy system (p. 334). "Unless we establish such a climate we run a danger of losing the nuclear option " (ibid.). Thus the principal decision criterion recognized by Nuclear Moratorium is social acceptability.

7. Risk-Cost-Benefit Considerations - Support for the view that society will utilmately decide the future of the nuclear option is found in one of the few references to risk considerations in the book in which the risk considerations of reactor accidents are like those associated with living in a flood area or

down stream from a dam. The population at risk assumes that the event will not occur, since the consequences cannot be considered acceptable by society. If a reactor accident occurs, the release of radioactivity to the environment could be significant; and social acceptance of a low probability, high impact reactor accident involves rationalization similar to that of a dam failure (p. 273).

There are, however, no formal risk-cost-benefit tradeoffs.

II. NUCLEAR POWER: ISSUES AND CHOICES

1. Risk Definition - No explicit definition of risk or of risk assessment is presented. Rather an implicit definition is employed reflecting a "threat" to the environment, human health and safety. The authors state that "risks," associated with catastrophic reactor accidents and with the health and environmental problems associated with the nuclear waste and plutonium, are real and must be considered in any assessment of nuclear power (p. 16). Risks to human health resulting from nuclear power in the generation of electricity are particularly uncertain and a subject of considerable controversy. These nuclear risks cannot be considered in isolation, but must be compared with the risks associated with coal-fired power plants, which are the principal alternative for electric power generation for the rest of this century (p. 159).

Health risks traditionally have been measured in terms of occupational accident rates. In recent years there has been an increasing awareness of the possible health effects of effluents of nuclear power plants on workers and the general public. The assessment of nuclear power health risks involves the analysis of occupational accident rates, radiation exposures for worker populations under normal operating condition, and the probabilities and consequences to public health of reactor accidents (ibid.).

Insofar as environmental risks resulting from the generation of electricity by nuclear power are concerned, any assessment requires a comparison with those of fossil fuels: particularly with coal, the main alternative for the generation of electricity. The book compares the principal environmental risks of the nuclear fuel cycle with those of the coal fuel cycle, insofar as both

might affect the air, land and water environments and, more generally, the global climate in the case of coal.

The safety of nuclear power plants is the central issue of Issues and Choices. Written before Three Mile Island, the book lauds the nuclear safety record which, as of 1977, had seen 200 reactor years of operation of commercial light-water reactors with no demonstrable adverse effects on public health. The book, however, is duly cautious about future projections of continued reactor safety. The book presciently notes that reactor accidents could have very serious consequences including psychological impacts on the inhabitants of adjacent areas (p. 213).

Noting that nuclear safety policy cannot depend only on experience, no matter how good, the evaluation of reactor safety risks must necessarily be based on analysis and judgment (p. 214). The book adopts the philosophy that the significance of nuclear risks depends on a comparison with the risk of competing energy sources, primarily coal. Such comparison is difficult because the safety problems of each technology are so different.

The greatest risk foreseen by the report is the possibility of proliferation of nuclear weapons. "The consequence of nuclear power that dominates all others is the attendant increase in the number of countries that will have access to the materials technology for nuclear weapons" (p. 271).

2. Fuel Cycle Coverage - Issues and Choices spans the entire gamut of nuclear fuel cycle elements. Mining is identified as a primary locus of occupational hazards (p. 173). Underground accidents result in about 0.2 deaths per reactor year. Open-pit mining results in approximately 0.15 deaths per reactor year. Nonfatal accidents are equivalent to about 1,100 days of worker incapacity per reactor year (p. 174). Miners are exposed to external radiation in the mine and to inhalation of dust on which radon decay products are absorbed. Radon emissions during mining may also have a public health impact, primarily through the diet and not through direct lung dosage. About 0.08 delayed deaths per reactor year are anticipated, making mine emissions the source of one of the largest contributions to radiation exposure in the light-water reactor uranium fuel cycle (ibid.).

Occupational accidents in the milling of uranium ore are poorly documented, but appear to be relatively low (on the order of 0.001 deaths per reactor year). Latent cancer deaths per reactor year resulting from random emissions from milling operations are estimated to be about 0.02 (ibid.). Milling operations result in the creation of huge tailings piles near the mills which continue to emit radon-222 for thousands of years, and are thus a prospective source of long-term exposure. One estimate puts cancer deaths resulting from the tailings piles at 0.2 latent cancer deaths per reactor year (ibid.).

Since relatively small volumes of radioactive material are involved in nuclear power generation after the initial mining and milling operations, the transportation, conversion and fabrication parts of the uranium fuel cycle are believed to result in relatively few injuries. About 0.01 fatalities per reactor year, from both occupational and population exposures, are projected (p. 176). Typically, reactor facility construction involved fatalities of 2 to 8 deaths per ten thousand man-years. Prorated over a 20 to 30 year plant lifetime, these fatalities correspond to an occupational dose rate of about 0.07 to 0.2 deaths per reactor year (ibid.).

During reactor operation, radioactive gases and volatile radioisotopes migrate out of the fuel through small cladding defects into the coolant. The treated effluents result in the ultimate release annually of about 500 curies of krypton-85 from each reactor. The resulting health risk is on the order of 7×10^{-5} deaths per reactor year (p. 176). Carbon-14 will also be released in the form of carbon dioxide during reactor operation, resulting in about 0.01 latent cancer fatalities per reactor year (ibid.).

The report emphasizes public concern with the possibility of nuclear accidents involving core melt and breach of containment. Considerable controversy is reflected as to the probable result of such accidents. WASH-1400 predicts 0.023 fatalities per reactor year. Issues and Choices, however, does not agree with WASH-1400 and projects that a possible average rate of loss of 10 latent cancer deaths per reactor year will be possible, although reductions could be gained by prudent site selection (p. 180).

Noting that public and occupational doses resulting from waste management and disposal are often regarded as insignificant, Issues and Choices states such belief may be due in part to a lack of experience with commercial waste management and disposal beyond the care of spent fuel and reactor cooling ponds. It is at present difficult to estimate the health costs of constructing and filling geological repositories or the actual effect of repository failure (ibid.).

When the uranium fuel cycle is defined to include reprocessing and recycling, new potential health risks are introduced. Reprocessing would result in the liberation of gaseous and volatile isotopes in the separation of uranium and plutonium from the other radioactive waste materials. Recycle of plutonium would introduce plutonium into most of the fuel cycle including transportation and fuel fabrication. Occupational hazards of reprocessing and recycle are almost entirely radiological and derive from handling radioactive waste materials in the reprocessing operations. Occupational latent cancer fatalities are projected to be at the low level of about 0.004 deaths per reactor year (ibid.).

Reprocessing and recycling would reduce the need for uranium mining and milling and thus potentially would reduce occupational and public health consequences of both operations. A 20% reduction is projected to result if all plutonium were recycled. Occupational fatalities would be reduced by about 0.05 per reactor year and population delayed fatalities would be reduced by about 0.02 per reactor year (ibid.).

3. Risk Assessments - It is the overall conclusion of Issues and Choices that "In a comparison of normal operations, nuclear power has smaller adverse health costs than coal" (p. 17). However, normal operations do not take into account the possibility of accidents, which could quite adversely affect health. "It is difficult to compare such rare but extremely severe events (as in nuclear accidents) with the continuous health burden due to fossil fuels, including such factors as acid rain..." (ibid.).

"The most serious risk associated with nuclear power is the attendant increase in the number of countries that have access to technology, materials

and facilities leading to a nuclear weapons capability" (p. 22). A particularly disturbing aspect of nuclear proliferation is that it could extend to some national terrorist groups (p. 25). Since no highly enriched uranium or plutonium is available in the present commercial nuclear fuel cycle, the terrorist threat will only emerge if plutonium is reprocessed and recycled or reactors requiring highly enriched uranium are introduced (p. 25). The risks associated with reprocessing and recycling of plutonium weigh strongly against their introduction (p. 30). The present administration's policy against reprocessing and recycle reflects this concern.

Over-zealous and ill-conceived government measures designed to counter potential terrorists could endanger civil liberties. The government must therefore, be particularly sensitive to the broader legal implications of measures undertaken to improve security against potential terrorist activities (p. 26). The likelihood of nuclear terrorism must be taken seriously, although it is impossible to quantify (p. 314).

Issues and Choices' consideration of nuclear waste management persuaded them that "nuclear wastes can be disposed of permanently with acceptable safety by deep burial in salt and other stable geological formations that are isolated from ground water intrusion" (p. 33).

The authors' summary assessment of the health impacts of the nuclear fuel cycle includes both occupational accidents and radiation-induced disease in workers and the public, resulting from both routine emissions and reactor accidents. Under normal operation conditions, each reactor-year of power production is estimated to involve between 0.2 and 0.5 accidental worker deaths, roughly half of which result from mining and the other half from reactor construction (p. 185). Occupational exposures account for about 0.2 to 0.3 fatalities per reactor year (p. 186). Total occupational fatalities were expected to be in the range of 0.4 to 0.8 deaths per reactor year (ibid.).

Assessment of public health consequences is much more uncertain. Population dosages appear to be dominated by radon emissions in milling and mining and by routine effluent emissions from reactor operations, notably carbon-14, tritium and krypton-85. The authors base their conclusions on

other's calculations (Final Generic Environmental Statement on the Use of Recycled Plutonium in Mixed Oxide Fuel in Light-Water Cooled Reactors, Nuclear Regulatory Commission Report, August 1976), which indicate that it is the dietary intake of the decay daughters of radon-222 which dominates population exposures. Total health risks for workers and the public are projected to be between 0.6 to 1.0 fatalities per reactor year (ibid.).

The average public health consequences of reactor accidents are even more uncertain. Methodological problems inhibit past efforts, particularly the WASH-1400 study. If all uncertainties are viewed pessimistically, the risk of reactor accidents might be as high as 10 deaths per reactor year (with a comparable number of genetic defects) for the first 100 reactors (p. 187).

"The possible impact of global climate appears to be the most serious environmental consequence of greatly increased electric power generation" (p. 210). Both coal and nuclear power contribute directly to the long term heating of the atmosphere. However, a much more serious threat appears to be posed by the carbon dioxide produced in fossil fuel combustion (ibid.). Recurrent unpredictability of natural climate variations and the untested effects of global temperature rise on cloud formation, rainfall, and regional weather patterns preclude any clear assessment of the actual impact of increased use of fossil fuels.

The report concludes that the coal fuel cycle generally has more harmful natural environmental impacts than does the nuclear power cycle (p. 217).

On balance, the local environmental consequences of the nuclear power cycle in normal operation are also not as serious as those from fossil fuel power generation (p. 211).

The study's review of the reactor safety problem led to eleven conclusions of which the following are herein relevant: (1) insufficient statistical data exists for predicting reactor safety for the rest of the century (p. 240); (2) WASH-1400 understates uncertainties and has serious methodological deficiencies, (ibid.); (3) on an average loss of rate basis, nuclear power compares favorably with coal even when the possibility of accident is included

(ibid.); (4) the adverse health and property consequences of even an extremely serious accident would not be out of line with other major peace time catastrophies (p. 241); (5) the possibility of an extremely serious nuclear accident, estimated to be a 25% chance of occurrence in 5,000 reactor years of operation, is considered acceptable (p. 241) and, more generally, the risks associated with light-water reactors are considered acceptable(ibid.). (6) finally, decisions regarding reactor safety will have to be made in the face of doubts which were estimated would persist for at least a decade, at the time the report was written (p. 242).

4. Risk Assessment Methodology - The report characterized itself and the entire study as an "inquiry" (p. xv).

Their study brought together 21 relatively famous individuals, including the present Secretary of Defense, Harold Brown, and John C. Sawhill, the former Undersecretary of the Department of Energy. The group met 13 times for a total of 31 days. Various government officials, scientific and industrial experts, and members of public interest groups were invited to attend as witnesses and as discussion participants. Several sub-groups examined specific areas such as safety, resources, health, demand, cost and so on. For example, an economic subcommittee considered various economic models employed in government and industry, and examined in detail the consequences of various economic assumptions. Attention focused on the critical review of major reports previously prepared on nuclear power (p. xvi); a broadly representative although not exhaustive spectrum of views were sampled. The 21 member group was supported by a staff and a variety of consultants. The study was undertaken over a period of about one year.

The principal methodology employed by the study was that of expert judgment exercised on reasoned argument.

The Issues and Choices study was, according to their own self-estimate, based on economic analysis (p. 17), insofar as the attractiveness of the nuclear and coal technology alternatives was concerned.

The great majority of the data considered by the study was contained in preexisting reports, for example GESMO (op. cit.) and WASH-1400 (op. cit.).

Thus the data studied was secondary rather than primary. For example, the study employed the basic work of the National Academy of Sciences: "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," report of the Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR, 1972), and upon Klement, et al., "Estimates of Ionizing Radiation Doses in the United States, 1960-2000," U.S. Environmental Protection Agency, 1972.

The study emphasized that, at lower doses and at low dose rates, radiation effects are more subtle and difficult to predict on the basis of experience with high doses. The relationship between biological responses and dose rates were estimated from experience at the higher doses and dose rates and from experimental data on non-human systems.

The study emphasized (p. 167) three complications:

1) The excess of cancer deaths resulting from radiation exposure may persist for the entire lifetime on an exposed population, whereas existing data were based on only the first 20 to 40 years after radiation exposure.
2) It was not clear from existing data whether the excess risk of cancer resulting from a given dose of radiation caused a constant number of additional cases in all adult age groups or a constant percentage increase above the natural risk in all age groups.
3) It was most useful to extrapolate the dose-incidence relation from the dose region of 20 to 400 rem down to doses a thousand or more times smaller. It was their conclusion that the original BEIR estimates were not in need of subsequent revision at the time of report preparation.

The report is particularly critical of WASH-1400, especially regarding its health effects predictions. The possibility exists that the expected number of cancers could be several times higher than those predicted by WASH-1400 (p. 179). Similarly the report states that the probability of a core melt with breach of containment of 5×10^{-6} per reactor-year (as predicted by WASH-1400) is of low reliability because of large uncertainties involved in the calculation. The WASH-1400 probability estimate could be low, under extremely pessimistic assumptions, by a factor of as much as 500. On the other hand, it could also be on the high side.

In the environmental effects area, great uncertainties are involved in predicting climatic changes associated with heating resulting from nuclear and coal utilities and carbon dioxide generation from coal stations.

The study's consideration of reactor safety recognized that judgment of reasonable people differ markedly in the area (p. 215). The study raises three principal questions: (1) whether nuclear power compared favorably with competing technologies on a predicted average rate-of-loss basis; (2) whether the health and property consequences of a single extremely serious accident would be in line with other peacetime catastrophies that society had been able to handle; (3) despite large uncertainties, whether a reasonable upper limit or ceiling can be placed on the probability of the class of extremely serious accidents.

A principal source of data upon which the committee based its decisions was, as noted previously, the WASH-1400 report. WASH-1400 undertook a detailed analysis of "event tree" and "fault tree" probability sequences involving the components and systems of nuclear reactors. An "event tree" is a procedure by which the probabilities of possible outcomes induced by one initiating event are tabulated. A "fault tree" is the reverse of an "event tree": a final outcome as postulated and the various sequences in combination with individual failures that could lead to that outcome are tabulated. The group found the WASH-1400 methodology faced a number of serious problems (p. 227): (1) the fundamental one that unknown or unsuspected failure mechanisms cannot be included in the analysis; (2) WASH-1400 answers are the result of the probabilities assigned at each of the branch points which,while sometimes based on experience, must at times be founded on judgment; (3) the probabilities of breaching each safety barrier are not necessarily independent, since "common mode" failures can increase the likelihood of failure of one barrier once another has been penetrated and the probability of such common mode failure is uncertain; and (4) the various probabilities may be correlated in different ways for different reactors over which safety predictions are averaged (p. 227).

The study's consideration of radioactive waste disposal, nuclear proliferation and the problem of terrorism all were based, apparently, on presentations by expert witnesses and internal group discussion. Little hard data

is presented in any of these sections, the report relying primarily upon a recitation of historical events and knowledge common within the technical community.

5. Safety Goal Treatment - Issues and Choices gives very little attention to safety goals per se. Rather the emphasis of the report is upon what the risk is, rather than what it ought to be. Thus treatment of safety goals is implicit rather than explicit, with the goals appearing, unstated as such, in the form of conclusions in the recommendations. For example, the study concludes that "nuclear power is only one of several energy options, and decisions about it should be made on the basis of sound national and international economic considerations, realistic accounting of social costs, and the paramount concern to avoid further proliferation of nuclear weapons" (p. 5). We may infer from this statement that one safety goal would be the prohibition of the proliferation of nuclear weapons.

Indeed, the study emphasizes the need to develop a U.S. non-proliferation strategy which, it recognizes, must be complex and comprehensive (p. 23). Most of the elements of such a non-proliferation strategy bear upon foreign policy considerations such as: "a foreign policy in support of international security, peace, and stability."

There are, however, more technical goals relating directly to nuclear power and the nuclear fuel cycle which, implicitly would help to control nuclear proliferation. For example, the study implies that controls should be placed upon the exportation of plutonium and highly enriched uranium (such as already exists) and other materials suitable for nuclear weapons and the facilities needed to produce them. The report also implies that controls should be placed upon uranium enrichment facilities and technologies, particularly upon the newer types of centrifuge and laser separation (p. 24). The report notes that "assured supplies of slightly enriched uranium at reasonable prices will also greatly reduce the economic rationale for other countries to build indigenous enrichment plants" (p. 25). The study recommends that plutonium reprocessing for recycle in light-water reactors should be deferred indefinitely (p. 34).

The study's consideration of the reactor siting problem touches upon supporting standards and guidelines then current in the NRC. Those siting criteria and procedures took population proximity into account by requiring that the population density out to 30 miles from the reactor not average more than 500 persons per square mile at the time of initial plant operation and not more than 1,000 persons per square mile in the plant's projected operation lifetime. The report observes that such procedures are only loosely related to the actual levels of radiological risk (p. 239) and implies they should be.

A rather more general safety goal is one of the eleven major points resulting from the study's consideration of reactor safety problems: "...there should be a continuing effort to improve reactor safety. To this end, greater effort should be placed on actual safety improvements, in addition to the present heavy emphasis on improving the ability to predict safety performance. Currently the regulatory process creates disincentives to improvements in safety and steps should be taken to change this situation" (p. 242).

Attempts to fit these loosely defined goals within the conceptual framework of the draft report by Mattson et al. are difficult, to say the least. However, in general terms, such goals as are implicit in the Issues and Choices report could, in the reviewer's view, best be categorized as: multiple; qualitative rather than quantitative; ends-oriented rather than means-oriented; more relative than absolute; more society-oriented rather than individual-oriented; both site dependent and independent; and more atemporal than time-related, as these terms are employed in the reference report.

6. Goal Formulation Criteria - Since there is little explicit consideration of safety goals in Issues and Choices, it is not surprising that there is virtually no attention given to decision criteria to be employed in formulating such goals. But once again, there are implicit criteria which can be seen by reading between the lines, for example, in the quotation with which we began the previous section on safety goals: "nuclear power is only one of several energy options and decisions about it should be made on the basis of sound national and international economic considerations, realistic accounting of social costs, and a paramount concern to avoid further proliferation of nuclear weapons" (p. 5).

In its discussion of reactor safety the study also considers the problem of developing standards of "acceptability" of nuclear risks. The study notes that because of the dissimilarity of risks between competing technologies, some analysts have avoided comparing technologies in searching for standards of acceptability. Rather, they have drawn comparisons with natural disasters such as hurricanes or earthquakes and man-made disasters such as dam failures or air crashes. The study concludes that "neither comparison with the safety records of competing technologies nor comparisons with accidents unrelated to energy are fully satisfactory " (p. 214). Comparisons with competing technologies enable one to examine the effect on health of alternative technologies, but they suffer from differences in the technical character of the competing cases. Disasters unrelated to energy are unsatisfactory comparisons for nuclear reactor accidents, since the context of the comparison is dissimilar. Calculations of an expected rate of loss leave a great deal of room for controversy whether the risk is "acceptable" or not. A calculated rate of loss, although small, is very uncertain and the consequences of an extremely serious nuclear accident may be unacceptable no matter how low its predicted probability.

The study implies that expert judgments are the only reasonable decision "criteria."

7. Risk-Cost-Benefit Considerations - In spite of the study's insistence that it followed an "economic analysis" methodology, there is very little attention paid to formal tradeoffs in risks, costs and benefits in the report. Most of the risk assessments formally and informally recognized as such are conducted without consideration of costs and benefits in a safety context.

There is however, a prominent exception to this overall judgment: Chapter 3, "Economics of Nuclear Power" (p. 109), which compares the costs, in dollars, of nuclear power with those of coal, identified as "the competitive energy source for the generation of electricity" (ibid.). The basic conclusion of the chapter is that, despite large uncertainties, nuclear, on the average, will probably be somewhat less costly than coal-generated power in most of the United States or, to be more precise, in areas that contain most

of the country's population (ibid.). When the report elsewhere speaks of economic analysis, it probably refers to this chapter on the "Economics of Nuclear Power" concerned as it is with such factors as capital investments, operating costs and the other usual cost categories.

The report also contains a chapter on "Energy and the Economic Future" (Chapt. 1, p. 41) which also employs an economic perspective. Noting that the principal justification for nuclear power is that it can make an important contribution to the U.S. and world economies, the chapter observes that nuclear power carries with it non-economic risks such as potential negative impacts on the environment and national security. However, it observes that society's willingness to accept these risks will depend strongly on the economic costs of avoiding them. The chapter addresses (p. 41) such questions as: how important is energy to economic welfare?; can the economy adjust to higher energy costs without reduction of economic growth or unemployment in the long run?; how might rising,real incomes, higher energy costs and changing values in life styles interact to influence energy demands upon the next half century?; and finally, if non-economic considerations suggest foregoing or delaying currently projected nuclear developments, what would be the economic consequences? (p. 41).

These questions are addressed with the aid of the Energy Technology Assessment (ETA) Model, discussed in the Bell Journal of Economics and Management, Autumn 1976 (p. 57). Although the model apparently employs conventional dollar equations, it professes to consider the benefits, for example, of breeder and laser enrichment and arrives at the overall conclusion that "energy costs within the range foreseen are not critical to determining the economic or social future. The fear that energy scarcity will force fundamental changes in economic and social structures or the life style of the industrialized world are not well founded " (p. 68).

In spite of such conclusions, there is no apparent capability of that model, or of any other employed by the study, to compare risks, costs and benefits on a quantitative basis.

A more qualitative assessment of the risks and social costs of nuclear power are reported in the chapter on, "Health, Environment and Safety." Noting that such comparison is not an easy task, the study observes that the possible social costs of coal and nuclear power involves such diverse health effects as delayed deaths, genetic disease, illness and discomfort, while the environmental effects range from land use problems to the possible modification of the atmosphere, possibly leading to worldwide climatic changes. Some of these social costs (such as the costs of improving the safety of the reactor, reducing pollution from coal, and payments to miners with black lung disease) are reflected in the market economic conditions. However, the general effects of emissions from coal and nuclear power plants are not included in such costs comparisons (p. 16).

The report continues: "analysis of social costs raises difficult and controversial methodological problems in valuing human life and health now and in the future. The greatest difficulty, however, is the uncertain state of knowledge regarding the effects on health and the environment of low levels of chemical and radioactive pollution and regarding the probability of nuclear accidents... It is impossible to estimate accident possibilities with any precision. Some risks may be unknown " (ibid.).

To conclude this review of Issues and Choices, the report speaks for itself (p. 17) regarding uncertainties in the consideration of social costs. "The range of uncertainty in social costs is so great that the balance between coal and nuclear power could be tipped in either direction with resolution of the uncertainties. It is unlikely, however, that the principal uncertainties will be resolved in the near future. We do not believe, therefore, that consideration of social costs provides a basis for overriding our conclusions, based on economic analysis of the comparative attractiveness of the two technologies and desirability of maintaining a mix."

Thus, Issues and Choices does recognize the importance of assessing the costs and benefits involved in risk assessment, but rarely makes any actual tradeoffs in arriving at its recommendations.

III. ENERGY: THE NEXT TWENTY YEARS

1. Risk Definition - The Next Twenty Years employs the word "risk" in two implicit connotations: as a hazard or threat to health and safety; and as an economic danger. The words "danger" and "hazard" are more frequently encountered than risk. The Next Twenty Years is primarily an economic study by distinguished economists and other experts who have given heavy emphasis to the role of market forces.

McGeorge Bundy states "this report makes a particularly valuable contribution by its insistence on distinguishing real from unreal dangers." The changes in Iran are cited as an example of special shocks representing real dangers, whereas the belief that we may be headed toward a sudden world-wide energy "gap" is an example of an unreal danger (p. xviii).

Consideration of health hazards is limited primarily to the environmental impacts of coal and nuclear energy in chapters 10 and 12, respectively.

2. Fuel Cycle Coverage - In a book dedicated to the economic impacts flowing from the growing oil problem, little attention is paid to the safety or risk aspects of the elements of the various fuel cycles.

The Next Twenty Years was sponsored by the Ford Foundation, as was Nuclear Power, Issues and Choices (supra). The Next Twenty Years reviewed that and more recent work and concluded that, for the most part, the findings on safety of the earlier study remain valid (p. 436). Those findings are summarized in The Next TwentyYears in the section on "Other Risks of Nuclear Power" (p. 436 et seq.).

The Next Twenty Years does devote some consideration to alternative fuel cycles and uranium consumption, observing that the possible exploitation of nuclear power programs to produce nuclear weapons has become a major issue of public policy (p. 425). The Next Twenty Years states that "the problem arises in large measure, because many countries, owing in part to their concern about dependence on others for the uranium needed to fuel reactors, have sought to reduce uranium consumption by means that increase concern about nuclear proliferation" (p. 425). The Next Twenty Years therefore, considers alternative reprocessing and enrichment schemes, involving both different technologies

and institutional arrangements, that might be more "proliferation resistant " (ibid.). It proposes to reduce uranium consumption in light-water reactors by various methods, for example, by moving fuel rods within a reactor more frequently to achieve more even burning. This procedure would assure that a larger fraction of uranium in the fuel rods can be made to fission (p. 429). The CANDU reactor is supported as a desirable alternative to the light-water reactor in that the CANDU requires no enrichment and uses about 20% less uranium than the light-water reactors on a once through fuel cycle (p. 431).

Consideration of the fuel cycle of coal is more limited, except for air pollution to which an entire chapter is devoted (Chapt. 10, p. 327 et seq.). Also,Chapter 11 (p. 373 et seq.)deals with air pollution management problems. This latter chapter is primarily concerned with questions raised by and about the Clean Air Act of 1970 and its subsequent amendments through 1977.

3. Risk Assessments - With the book's emphasis upon the economic impacts of the energy problem, most assessment statements are concerned with such matters rather than with health and safety per se. In its consideration of the nine so-called fundamental realities, which in the view of The Next Twenty Years define the energy problem for that period, the word risk appears only in the economic sense of a danger. Thus, in "reality" number 2, "Middle East oil hold great risks, it is so valuable that the world will remain dependent on it for a long time" (p. 3). And again,the high prices of oil strains the world's economy and interruptions in the supply of oil could shatter world peace and stability (p. 10).

In reality 4, the national environmental effects of energy use are recognized as serious and hard to manage. The Next Twenty Years sees some energy-related activities involved in environmental effects that are of such potential magnitude and are so difficult to control,as a technical matter, that they may ultimately constrain the use of some energy sources (p. 26). For example, the evolution of carbon dioxide from the burning of fossil fuels may greatly restrict the use of such fuels in the future. The Next Twenty Years concludes that given careful and flexible management, energy can be produced and consumed in the United States, at levels they think likely to be needed over

the next twenty years, without undue harm to human health, natural systems or esthetic values (p. 27).

However, U. S. environmental policy has consistently ignored certain central facts of the very environmental problems they are supposed to resolve. In particular, basic societal questions are too often avoided or left unresolved in the open political process, where they should be handled, and are pushed into administrative and legal channels where issues of fact and procedure act as proxies for the underlying basic conflicts (p. 28).

The Next Twenty Years is particularly critical of the U.S. Clean Air Act and its underlying assumptions: that science can find certain levels of air pollution that are "safe"; that air everywhere must meet that standard by a certain date; and that regulatory processes can dictate the detailed responses of each of the thousands of emission sources (p. 29). The effects of air pollution are too complex to be captured in a rigid number: air is only more or less harmful, depending on: the concentration and duration of exposure; the combinations in which pollutants are inhaled; and the size, health, age distribution and smoking habits of a population exposed (ibid.). The Next Twenty Years is insistent that the costs of controlling pollution, and the costs imposed on society by that pollution, should be included in the price of energy. And social judgments must be made about how much to spend to reduce pollution, how fast to make progress overall, and how far to go ultimately (p. 30).

In an assessment which supports the DOE's Strategic Petroleum Reserve, The Next Twenty Years states that a petroleum stockpile is essential for dampening shocks to the economic system and in providing an interval during which efforts can be made to mediate disputes or to fashion countermeasures. Nevertheless, technology in itself offers no complete "fix" to the energy problem. Society will have to make extensive changes in the way it gets and uses energy (p. 31).

The Next Twenty Years principal risk concern, in the more conventional use of the word, is the risk posed by nuclear weapons proliferation, which it relates primarily to facilities for the enrichment of uranium and to the separation, shipment and subsequent storage of plutonium (p. 59). There is no

persuasive technical or economic reason for the United States to reprocess fuel from commercial reactors or to move to commercial breeder reactors within this century and probably for a decade beyond (p. 60). Nevertheless, it is desirable that nuclear fission be maintained and improved as an energy option for the next century, even if rising costs and concern about safety slow its growth and limit its use in the short run (ibid.).

Apart from conservation, The Next Twenty Years concludes that, for the next two decades, coal is the only energy source that can increase its contribution to the world's energy requirements rapidly and economically (p. 61). The trouble with coal, however, is the evolution of carbon-dioxide and the resulting climatic effects resulting therefrom. The Next Twenty Years concurs with the judgment of the National Academy of Sciences that "the principal limiting factor on energy production from fossil fuel over the next few centuries may turn out to be the climatic effects of the release of carbon dioxide" (p. 334). The use of coal is further complicated by the formation of sulfates produced by chemical transformations of sulfur dioxide emitted by the combustion of cost, and by the emission of nitrogen oxides which can cause acute and cronic injury to the lungs.

To conclude, McGeorge Bundy says, "the single most important element in the continuing crisis of energy policy may be the continuing failure in our national understanding of it" (p. xviii).

4. Risk Assessment Methodology - The Next Twenty Years employs a combination of reasoned argument based on physical facts, primarily, and economic analysis employing logical constructs and econometric models. The majority of the study participants were themselves economists and the emphasis of the report is primarily economic. The study group gave particularly heavy emphasis to the role of market forces.

The group met once a month two days every month over a period of about a year and a half, with extended workshops in August 1978 and January 1979 (p. xxii). They invited and listened to people from government, industry and various interest groups, particularly in the consumer and environmental

areas. They commissioned background papers by various experts and held discussions with legislators and their staffs.

Little emphasis was given to matters of public safety, except for the impacts of coal and nuclear power upon the natural environment. The methodology employed in those few instances is primarily reasoned judgment and acceptance of certain conclusions of other groups, particularly the first Ford study on Issues and Choices.

Reflecting its dependence upon such reports, the data sources employed throughout the report are primarily secondary, looking to other reports for primary data. A random sampling of such data sources includes: the Department of Energy, Monthly Energy Review; the Energy Balance in OECD Countries, Background Papers for Energy: The Next Twenty Years, (Ballinger); Energy Flow through The United States Economy; and How Industrial Societies Use Energy: A Comparative Analysis (pp. 82 - 84).

The Next Twenty Years is very aware of uncertainties involved both in its data sources and in its own assumptions and conclusions. Thus, in reality 4, on the environmental effects of energy use, they note that "there is a high degree of uncertainty surrounding the mechanisms and extent of damages and risks, and the costs of reducing the threats can depend critically on how the threats are defined and managed" (p. 4). These uncertainties, which surround environmental problems, come from the basic complexity and the dynamic nature of natural and social systems. Dealing with complex evolutionary systems, it is not possible to identify simple cause and effect relationships or to predict with confidence the ultimate effects of action or inaction (p. 27).

In its analysis of oil import impacts upon the economy, The Next Twenty Years states "the greatest uncertainty is our inability to predict the production, price and revenue strategies of the key oil-exporting countries" (p. 211).

There are few numerical estimates of such uncertainties. And the considerations related to risks are constrained by the limited discussion of impacts on safety and health, which constitutes only a small portion of the report.

5. Safety Goal Treatment - The Next Twenty Years presents no safety goals specifically designated as such, but offers a number of conclusions and

recommendations which can be recognized or interpreted to be safety goals. Thus, the report recommends that research on the scientific facts underlying pollution should seek to define the general relationships among pollution, human health and other values that are protected by cleaning the air rather than to ascertain "no damage" levels (p. 55). Rigid deadlines and standards should be de-emphasized, but overall progress should be speeded up in combating environmental pollution. The goal of air pollution policies should not be to accomplish specific air quality standards by specific deadlines, but rather to make continuous progress over time toward the general objective of cleaner air, giving priority to those areas where the value of cleaner air is greater for health, esthetic or economic reasons (ibid.). Furthermore, air pollution control policies should concentrate on providing incentives for making progress toward cleaner air in a way that is cost-effective over time. The Next Twenty Years recommends moving toward a rather different policy in which social judgments would be made about whether to apply more or less pressure toward cleaner air, leaving market processes to determine the details (p. 56).

To combat nuclear proliferation, The Next Twenty Years recommends offering economic incentives and supplying assurances to dissuade other nations from premature or otherwise undesirable enrichment, reprocessing and breeder development. It supports continuing the "go slow" policy on reactor fuel reprocessing and breeder commercialization (p. 60).

And it recommends continued research into the carbon dioxide problem. "The sooner it is learned just what the relationships are among coal use, carbon dioxide build-up and global climate, the sooner the long-term potential for coal and other fossil fuel can be defined" (p. 63).

Considering the environmental problem posed by coal , The Next Twenty Years states that it is doubtful that a meaningful threshold exists for any pollutants and that forcing scientists to pick a number that purports to be a threshold of some kind probably is not a useful administrative procedure for setting a policy goal. It is certainly not a scientific procedure and should not be disguised as such (p. 346). Using judgmental margins of safety to incorporate many

non-scientific issues in the setting of a threshold standard is better than ignoring these other issues altogether (p. 347).

The Next Twenty Years supports attempts to establish relationships between exposure and effects, but notes that the basic problem, beyond the data limitation, in establishing such a relationship is to adjust correctly for factors other than pollution exposure that affect health (p. 357).

The Next Twenty Years is repeatedly critical of the 1970 Clean Air Act and of its subsequent amendments. They imply that the cost of meeting the standard should enter into the EPA administrator's decision about where to set those standards (p. 375). "Everybody seems to understand (but not to acknowledge) that the standards are only administrative fictions, and there is no reason to think that the EPA administrator did not use his "best judgment" in choosing them initially - which is all he was required to do by law." The Next Twenty Years recommends that the National Ambient Air Quality Standards, which have been de-emphasized since 1970, continue to play a role in the administration of the Clean Air Act which is inappropriate. Standards should be completely de-emphasized or, by implication, eliminated (p. 402). On top of the basic State Implementation Plans, the National Ambient Air Quality Standards do not add up to a logical policy for dealing with long distant transport and low level effects of pollutants (p. 403).

The Next Twenty Years recommends the simplification and de-centralization of air quality standards. It favors use of centralized administrative processes to establish guidelines and incentives and a general framework to monitor performance, and recommends needed changes to gather the basic information required. They also recommend letting local agencies, private firms, and individuals make their own best detailed standards adjustments (p. 405).

A general recommendation is that the air pollution policy of the United States should use market forces to do those things that market forces do well within a general framework of property rights, law and regulation (p. 407).

As an example of the use of market forces for setting standards, The Next Twenty Years believes that mining and milling companies should be made to bear the burden of protecting the public from the radioactive emissions from

the tailings insofar as that can reasonably be done through the setting of standards by the federal authorities (p. 453).

Considering how the regulatory agencies, and the Nuclear Regulatory Commission in particular, could improve their performance, The Next Twenty Years recommends "one approach to reducing lead-time would be for the NRC to consider the plant design and the site before the utility is prepared to file the application for the construction permit." Such a reform would be possible only if standardized plant designs were considered (p. 528). Noting that one of the major complaints of the utility industry has been "ratcheting" of requirements (i.e., backfitting of changes for marginal safety gains), The Next Twenty Years supports the idea that new knowledge pointing to a safer way of doing something ought not to be ignored simply because the cost will be higher. Thus, by implication, The Next Twenty Years supports continual updating of safety goals and standards.

Regarding the reference paper by Mattson et al., the implicit safety goals reflected in The Next Twenty Years have been classified by the present author as follows: Multiple rather than single; both quantitative and qualitative; more ends-oriented rather than means-oriented; relative in preference to absolute; society-oriented rather than individual; site-dependent; and more time-related than atemporal.

6. Goal Formulation Criteria - In spite of its use of econometric argument, analysis, and occasionally models, the basic decision criteria implicit in all the decisions of The Next Twenty Years is expert judgment. However, that expert judgment must be modified and hopefully reflect social judgments. For "failure either to make the required social judgments or to provide mechanisms for implementing and modifying them efficiently can result in environmental management programs that are ineffective and too costly" (p. 28). Particular attention should be placed upon the specification of objectives. For minor differences in objectives can result in major differences in the cost of accomplishing them (p. 28). Also, policy considerations can discourage the right overall long-run changes by giving excessive concentration to narrow short-term objectives.

There is concern, however, that too often the procedures originally intended to broaden participation by society in governmental decisions are

today used to delay and frustrate the implementation of social judgments (p. 29).

The Next Twenty Years' consideration of breeder reactors gives an example of its judgmental decision criteria: "Our judgment is that breeders will not need to be employed on a commercial scale before the year 2010" (p. 54).

The report is particularly concerned by air pollution decision making legislated by the Congress in the Clean Air Act which is based on the concept that there is a threshold concentration level for some air pollutants below which there are no adverse effects. There are few environmental stresses for which the low end of the dose-response curve has been examined quantitatively. That fact must be confronted in air pollution decision making (p. 345). The report reportedly opposes incorporation of the concept of threshold concentrations into the process for setting air quality standards (p. 346).

The Next Twenty Years is concerned that the decision processes under the Clean Air Act are becoming more complex, especially where new emission sources are concerned. Cost, delay and uncertainty involved in obtaining approval for a new source discourage some potential applicants (p. 384).

The Next Twenty Years' concern with decision making is reflected by the fact that Chapter 14 is entitled, "Jurisdiction, Regulation and Decision Making" (p. 513 et seq.). In that chapter, the report exhibits an ambivalent attitude toward intervention by private citizens. They state that the ability of citizens to intervene in governmental decision making is an illustration of the notion of participative democracy. But, on the other hand, raising intervention to the level of a quasi-constitutional right is not self evidently consistent with the fundamental notions of representative democracy (p. 536). Nevertheless, advocacy can help to clarify relationships between competing values in the rulemaking process. "Although there is a better decision effect (resulting from intervention) one cannot be sure what percentage of private intervention actually lead to better decisions, especially in view of the tendency of intervention to carry with it adjudicatory methods and detailed judicial review" (p. 537). In order to reduce the associated delays, rigid limitations could be imposed

upon the time when private intervention would be permitted to occur (p. 541).

In general, The Next Twenty Years favors the more generous use of notice and comment on rulemaking and much less use of adjudicatory techniques (p. 540).

7. Risk-Cost-Benefit Considerations - The Next Twenty Years is more concerned with economic impacts than risks to health and safety, with the exception of the environmental area. Considering the Clean Air Act, The Next Twenty Years recommends a three-step procedure for incorporating scientific risk estimates and tradeoffs into the control program: (i) a thorough review of the known biological effects; (ii) a definition of exposure levels for various segments of the population; and (iii) an estimation of the total health effects (mortality and morbidity) to be expected at different levels of postulated exposure. They recommend such a procedure should also be applied to other pollutants which currently are regulated on the basis of threshold concepts (p. 348).

More generally, when faced with such complexities and uncertainties as confront the decision maker in the environmental management field, basic judgments must be made about what level of costs and risks should be incurred in one area of life in order to reduce costs and risks elsewhere. And social processes and institutions must be established for implementing and continually modifying these judgments in the light of new information and changing circumstances (p. 28).

The present Clean Air Act requires a certain weighing of risks and benefits; however, each of the concepts involved in these procedures is far from clear cut where definitions are required (p. 344). In a modern world where there are many new and old dangers and increasingly sensitive ways of identifying them, absolute safety cannot be assured, so risks must be estimated, compared and evaluated relative to benefits, either openly or not (p. 347). It is particularly difficult in this regard, however, to measure the benefits such as the damage prevented by expenditures for pollution control (p. 366).

In protecting human health, a "margin of safety" is often employed which in theory is a compensatory device to protect the public health in the presence of scientific uncertainties. In practice, however, its use permits the exercise of value judgments about the seriousness of the threat, the number of people affected, the potential benefits and costs involved in regulation, etc. Thus, the margin of safety becomes something of a safety valve or "fudge factor" allowing costs and benefits to be considered even when they are not supposed to be (p. 346).

In making cost-benefit analysis, it is very difficult even to measure the costs, much less the benefits. Contrary to popular opinion, the costs of delays occasioned by the intervention process are difficult to determine. There are also indirect costs; for example, those involved with financing difficulties arising from the intervention process. Generally, uncertainty is costly, but it is unclear how to put a cost figure for cost-benefit purposes on what is termed "the uncertainty effect" (p. 538). (The Next Twenty Years determines two principal benefits: a so-called better deicision effect, and a participation effect arising from intervention.) Costs of delays and indirect costs are difficult to value. So cost-benefit analysis, although attractive in principle, is most difficult in practice, particularly in the private intervention area.

IV. ENERGY IN AMERICA'S FUTURE

1. Risk Definition - America's Future defines, by implication, risk to mean a hazard to human well being (p. 34). It explicitly talks about comparative risks, examines how the levels and patterns of risk compare among the different energy technologies (p. 36). The major risks of concern to America's Future are catastrophic threats. "In the public mind, the danger of energy-related catastrophies appears to be linked mainly with nuclear energy because of the almost automatic mental connection among nuclear fuels, nuclear explosives, and radiation" (p. 41).

Although the major portion of America's Future is concerned primarily with economic analyses of energy supply and demand, a substantial part of the book is devoted to questions related to risk: mainly, Part IV, "Health, Safety

and Environmental Impacts," embodying Chapters 12 through 14 (pp. 343-397). The health risks considered extend from "predictable small increases in the usual illness rates among the general public to well-documented accidents to coal miners" (p. 343). Chapter 14, "Catastrophic Threats Associated With Energy Technologies," defines the word "catastrophy" to mean a "highly uncertain or low-probability event, having possibly severe impacts on a large number of people" (p. 384). Although the word catastrophy is usually employed in a physical or technical sense, America's Future observes that the interaction of politics with technology could also cause social catastrophies.

As the book also emphasizes that the use of nuclear power and the availability of nuclear fuel technology relating thereto could indirectly increase the probability of catastrophic nuclear warfare (p. 384), one may conclude that risk also is implicitly defined by America's Future to include threats to national security.

2. Fuel Cycle Coverage - Although America's Future does consider various aspects of the fuel cycles of the various energy technologies considered, the book relegates such consideration to a secondary role. The elements of the nuclear fuel cycle, for example, are presented in two notes (p. 282 and p. 390). Those notes however, present merely a listing or layman's definition of the components of the fuel cycle - including mining, milling, conversion, enrichment, fuel fabrication, power production and waste management, and reprocessing and fuel enrichment of nuclear fuels (pp. 282 and 390).

Similar elements of the coal fuel cycle are also touched upon. Major emphasis is given mining and the problems of miners' susceptability to accident and to disease arising from their occupation. Coal transportation is given particular emphasis (p. 486 et seq.).

In considering various safety aspects related to the nuclear fuel cycle, America's Future recognizes the possibility that nuclear materials might be "discharged" accidentally at any point in the fuel cycle, but asserts that the probability of any substantial discharge can be made exceedingly small and the adverse effects of an accident can be substantially reduced (p. 500).

America's Future emphasizes that nuclear wastes pose grave risks, but does not specify precisely what they are. Rather the book's treatment emphasizes recommended roles for the U. S. Government, noting that the acceptability of nuclear power would be substantially enhanced if the U. S. Government made specific arrangements to take Title II possession of nuclear wastes (p. 498). Furthermore, the Federal Government should develop large-scale regional spent-fuel depots where spent-fuel assemblies could be gathered from operating reactors after an initial cooling-off period at their respective power plant sites (p. 499). Safe permanent disposal must be demonstrated, and this latter problem has two parts: the disposal of obsolete power plants and facilities which have become radioactive during operation; and the disposal of high level wastes - either intact spent-fuel bundles or the residues of military and commercial reprocessing (p. 499).

3. Risk Assessments - Contrasting the relative risks of generating electricity by coal or by nuclear plants, America's Future estimates that, if all the electricity generated in 1975 had come from coal, the total number of associated fatalities would have ranged between 200 and 4,000; whereas if the electricity had been generated entirely from nuclear sources, total fatalities would have been substantially lower with estimates ranging between 60 and 900. This latter prediction, conservatively assumes a nuclear (class 9) accident probability 100 times higher than the controversial Rasmussen report (p. 6). But, the risks associated with coal could be reduced through the introduction of technologies which use coal in clean ways, for example, through the use of synthetics. On the other hand, it is unlikely that the employment of synthetics would produce less disturbance to the overall environment than would the use of conventional petroleum and natural gas (p. 7).

Considered on a (1GWe)* power plant-year basis, the maximum estimated fatalities for coal total 14, of which 8 result from air pollution, 1 from transportation, and 5 from mining, including black lung disease (p. 36). The corresponding estimated maximum number of nuclear fatalities total 3, of which .005 result from routine radiation emission, 0.3 result from gaseous wastes, 2 result from reactor accidents, and 0.4 from occupational accidents and exposure to radiation (p. 37).

*Equivalent to 1,000 Megawatts, or one million Kilowatts of capacity.

America's Future devotes considerable attention to the problem of land use and environmental impacts thereon. For example, the book concludes that the most extensive impacts on land use result from the mining of fuels, especially by surface operations. This is a particularly serious problem for coal: the land disturbed by mining averages out to from between 300 and 600 acres per plant-year, depending on the ratio of surface to underground mining. For nuclear energy, the disturbed mining acreage comes to about 60 acres per power plant-year (p. 38).

America's Future is much concerned with the problem of nuclear proliferation, and particularly with the contribution thereto which would result from the introduction of a large breeder reactor industry (p. 42). In its view, protection against nuclear materials diversion would probably become less effective if plutonium were to become an item of world-wide trade as part of a breeder reactor economy (p. 43).

The major catastrophic threat associated with fossil fuels is seen by America's Future to be their contribution of carbon dioxide, which might substantially raise global temperatures. Levels of emissions coresponding to atmospheric temperature increases of several degrees Celsius could be reached by the middle of the 21st Century on the basis of rough global extrapolation of fossil energy use (p. 45). The threat inherent in the carbon dioxide build-up resulting from the use of fossil fuels is regarded as critically important by some climatologists. However, in the view of America's Future, the real threat is a distant one. It might be possible to develop counteractive measures to reduce or negate the impact (p. 45). The same considerations apply to the more localized problem of acid rain resulting from fossil fuel emissions, which are seen as potentially reversible and even more remote than the carbon dioxide problem (ibid.).

Summarizing its conclusions regarding catastrophic threats, America's Future emphasizes the dangers of nuclear diversion and proliferation, and of nuclear power plant accidents. The probability of these latter accidents become greater, obviously, as more reactors become operative but the risk is immediate (pp. 395-396). Great temperature changes are not expected for many decades

as a result of emission of carbon dioxide by combustion of fossil fuels, and the acid rain impact would be considerably lessened through the use of new coal conversion techniques and evelopment of synthetics (ibid.).

4. Risk Assessment Methodology - America's Future was written for the general public under a grant from the Andrew W. Mellon Foundation to the Resources for the Future (pp. xix-xviii). The principal modus operandi was to view the "wealth of special studies" concerned with energy problems and to supplement those studies with additional ones commissioned specifically by Resources for the Future. Although a wide variety of specialists were consulted in preparing the book, the main veiwpoint of the book reflects economic values, since the majority of the authors were themselves economists.

Accordingly, the overall methodology might best be described as economic analysis supplemented by reasoned argument based on physical facts drawn from other sources. For example, in its various energy projections, America's Future draws upon work by the Institute for Energy Analysis (p. 204), the Report of the National Academy of Sciences' Committee on Nuclear and Alternative Energy Systems (CONAES) (p. 208), the U.S. Department of Energy Market Oriented Program Planning Study (MOPPS) (p. 211), the Electric Power Research Institute (EPRI) (p. 215), and a special study group jointly sponsored by Resources for the Future and the National Institutes of Health (p. 216).

In its examination of the health impacts of energy technologies involved, America's Future employs a standard unit of comparison: the impacts associated with a one gigawatt (1GW) power plant (p. 343).

It also makes extensive use of comparisons based on time proximity. For example, nuclear power technologies enhance the present risk of nuclear warfare which has a corresponding element of immediacy. Climate modification, on the other hand, is a threat for the more distant future. The nearer-term threat is more to be feared, since the longer a threat is delayed the greater the possibility becomes of coping with the threat through innovations that can be achieved over time (p. 397).

The data sources employed by America's Future are primarily secondary. As examples, the following are offered: U. S. Department of Commerce Survey of Current Business, and the National Income and Produce Accounts of the United States (p. 123); and Unpaid Costs of Electrical Energy: Health and National Environmental Impacts from Coal and Nuclear Power, by Ramsey (p. 346).

America's Future takes repeated note of the fact that scientific data and analysis needed to measure and evaluate impacts, particularly those of health and safety as well as environmental, are often not well established. However, the careful use of existing data within a consistent framework of comparative analysis can still narrow the issues and make them more comprehensible (p. 34).

The great uncertainty about what results the most commonly suggested energy policies might produce is one of the four underlying problems to which the book is addressed (p. 1). For example, accompanying their assessment of the fatalities associated with coal, (which ranged, as noted above, from 200 to 4,000) is the comment that this wide range reflects the vast uncertainties in the scientific data relating pollutants from coal combustion to human health (p. 6). Indeed, a substantial amount of uncertainty is recognized as surrounding the estimates of deaths and illnesses associated with all of the various energy processes including, for example, the debate over the effects of low-level radiation whether from nuclear or coal uses. The uncertainties are so broad in almost every respect that America's Future found it impossible to compare firm values for coal vs. nuclear power, but rather were reduced to citing a wide range of possible impacts for each (p. 36).

A high degree of uncertainty is recognized in employing all safety data (p. 44). Yet, as poor as the data base is for analyzing health impacts resulting from fossil fuels and nuclear power, the data and analytical concepts are even poorer for assessing possible catastrophic impacts. The factual and conceptual base is perhaps weakest in connection with the possible causal relationship between nuclear war and the productive use of nuclear energy (pp. 41- 42).

America's Future devotes a special note to the uncertainty in assessing occupational risks (p. 364). Regarding deaths and injuries in mining, the report questions whether past trends, which are well known, will continue into the future. In the case of nuclear technology, the predicted fatalities from radiation cannot be distinguished statistically from the background of normally occurring cancer deaths at the low levels of radiation experienced. In the case of shale oil, it is exceedingly difficult to estimate occupational accidents for a relatively untried technology. Similarly, uncertainties for the new solar home-heating industry arise from a lack of related experience (ibid.).

America's Future observes that the effort to enhance environmental quality is hampered by uncertainty about prospective environmental requirements. Such uncertainty delays investment and inspires "safe" rather than optimizing decisions (p. 455).

In areas outside health and safety, America's Future emphasizes that energy supply and conservation opportunities are surrounded by uncertainties. Price uncertainty particularly arises from the lack of knowledge about world energy supply and demand conditions and from the inability to predict OPEC behavior (p. 468).

5. Safety Goal Treatment - America's Future does not emphasize safety goals per se, but a number are offered indirectly and a variety of others may be identified as such.

The overriding emphasis of America's Future is the need to find a public consensus. "A consensus on goals is essential. Not only to provide a starting point for launching timely initiatives to meet long-term needs, but also to aid in coping with short term problems." (p. 2). To form the basis for wise and effective action, a consensus does not have to please everybody or indeed anybody. The essence of consensus is that the overwhelming majority will consent to it (p. 4). Noting that it seems reasonable to assume that nuclear technologies can be made still safer, America's Future states that "what we need to determine is whether it is possible to produce a national consensus

on moving ahead with nuclear power or whether there is an alternate consensus on accepting the full consequences of a policy that does without it" (p. 8). Asking, what is society's attitude toward catastrophic events?, America's Future states that this is a question on which universal agreement is not going to be found and for which even a consensus may be difficult if not impossible (p. 44). Resolution of controversies on the role of nuclear power depend ultimately upon public disadvantages of the various energy alternatives (p. 64).

Turning to more specific safety-related goals, America's Future implies that, unless basic safety concerns are first satisfied, there is little chance that the shortening of licensing times desired by utilities will ever be realized (p. 64).

Goals should be fully specified when balancing the benefits of environmental quality improvements against their costs (p. 452). Environmentally related policy should not be based on approximate objectives that are measurable or popular, but rather on relevant criteria (p. 453). And those whose interests are effected by the higher costs of facility siting decisions should be represented better in the decision process (p. 454). Tradeoffs should be clarified and procedures for compensating a few to avoid more costly corrections "in kind" would lessen pollution expenditures that almost all would consider excessive, if the choices were presented clearly (ibid.).

The report recommends development of procedural reforms to resolve conflicts and improve management (p. 456). Policies are recommended that would not delay getting benefits from processes which are probably safe, but which would quickly be stopped in the unlikely event that harm was, in fact, detected. And the economic burden of uncertain environmental risks should be spread over the entire community for whose benefit the energy choices are made (p. 456).

America's Future suggests that one possible way of bringing individual incentives into accord with social benefits is to "hold harmless" (that is to compensate for subsequent loss due to regulatory change) those who in good faith undertake actions which conform with existing environmental requirements.

Such compensation would be initiated only after explicit actions by regulators were found to have tightened previous standards (p. 457).

America's Future implies support for controlling results rather than processes as a means of countering unproductive environmental quality expenditures. Environmental quality regulation should exploit private economic incentives by giving those who produce pollutants a stake in reducing their quantity at the lowest possible cost (p. 457). More specifically, the report suggests allowing neighboring firms to "purchase" emission reductions from each other. More generally, emission charges would satisfy the cost internalization goal of pricing reform and enable comparison of the benefits derived from the improved environment with the associated costs in goods and services foregone (p. 458).

By implication, America's Future opposes multi-level and overlapping regulatory jurisdictions and the use of procedural technicalities to obstruct actions on which conflict over substance cannot be resolved (p. 458).

In formulating a strategy for reducing the safety and environmental concerns about nuclear power, America's Future suggests three elements: (i) issues should be clarified by removing objections that are not relevent to decisions about the domestic nuclear operation; (ii) critics of the nuclear option should be reassured by a willing commitment to sufficient overdesign of safety precautions so that they can agree that nuclear power is safer and more benign environmentally than its alternatives; and (iii), economic uncertainty resulting from health and safety concerns should be lessened through federal assumption of economic risks, undertaken in a fashion which would require consumers of nuclear energy to bear the costs of those risks accepted on their behalf.

Putting safety foremost requires: changes in institutions to sever the connection between a direct economic burden and additional safety; changes in regulatory systems to increase incentives to assure safe operation and avoid unsafe practices; and changes in approach to take account of the special types of concern that the public has with regard to nuclear power.

To combat the accidental discharge of radioactivity, America's Future recommends: reemphasis of ongoing efforts toward careful design to minimize

hazards; "defense in depth" to lessen effects of accidents should they occur; and setting up institutions that separate the diagnosis of potential hazards from the responsibility of paying for correcting them, so as to avoid conflicts of interest tied to financial incentives (p. 500).

To further protect against core melt-down, America's Future recommends: greater emphasis be placed on "containment strategy" to include siting of nuclear plants further from population centers; making reactors smaller; adding "core catchers;" and placing new plants underground, where appropriate. The report also recommends that prompt recognition of hazards be facilitated by independent surveillance of power plant operation and maintenance (p. 502).

More generally, safe operation and maintenance require a system which applies effective sanctions against careless operation or willful violation of safety procedures. To forestall sabotage, authorities should provide that no one person could produce a failure of both primary and back-up safety systems in case careful screening of employees failed to exclude potential malfactors. More effective training of guards and more responsive back-up security forces are supported which would prevent unauthorized entry into a nuclear plant by outside intruders acting in force. Greater Federal supervision of security systems and possible government take-over of security responsibility are suggested (p. 540) as a means to counteract terrorists.

Regarding the reference paper by Mattson et al., the socially-oriented safety goals suggested by America's Future are characterized by the present author as multiple; qualitative; ends-oriented; relative; more society than individual oriented; site dependent; and time-related.

6. Goal Formulation Criteria - In arriving at its recommended consensus, America's Future emphasizes that policy decisions cannot be made by relying on precise calculations to compare benefits and costs of alternative choices. That technique works only when all major aspects of energy decisions can reasonably be expressed in terms of a common denominator, a rare phenomenon (p. 11). The report believes that decisions about energy acquisition should not be delayed by consideration of highly unlikely or even unknown future environmental problems. It recommends improved management decision processes

related to environmental questions, but notes that such processes cannot be resolved or be obtained easily (p. 456).

Noting that different interests are represented by each level of government and each regulatory unit, the report nevertheless asserts those interests must be unified or reconciled in government decision processes. It suggests that the trend toward separation of promotional and regulatory functions might be reversed to obtain better decisions (p. 459).

With regard to external intervention, America's Future suggests the possible assigning of weights to issues on which intervention is allowed so as to diminish effort on less important ones (ibid.).

The underlying approach of the nuclear power enterprise and its regulators has been to compare benefits and costs, including special concerns for health and safety risks and then to reach decisions which apparently promise optimal results. Those decisions, however, have not led to a level of safety and to widespread public acceptance of the nuclear enterprise. The report decries the usual process of decision making as not taking adequate account of the seriousness with which society views the large scale of potential impacts, the long time it takes for nuclear materials to lose their threat and the fact that large numbers of people could be put at risk without having any effective choice in the matter (p. 498).

In reaching decisions regarding the siting of nuclear facilities, America's Future recommends two criteria: sites should be chosen to minimize the opportunity for accidents; and sites which endanger large population centers should be excluded from consideration (p. 500).

More generally, in making energy choices America's Future states that "we need a decision process that all contending parties will respect and value sufficiently to protect, even when the outcome requires that original stands be modified" (p. 537). The report supports a philosophy of reaching decisions through approaches which meet the minimum requirements for acceptability by all important groups but which may not be the preferred path for any of them (p. 539). In striving for consensus among conflicting value systems, a major basis for unity relates to the processes by which decisions are made and expressed.

The social stability inherent in a "constitutional" political system is that the decision processes are agreed upon prior to acquiring knowledge of the specific outcomes of that process. All parties, therefore, have a stake in preserving a process which they deem to be fair and therfore are more likely to accept the decisions arrived at (p. 543). All parties to the energy debate can live with continued tension, but none can tolerate the prospect of a change which conflicts with fundamental precepts of its own value system. Living with conflict implies avoidance of total victory or total defeat by any side (p. 544).

7. Risk-Cost-Benefit Considerations - Rather than tradeoff between risks, costs and benefits, America's Future is more concerned with tradeoffs between near term and more distant objectives in arriving at a consensus on energy policy (p. 65). Furthermore, it emphasizes that it is very difficult to compare fatalities, illnesses, and injuries with the dollar cost of energy production. It is difficult, if not impossible, to express all health risks themselves in the same type of units (p. 343).

Risks to national security or to economic prosperity posed by energy imports may be interpreted as added social costs which can be internalized. These additional costs lower the net benefits from importing energy. However, since the costs are imposed on the economy as a whole rather than on energy importers, they do not customarily affect private decisions as to how much to import. Thus, it is important to understand that the risks imposed by oil imports may be weighed against the benefits from allowing imports to continue (pp. 426-427).

The word risk in such considerations really represents an economic hazard rather than a threat to health and safety per se. And, generally, the social cost imposed by such risks cannot be quantified satisfactorily.

Considering risks associated with environmental pollution, the view of America's Future is that substantial improvements in administering environmental regulations can only come from resolving as many substantive conflicts as possible and from getting people to think about tradeoff between environmental quality and other factors in a new way. The book recommends a new "social compact" regarding such issues. Such improvement is one

final aspect in arriving at the recommended consensus which America's Future believes represents the sine qua non in arriving at a feasible energy policy.

V. ENERGY IN TRANSITION

1. Risk Definition - Energy In Transition offers several definitions of risk. First, risk is the measure of the expected average value of consequences from some unit value of operation of a system" (p. 280); for example, the expected* fatalities incurred per gigawatt electric-year (GWe-yr) for a proposed electrical generating facility. This definition of risk is employed in the safety analysis of nuclear reactor operations. Three separate areas of operation are considered: Discharge of radioactivity to the environment resulting from reactor operation, possibly resulting in public morbidity; exposure of nuclear power plant workers to radiation from contaminated equipment; and discharge of radioactive effluents in the nuclear fuel cycle.

However, in Chapter 9 on,"Risks of Energy Systems," risks are defined in two other ways: to convey the possibility (probability) of loss or to denote a dangerous element or factor (p. 423). Chapter 9, examines the risks associated with three principal groups of energy systems - fossil fuel, nuclear, and solar - with particular focus on the generation of electricity. The reports notes that our knowledge of several important risks, as well as our knowledge of how to control them, is recent and incomplete. The major categories of risk considered in this chapter include industrial operations, atmospheric pollution, shortage of water and change in climate.

2. Fuel Cycle Coverage - Energy In Transition groups the risks considered by their origin in the various steps of each energy fuel cycle, including: extraction and processing of the energy resource; transportation and storage; use in the production of another fuel (liquid fuel from coal, for example); in

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*"Expected" values in statistical decision theory are mathematically equivalent to the consequence of a risk-taking activity times the probability of the consequence.

electricity or power application; the disposal of wastes; and possible recycle (p. 423). The report's use of the words "energy cycle" is the same as the engineering literature use of the words "fuel cycle," which is synonymous with energy cycle as employed by the report.

The largest radioactivity releases come from the underground mining of uranium and from the milling process by which the ore is concentrated. Uranium mining hazards have been estimated at about 15 deaths per year per 10,000 miners. Per miner-year, the hazards of uranium mining are comparable to those of coal mining, but because the same energy is recoverable from only about 1% as much material the mortality of uranium mining per unit of power is far less serious than that of coal mining (p. 216).

Additional radioactive emissions come from the mill tailings, which contain over 80% of the ore's original radioactivity. Past practices have been careless, resulting in the exposure of the tailings to weathering and subsequent incorporation into concrete and landfill for homes and schools in extreme cases.

Releases of radioactivity during nuclear power plant operation are estimated to increase environmental radiation by only a small fraction of the existing background. The resulting effect per unit of power generated is small compared to the mining risks or the operating risks of other energy sources (p. 216).

Consideration of the possibility of reactor accidents is considered in section 4(c) of the book.

Radioactive emissions from reprocessing plants - for example, krypton-85, tritium, and carbon-14 dioxide - most experts agree would present no major technological waste disposal problem. However, the development of fissile material, either uranium-233 or plutonium-239, presents a threat because of the potential for theft or illicit diversion. There is also the risk that countries installing reprocessing plants would thereby have the means to build up arsenals of nuclear weapons.

Energy In Transition employs the terms "safeguards" as the rubric under which it collects all the measures by which the manufacturer of bombs from nuclear fuel materials could be developed. The principal "safeguards" concern

is reprocessing. Safeguard methods proposed include materials accounting, and personnel screening, but the chief one is security: the limitation and control of access to the reprocessing plant, multiple checking of shipment authorizations and deliveries to shipping; and monitoring of access points and of the personnel involved.

Geological waste disposal problems are site-specific: requiring sites that exhibit a high degree of stability, transmit water only by pore flow, and offer no ready access to groundwater. Storage in such sites would present much smaller risk to the public than that of routine emissions from the rest of the fuel cycle (p. 221).

3. Risk Assessments - The problem of nuclear weapons proliferation is real and is probably the most serious potentially catastrophic problem associated with nuclear power (p. xv).

Energy In Transition supports energy conservation as deserving the highest immediate priority in energy planning (p. 4). The risks associated with energy conservation are lower than those of any other energy alternative.

The most critical near-term energy supply problem for the United States is fluid fuels (p. xiv). As fluid fuels (primarily oil) are phased out of use for electricity generation, coal and nuclear power are the only economic alternatives for large-scale application in the remainder of this century. In terms of public risks from routine operation of electric power plants, coal-fired generation represents the highest overall level of risk, with oil-fired and nuclear generation considerably safer, and natural gas the safest (p. xv). On the other hand, coal power plants and the coal fuel cycle are not subject to low probability, high consequence accidents or sabotage. The hazards of coal can be made relatively predictable (p. 15).

The health problems associated with coal affect both its production and its use. The health of underground miners presents particularly complex and costly problems.

Noting that accidents are the most accurately assessed of energy-related risks, the report states that coal is the most dangerous of modern energy sources: about 10 times as many accidental deaths occur in the coal energy

cycle from mine to power plant as in the production of an equivalent amount of power from oil, gas or nuclear energy. Most of the accident risks associated with coal occur in deep mining and rail transportation.

If the effect of carbon dioxide accumulation on climate should become a major global environmental issue in the early years of the 21st century, it would be aggravated by utility commitments to the use of coal because power plants have useful lives on the order of 30 to 40 years (p. 15). The report expresses concern that before the middle of the next century emissions of carbon dioxide from the combustion of fossil fuel (primarily coal) may produce such concentrations in the atmosphere that large and virtually irreversible alterations may occur in the world's climate (p. 20).

In the area of large-scale accidents the committee is in general agreement with the appraisals of the reactor safety studies conducted by the American Physical Society study group ("Report to the American Physical Society by The Study Group on Light-Water Reactor Safety," Reviews of Modern Physics, 47, Summer 1975) and more recently by the Reactor Safety Review Group ("The Risk Assessment Review Group Report to The U. S. Nuclear Regulatory Commission," NUREG/CR-0400, Washington, D.C., September 1978). But "WASH-1400 contains some estimates that are excessively conservative and others that are almost certainly too optimistic " (p. 54).

Considering ecosystem effects, the Risk and Impact Panel of the study committee concluded that the energy source most destructive per unit of energy output is hydro-electric power (p. 55). Nuclear power effects ecosystems less than any other source of energy, even if one considers the whole fuel cycle (p. 56).

While noting the potentially catastrophic "greenhouse" effect on the climate affected by emission of large quantities of carbon dioxide, the report observes that nuclear reactors will have much smaller effects on climate than fossil fuel installations because of their negligible emission of carbon dioxide.

Natural gas presents the smallest environmental risks in both production and consumption, although there is the possibility of serious accident in the transportation and storage of liquified natural gas (LNG).

The risks of nuclear power inducing cancer and genetic effects are very small in comparison to the overall incidents of cancer and genetic effects in the general population (p. 60).

Solar energy technology appears very promising from the standpoint of health and environmental risk, with the exception of hydro-electric power, often classified with solar energy, which, as noted previously, has great destructive potential (p. 61).

Conservation is the least risky strategy from the standpoint of direct effects on the environment and public health.

The most serious potentially catastrophic problem associated with nuclear power is that of possible nuclear weapons proliferation (p. 71). There was general agreement that the greatest threat of nuclear technology lies in existing stockpiles of nuclear weapons and weapons materials throughout the world (p. 219).

Chapter 9 deals with risks of alternative energy systems. The analysis is basically quantitative. For nuclear, the number of serious genetic effects per GWe-plant-year is estimated to be about 0.5 (p. 446). For a large domestic nuclear power program of 300 reactors (each of one GWe capacity) the projected annual increment in risk would ultimately be about 100 cancer deaths and about the same number of serious genetic defects (ibid.).

Noting that there is a need for research to contribute to better understanding of the factors that determine public perceptions of the health and environmental risks of energy systems, and that determine the acceptance thereof by different subgroups within the public, the report states that "no strategy for risk reduction in energy systems can be fully acceptable if it does not take into account these public perceptions and judgments, even when they are seen as unfounded by experts" (p. 490).

4. Risk Assessment Methodology - Energy In Transition is the final report of the Committee on Nuclear and Alternative Energy Systems (CONAES) of the National Academy of Sciences' National Research Council. Undertaken in response to a request by the administrator of the Energy Research and Development Administration, CONAES was composed of some 16 distinguished

members who brought into being four major panels which were in turn supported by 22 resource groups and a number of consultants estimated at about 300 in number (p. vi). The study was undertaken over a 4-year period. One of the four panels was intimately concerned with the matters of this present report: the risks and impacts of energy supply and use. The overall study was intended to assist the executive and legislative branches of the government in their assessment of the appropriate goals of nuclear and alternative energy systems in the nation's energy future in the period between 1985 and 2010.

The study's main emphasis was upon energy supply and demand. The principal methodology employed was a combination of econometric models and scenarios. This methodology bore little concern with risk assessment, although a clear relationship can be established.

The panel on risks of energy systems employed its own methodology, or more precisely, methodologies. First, the panel made extensive use of descriptive statistical data from diverse sources. Second, in dealing with the quantitative assessment of risk due to emissions and wastes, the classic dose-effect curve was used whenever feasible. The dose was one of two kinds of toxic agents: chemical or radioactive. The effect was measured in mean death rates per 100,000 years or in other appropriate units.

In employing such dose-effect curves, the panel on risk of energy systems made particularly extensive use of the Japanese atomic bomb survivor data collected by the Radiation Effects Research Foundation under the sponsorship of the National Academy of Sciences.

The panel emphasized that adequate dose-effect curves are rarely available for the very low ranges of exposure that are now at issue in the regulatory process. Three approaches were recommended to make estimates at the low dosage ranges: (1) when the mode of action of the toxic agent is adequately known as well as the dose-effect curve, and the population at risk is sufficiently well defined, extrapolation or interpolation of the curve poses no difficulty (p. 437); (2) experiments with animals might be used to set upper bounds of permissible dosage, provided that additional margins of safety in dosage or exposure have been incorporated in the process (ibid.); and (3) further large-scale epidemiological studies could be undertaken to define the dose response

curve in the low-dose region. These approaches, however, were not adopted by the CONAES report itself, rather high-dose results were extrapolated on the assumption that effects will continue to follow dose on a curve of the same shape in the unexplored lower dose region. In the case of radiation protection, this was done by linear extrapolation (ibid.).

In considering the effects of natural background radiation, two methodologies were employed. First, by the use of factors based on a combination of experience, experiments and judgments as well as by field studies; and second, by comparison of cancer deaths rate of selected geographic regions whose natural backgrounds differ appreciatively. The Risk and Impact Panel employed a factor of 2×10^{-4} cancer deaths per person-rem, although the report itself recognized that the factor might be an overestimate (p. 439).

In its consideration of the death rates of geographic regions with widely differing natural background, the Panel arrived at the interesting conclusion that states with the highest background have the lowest cancer fatality rates. "...The study performs the function of again raising an interesting question that would require great effort and sophistication to resolve, assuming that such resolution is feasible" (ibid.).

The principal concern of the study was with the supply and demand of various types of energy. CONAES asked several of its panels to develop models of energy and the economy to make plain the interrelation among the various variables influencing supply and demand for the various forms of energy. Those models were then applied to various sets of assumptions about: for example, the growth rate of the economy, changing prices for energy over the next three decades, consumer response, etc. More particularly, the Modeling Resource Group employed econometric models to estimate the consequences of various economic and policy assumptions (p. 530). The Demand and Conservation Panel focused on the demand for net energy delivered to the point of consumption. And it had been hoped that the Supply and Delivery Panel would be able to generate supply curves for each primary fuel; however, that hope did not prove feasible in practice (p. 531).

Perhaps the best summation of modeling in general was incorporated in the individual statement of Kenneth E. Boulding, in which Harvey Brooks, one of the two co-chairman concurred: "All model building involves assumptions about constancy of parameters of the system. In social systems, however, parameters are not constant, which is why model building must always be treated as productive of significant but rather dubious evidence and certainly never as productive of truth " (p. 616).

b. Data Sources - By far the great majority of the data employed by Energy In Transition was derived from other reports and sources: for example, from the Annual Report to Congress of the U.S. Department of Energy, from the Energy Information Administration, and from the American Petroleum Institute's Basic Petroleum Data Book. Such data were therefore, secondary, rather than primary.

There is no data base adequate for a final choice among the proposed alternative solutions for sites for radioactive waste disposal.

Energy In Transition essentially agrees with the Nuclear Regulatory Commission's criticism of WASH-1400 as embodied in the report of its Risk Assessment Review Group (p. 285).

The coal data employed by the study came from a wide variety of sources, including Mitre Corporation, the U S. Council on Environmental Quality, the AEC and the Nuclear Regulatory Commission itself (p. 429).

c. Uncertainties - The report notes that "the spread of uncertainty in present estimates of the risks of both coal and nuclear power is such that the ranges of possible risk overlap somewhat." The large range of uncertainties that still attaches to nuclear safety calculations makes it particularly difficult to provide a confident assessment of the probability of a catastrophic reactor accident (p. xv). The greater the technical uncertainties, the more room there is for interpreting whatever knowledge exists to support one's own subjective preferences. Not uncommonly, decisions among technological options which ought to be reached have not yet been reached because the technical uncertainties involved cannot be fully resolved (p. 37).

The study was particularly concerned with the difficulty in comparing (in a quantitative fashion) risks to the environment and to the health and welfare of people, because "our information about them is subject to great uncertainties" and because there is no widely accepted common scales for measurement of different kinds of risks and adverse effects (p. 48).

In one of its few quantitative considerations of the effects of uncertainty, the report notes that uncertainties in the probability estimates regarding nuclear accidents are almost surely several times larger than those estimated by WASH-1400. If larger uncertainties are used, the mean or expected number of fatalities from nuclear accidents could be higher by a factor of 10 or more than the medium values given by WASH-1400 (p. 54).

The statistical estimates of the WASH-1400 report should be corrected upwards. The use of medians, rather than means, of certain probability distributions result in the estimation of higher average risks than those of WASH-1400, but not so high as to be alarming. There remain legitimate grounds for controversy whether the risks of reactor accidents ought to be an important consideration in decisions about nuclear power (p. 217). The WASH-1400 data on common-mode failures are particularly difficult to validate. The study judges that some WASH-1400 assumptions on this point are questionable. However, the panel on Risk and Impact could not specify what the effects of the WASH-1400 assumptions really might be (pp. 284-285). More generally, the report appears to support the criticism of WASH-1400 authored by the nuclear reactor industry that any fault-tree analysis depends critically on its input data and that the input frequencies employed by WASH-1400 were consistantly overestimated (p. 284).

CONAES also emphasized that many uncertain assumptions were made in constructing its economic models and that a great deal had to be simplified or left out of their considerations.

To conclude this section, another quote from Boulding is appropriate: "it may be that the most significant conclusion of this report is its constant emphasis on the profound uncertainties that beset even the most crucial aspects of this problem " (p. 731).

5. Safety Goal Treatment - A major implicit goal is the need to influence the public appraisal of nuclear power, particularly with regard to the potential international proliferation of nuclear weapons, the safety of the nuclear fuel cycle, and the question of nuclear waste treatment and disposal (p. 25).

The report recommends that the Federal Government should immediately proceed to develop criteria for geological waste disposal (p. 35). Furthermore, standards should be set and enforced for the treatment of abandoned mines and of tailings from mines and mills (ibid.).

The report questions whether or not emission pollution standards have been set at the most efficient levels, which adequately protect health but are not needlessly restrictive or costly, suggesting such would be an appropriate goal (p. 51). In general, standards should be based on all available evidence: including any type of induced discomfort, promotion or induction of disease, and possible genetic effects (ibid). Standards should be regarded as reflecting the best judgment of experts at the time they are instituted and thus subject to change with increases in knowledge and changes in the political and social value judgments which the standards reflect (p. 52).

The report emphasizes that there is an urgent need for research that will contribute to better understanding of the factors that determine public perception of the health and environmental risk of energy systems and of their acceptance by different subgroups within the public. No strategy for risk reduction in energy systems can be fully acceptable if it does not take into account these public perceptions and judgments (p. 61). The judgment of how safe is safe enough must be made by society. In making that judgment, the most appropriate standards in the case of nuclear energy would be based on comparisons with risk of alternative sources of the risks of not having this sort of power at all (p. 280).

As a general safety goal, the report emphasizes that releases of large magnitude of radioactive effluents must never be permitted as a basic design criteria for nuclear systems (ibid.).

Most of the standards governing risks have been established by administrative action under federal legislation, including standard procedures for

inclusion of public opinion. Many of these standards have been based on the best available control technology (BACT) and on requirements that there be no significant deterioration with preexisting ambient levels of pollutants (p. 426).

The report appears implicitly to support the procedures behind federal regulations promulgated by EPA and NRC, for example, the NRC decree that reactor emissions should be as low as reasonably achievable (p. 441). It also supports the EPA position that permissable levels of pollution should be as low as regulation can drive them at some practical cost, but what cost is practical is a matter of opinion (pp. 442-443).

The greatest hazard associated with high-level waste disposal is likely to arise in conjunction with its transportation, and CONAES recommends locating the waste repository near its satellite reactors for reprocessing plants (p. 447).

The report appears to support standards defined as the amount of pollutant in a cubic meter of air or as an allowable fraction of the total atmosphere (p. 448).

CONAES implicitly supports the reevaluation of standards as further knowledge is gained (p. 450). Noting that the difficult task of setting standards for ambient air quality and emissions has been greatly complicated by lack of precise knowledge of the levels at which epidemological effects first appear and by the diversity of such effects, the committee recommends that "investigations center on the dose-effect curve (or exposure-effect curve) in the region near and below present ambient air quality standards" (p. 489).

Energy In Transition does not emphasize the development of safety goals per se; rather, goals are secondary to their assessment of the safety hazards of the various energy systems. However, insofar as those goals are explicated by the report and insofar as they impinge upon the formulations of the draft report by Mattson et al., the following comments represent the present reviewer's opinion. CONAES would appear to support: multiple goals rather than a single overriding safety goal; combined quantitative and qualitative goals; ends-oriented vs means-oriented goals; and to support relative vs absolute goals; society-oriented

goals to individual goals; and site-dependent preferred to site-independent goals. The continued emphasis on changing goals as new knowledge is gained would definitely support time-related vs atemporal goals.

6. Goal Formulation Criteria - Philip Handler, President of the National Academy of Sciences, in his introduction to Energy In Transition, observes that "an unusual aspect of this report is its conclusion that future decisions concerning nuclear energy will be determined by public perceptions of risks and benefits at least as much as by rigorous conclusions drawn by scientists on the basis of scientific analysis" (p. ix). Handler's observation perhaps reflects the final paragraph of the co-chairman's letter forwarding the report which states "...energy policy involves very large social and political components that are much less well understood than the technical factors. Some of these sociopolitical considerations are amenable to better understanding through research on the social and institutional characteristics of energy systems... However, there will remain an irreducible element of conflicting values and political interests that cannot be resolved except in the political arena" (p. xvi). Both of these statements reflect the conclusion of the overview of the report which states that "to a great extent...technical questions as well as social and institutional ones will be decided by political processes" (p. 37).

Energy In Transition repeatedly referres to sociopolitical problems. It emphasizes that energy problems do not arise from an overall physical scarcity of resources, rather the problem lies in effecting a socially acceptable and smooth transition from the gradually depleting resources of oil and natural gas to new technologies (p. 72). This energy policy involves very large social and political components which are much less well understood than the technical factors. There will always remain an irreducible element of conflicting values and political interests that can only be resolved in the political arena. The acceptability of any such resolution will be a function of the processes by which it is achieved (ibid.). Public appraisal of nuclear power is particularly difficult to analyze. Technical, political and social issues flow together, change and diverge. Public attitudes are influenced by technical information and opinion; and nuclear technology, in its continuing development, must respond to political and social influences (p. 261).

The report's study of energy systems' risks identified three bases for comparison: (1), energy-related risks of a given kind may be compared with risks arising from the background effects of the same kind; (2), cross-comparisons may be made among alternative energy technologies, systems or strategies with respect to similar kinds of risks; (3), energy-related risks may be compared to more familiar risks of a different nature (p. 39). The study avoided comparison of energy-related risks to non-energy risks because it was believed to have little pertinence to energy policy decisions. Rather, the first two approaches were followed, with emphasis given to the comparison of similar types of risks from different energy technologies and strategies.

The Panel on Risks of Energy Systems, noting the matching of risks may be difficult, concluded that such decisions call for the exercise of judgment (p. 423).

Energy policy must be formulated with the knowledge available at the time of formulation. Even were such knowledge greater than it is today, difficult decisions would still have to be made. The risks of various energy systems are of different types and cannot all be reduced to common measures. Moreover, judgment will continue to dominate these decisions (p. 422).

Although many quite different types of risks are incurred in the operation of an energy system, the Panel states that the evaluation of total damage based on all contributing factors must be a matter of judgment and that additional judgment must be brought to bear on decisions about "acceptable levels of risk."

In its section on methods and analysis of study projections, Energy In Transition again emphasized the importance of judgment. "Judgment alone decides whether some factors are important and whether others can be safely neglected, at least in the first approximation (in designing and employing models). Models cannot predict the future, but simply represent statements contingent on the consequences of assumptions and public policies. Nor can the consequences be regarded as rigorously deduced conclusions from the set of explicitly stated assumptions. Many detailed judgments accompany reason in these cases: judgments about the costs of new technologies; or the rate of future resource

discoveries, or the likely responses of producers and consumers, etc." (p. 529).

Thus, in the view of Energy In Transition, judgment will continue to predominate in decisions among energy alternatives and it is unlikely ever to be superceded by formal analysis of risks and benefits (or by the application of econometric models). This fact underscores the importance of an informed and open public debate (p. 490).

7. Risk-Cost-Benefit Considerations - Energy In Transition compares risks, costs and benefits primarily on a judgmental basis rather than via any formal quantitative analytical mechanism. Interestingly, the initial request from ERDA asked that the National Academy of Sciences undertake "a detailed and objective analysis of the risks and benefits associated with alternative conventional and breeder reactors as sources of power" (p. ii). The Governing Board of the National Research Council, however, preferred a "comprehensive and objective study of the role of nuclear power in the context of alternative energy systems" (ibid.). ERDA accepted the NAS/NRC revised objective, indicating their acceptance of the fact that any detailed and objective analysis of risks and benefits would be quite difficult if not impossible except on a judgmental basis gained by placing the problem in a broader sociopolitical context.

The study itself notes that the sociopolitical aspects of energy planning need to be much more thoroughly explored. For example, conventional analysis of the risks associated with energy systems and strategies gives relatively little emphasis to the distribution of risks and benefits although from a sociopolitical standpoint the distribution of these risks and benefits may be more significant than the net effects (p. 58).

The problem of conducting risk-benefit tradeoffs was recognized by the study as being acute: subjective estimates of the magnitudes of the risks had to be balanced against equally subjective estimates of the benefits which nuclear power or other energy source might provide in easing the world's energy supply problem (p. 219). Furthermore, as the Panel on Risks of Energy Systems notes, "there are limitations to the control of risk. As the reduction

in risk becomes more refined, the incremental benefit eventually diminishes and the cost rises disproportionately. No amount of regulation can insure a risk-free society, nor should it be assumed that such a goal is desirable" (p. 427). However, since facts are frequently insufficient for clear-cut quantitative analysis, estimates of costs and benefits may become highly speculative. This is particularly true if sociological data are involved.

Although the panel for the most part did not undertake detailed cost-benefit comparisons, it did observe that as standards (for exposure, for example) are driven lower and lower by regulation, protection tends to become more costly and cost-benefit considerations become important. Thus, it might well be that unnecessarily costly environmental restrictions would lead suppliers to use alternative technologies that had greater risks.

The Panel on Risks of Energy Systems did employ cost-benefit analysis of a more quantitative nature in its consideration of certain health risks. For example, they questioned the EPA position that permissable levels of exposure to radiation should be as low as regulation can drive them "at some practical cost." The matter of what cost is "practical" is a matter of opinion. They called attention to the opinion of the Nuclear Regulatory Commission that $1,000 per reduction of one person-rem is a favorable cost-benefit ratio (10 CFR 50). Using a risk of cancer death estimated to be 2×10^{-4} per person-rem, the NRC policy thus entails a cost of 5 million dollars per avoided cancer death (p. 443).

However, such quantitative assessments are the exception rather than the rule, both in Energy In Transition as a whole and even in the chapter by the Panel on Risk of Energy Systems.

In concluding this discussion on risk-cost-benefit trade-offs, it is enlightening to include a comment of committeeman Kenneth E. Boulding (p. 615): "a curious general characteristic of the report, that reflects almost all discussions of this subject, is that the "risk" always involves (uncertain) costs or negative goods, whereas benefits are often implicitly assumed to be certain. Under these circumstances, risk of the loss of benefits can easily be grossly underestimated and this can distort the whole judgment in regard to the net

benefits of different policies. If over-estimation or over-visibility of the real costs of different forms of energy leads to a loss of the benefits - often invisible and taken for granted - we may find ourselves in very bad shape...there is something (about) the discussion of this problem that takes benefits for granted and puts all the emphasis on uncertain costs."

VI. ENERGY FUTURE

1. Risk Definition - Energy Future gives scant attention to the subject of risk assessment. The book, rather, is focused on energy supply, searching for solutions to the difficulties raised by the Arab oil restrictions. Physical risks are treated in a disconnected fashion; indeed, the word "risks" does not even appear in the index or table of contents. The book has much the flavor of a political tract, favoring conservation and solar energy as the most likely solutions for the future energy scarcity envisioned.

Although the book does mention safety problems in a general sense, particularly those associated with nuclear energy, the work risk, when it occurs, seems to have more the connotation of an economic or financial loss rather than a hazard to health and safety or danger to the environment. Thus, the risk, in the sense used by Energy Future, confronting the United States is that we will not find a satisfactory energy replacement for oil. The main result is a loss to the national economy.

Just as the word risk appears only rarely and then with the general connotation of economic or financial loss, there is also no real risk assessment in Energy Future, except in a very general sense. There is certainly consideration of the risky international situation posed by the energy problem, and the pros and cons of various alternative energy sources are reviewed in seeking to answer that problem. In this sense, "risk" assessment is made. But insofar as an assessment is concerned which would contribute to the safety goals paper by Mattson et al., Energy Future offers minimal substantive discussion.

2. Fuel Cycle Coverage - Energy Future does report upon some of the (primarily) environmental problems posed by the various portions of the nuclear fuel cycle. Chapter 5, "The Nuclear Stalemate " (P. 108 et seq.),considers

such problems from a primarily historical viewpoint. Most of the chapter is taken over with a discussion of the pros and cons of nuclear power as argued on either side by critics and supporters. In the infrequent references to safety risks, little is done to analyze them. Technical details of the various risks embodied in the nuclear or other fuel cycles of nuclear cost and other fuels are generally lacking. As an example of one of the statements directly concerned with safety and nuclear fuel-cycle elements, Energy Future states "There does not appear to be any safety problem associated with indefinte, interim spent-fuel storage" (p. 134).

Typical of the lack of depth with which Energy Future considers the risks of the nuclear fuel cycle consider the following: "The hazards of waste disposal and nuclear weapons proliferation are only the most recent in a long series of charges leveled against nuclear power" (p. 109). The succeeding discussion considers the problem presented rather minimally in only brief terms: "on one side are government and business leaders and their allies from the scientific and engineering communities - the nuclear advocates - while on the other side are the oponents of nuclear power who ask such questions as; what are the effects of low level radiation; what is the probability of a major accident; what would the consequences be of such an accident; can the dangerous waste products of nuclear power be permanently isolated from the environment; etc." (pp. 109-110). And again, "since the early 1970's it has been virtually impossible to make any substantive statement about reactor safety that would not be challenged by either nuclear advocates or nuclear critics as inaccurate or misleading" (p. 122).

In considering the coal fuel cycle, Energy Future states "Serious environmental problems exist in practically every part of the coal system. During production, underground mining can result in acid drainage, subsidence, and coal workers' pneumoconiosis (black lung disease). Surface mining requires careful reclamation...transportation of coal creates its own set of environmental effects, including disruptions of communities by unit trains and possible depletion of water by slurry pipelines. Finally, coal consumption generates still another set of serious environmental hazards including emissions of

sulfur dioxide, nitrogen oxide, trace elements and carbon dioxide into the atmosphere...and chemical discharges into the water and the solid-waste-disposal problem of coal ash (pp. 91-92).

3. Risk Assessments - In keeping with the interpretation of "risk" as including social, economic and environmental effects as well as safety impacts, there are some statements in the book worthy of reporting, of which the following are typical.

"...nuclear power offers no solution to the problem of America's growing dependence on imported oil for the rest of this century. If nuclear and other conventional energy sources cannot substantially increase their contribution to U. S. energy supplies, the nation must look to the unconventional alternatives: conservation and solar power" (p. 135).

"...imported oil poses too many risks to be calmly accepted...We have tried to put a figure on the "real" cost of a barrel of imported oil...Our best estimate of the costs...came out at $30 to $40 a barrel in 1979 dollars" (p. 9).

"Whatever the outcome of U.S. oil-pricing policy, an important fact should not be lost sight of: even world market prices would still be much too low to reflect the real risks caused by oil imports. These include such things as higher oil prices, slower economic growth, and international political tension, virtually all participants in the debate having lowered the costs associated with these risks" (p. 47).

Considerable emphasis is placed upon public perception of the energy shortage. For example, "the public at large seems to doubt the reality of the gas shortage, to suspect corporate manipulation, and to question the rationale for higher gas prices" (p. 75).

Energy Future emphasizes the social problems associated with the coal industry. Fundamental issues of labor productivity and motivation, managerial thinness, distrust of coal operators, and social insecurities still remain in the coal industry, presenting them with difficult, although not impossible, operating barriers (p. 97).

The overall energy problem assessment proposed in Energy Future is contained in the following: "The prospect for dramatic increases in domestic supplies from four conventional fuels - oil, gas, coal, and nuclear - is bleak"

(p. 221); and again, the cornerstone of our thinking is that conservation and solar energy should be given a fair chance in the market system to compete with imported oil and the other traditional sources (of energy)" (p. 226).

4. Risk Assessment Methodology - Energy Future was written by two editors and five authors who, according to the acknowlegement, interviewed some 1,000 or more business executives, government officials, labor union leaders, analysts, academics and other specialists (p. vii).

The book's study method can best be described as argumentative, based on historical and (popularized) economic analysis, with most of the data coming from other publications and, presumably from the more than one thousand interviews noted above. The latter are never identified since the interviewees were assured of anonymity.

In the authors' words, "We have...tried to apply what might be called a managerial perspective, broadly defined. We attempt to assess priority and potential, evaluate costs and risks, compare returns on different forms of investment, examine how people and resources can be effectively mobilized, and suggest what can be done to mediate conflicts among competing interests... We explore energy questions from the bottom up, examing not only the technical and economic models and possibilities, but the political and institutional realities as well" (p. 8). The authors particularly note that "predicting oil prices and their economic effects involves art, as well as science, requiring sensitivity to the political situation as well as to straight economics" (p. 47).

Most data employed by Energy Future are secondary, being drawn from other sources. For example, Table I-1, a critical table for their discussion, is taken from the Department of Energy, Energy Information Administration, Annual Report to Congress, Volume 3, 1977. And in attributing statistical sources for data employed in Chapter 2, "After the Peak: the Threat of Imported Oil," are drawn from a variety of secondary sources, including the British Petroleum Company's statistical review of the world oil industry and the Central Intelligence Agency's "International Energy Statistical Review of April 19, 1978" (p. 269).

Energy Future emphasizes the uncertainty confronting any energy policy analysis. They observe that "the task of policy formulation is made even more difficult by the vocal and sometimes quite bitter debates that now becloud the American political process...the disagreements can be striking... How can governments make reasonable choices when confronted with such uncertainty" (p. 7).

The authors state that they based the book on three major premises: (1), they viewed the oil crises of 1973-74 and 1978-79 not as isolated phenomena but rather as part of a major transition for both energy producers and users; (2), they firmly adhered to the view that healthy economic growth is essential and that reliance on the free market is the best way tc achieve it; and (3), in their view, thinking about energy raises important questions about income generation and distribution and that s me attempt, however rough, had to be made to assess the total "social costs" embedded in the problem (p. 8).

In their forecasts, Energy Future based their projection of the future upon seven key uncertainties: (1), the rate of economic growth in the U. S. and elsewhere in the world; (2), energy usage per unit of economic output; (3), oil production in Saudi Arabia which they identify as the controlling uncertainty; (4), oil production in other OPEC nations; (5), oil production in non-OPEC nations; (6), contributions from conventional energy sources; (7), and contributions by non-traditional sources, such as shale oil, solar, etc. The authors note that "different assumptions can produce enormously different forecasts" (p. 37).

The authors also state that "all forecasts should thus be offered with some modesty."

Uncertainties in more technical areas are treated by Energy Future as disputes between experts. For example, in their discussion of liquified natural gas (LNG) the authors state: "Some scientific experts have claimed that the handling and transportation of LNG poses great hazards to the public... equally reputable scientists support the gas industry's view that such risks are under control..." (p. 80).

In considering the nuclear stalemate, the authors state: "in my opinion, no credible bottom line comparison can be extracted from any existing data... it is still possible to assert that atomic energy is or is not competitive by choice of assumptions that suits one's interests" (p. 124).

5. Safety Goal Treatment - Since there is very little discussion of risks, other than of economic or financial loss, there is limited discussion of safety goals per se. "Resolution of the nuclear safety controversy will require more than a consensus of established scientific and engineering judgment" (p. 123). Yet another is: "the burden is now plainly on the nuclear advocates to provide answers to specific technical criticisms of standards and practices for reactor design and operation and inspection. In addition, the burden is on the Department of Energy to implement a waste disposal program that has the support of pragmatic nuclear critics as well as nuclear advocates" (p. 135).

In the view of this reviewer, these examples present at best rather indefinite safety goals and, in terms of the paper by Mattson et al., highly qualitative rather than quantitative. They could also be classed as society-oriented rather than individual-oriented goals but any further classification in terms of the reference categories of goal forms is inappropriate.

6. Goal Formulation Criteria - Generally, Energy Future supports the position that decisions must be arrived at with active public participation. Indeed,a recurring theme throughout the book is that such decisions cannot be left to the experts. The public must be admitted and listened to. The reviewer is completely in accord with this view. However, Energy Future does not say specifically how the public is to help in that decision process other than by being consulted in some general,undefined way. Explicit decision criteria for dealing with safety goal formulations are absent in this book.

The views of Sergio Koreisha and Robert Stobaugh, authors of the appendix,"Limits to Models", are that "econometricians build and operate models which consist of mathematical equations based upon relationships derived from economic theory and estimates based on historical statistical relationships.

The use of such models have often been characterized as "looking forward through a rear-view mirror"... The technologists meanwhile base their analysis mostly on engineering costs estimates... Results of both types of formal models... are often modified by personal judgment to make the results correspond more closely to the specialist's understanding of the real world" (pp. 234-235). "The major studies since 1973 have given us predictions about the U.S. energy situation that have consistently been more optimistic than the reality has proven to be" (ibid.). Public officials increasingly fall back on the computer model as their ultimate authority. The authors conclude that energy policy has been effected to an important extent by formal models (in a presumably negative fashion) (p. 235). "...It should be clear that the predictions derived from energy models are subject to a great deal of imprecision" (p. 262). Models can be extremely useful in the formulation of energy policy, and they allow decision-makers to test their ideas "on paper" without manipulating the actual system. "But a model is not reality" (p. 265).

7. Risk-Cost-Benefit Considerations - Energy Future uses the word "risk" more in an economic or financial loss sense than as directed to health and safety considerations. The authors employ general economic, analytical methods for developing "social costs." External costs in the form of environmental and health problems are recognized but not quantified.

For example, "nuclear energy has a set of external costs even more controversial" (p. 220). How, specifically, are they to be determined? Such general statements are supported by equally general statistics. Energy Future asks "what are the total costs and benefits involved in any decision..." (p. 8). But they do not answer the question, except in generalities.

VII. JOBS AND ENERGY

1. Risk Definition - As its name suggests, the concern of Jobs and Energy is for the employment and economic impacts of nuclear power conservation and other energy options, with primary emphasis upon employment. Practically

no consideration is given to health or safety effects. There is, as would therefore be expected, no definition of the word risk and it is rarely used in a health or safety context. Rather, Jobs and Energy is concerned with the risk of unemployment or more precisely with comparative employment corresponding to the various energy options.

2. Fuel Cycle Coverage - One of the few references to health and safety risks is in the introduction to the book. "The risks of toxic leakage from nuclear waste dumps and the hazards of uranium mining and milling operations have become a matter of increasing concern. The health effects on workers and surrounding communities of exposure to low-level radiation are the subject of intense debate in the scientific community. It may be decades before definitive analysis is possible. Furthermore, the possibility of accidental public contamination by large amounts of radioactive substances poses a continuing threat to our health and environment" (pp. 2-3).

3. Risk Assessments - Two general assessments are made of risks in the safety sense. One relates to coal and the other to nuclear energy. In the first, the book asserts that increasing use of coal poses serious environmental health and safety problems. "Underground coal mining is extremely hazardous..." (p. 2). The report also notes that coal combustion releases large amounts of heat and pollutants which have contributed to acidity of rainfall in the northeastern United States (ibid.).

Notice is made of maintenance requirements and equipment malfunctions of nuclear plants which have caused the installations to remain shut-down for longer periods than anticipated causing increased costs. In addition, attempts to insure health and safety have also added unanticipated (but undefined) costs (p. 2). For example, workers may fall off roofs or ladders during installation of solar equipment (p. 4). It is hard to find any other statements related to risks to health and safety in Jobs and Energy.

4. Risk Assessment Methodology - Jobs and Energy defined the energy problem as the challenge of meeting our social and economic goals with a minimum use of energy. The central question posed is, "What are the long-term employment effects of a region-wide emphasis on conservation/solar as opposed to

construction of additional nuclear generating capacities?" (p. i). Jobs and Energy's approach constitutes a highly detailed economic analysis of one specific geographic region: Nassau and Suffolk Counties on eastern Long Island. There is little discussion in the book on uncertainty regarding installation costs or cost savings, or rate of customer acceptance over time.

Jobs and Energy makes substantial use of primary data, that is, data developed expressly for the study and not borrowed from other sources. Considerable secondary sources are also used.

A detailed description of the methodology employed by the economic analysis of Jobs and Energy is given in appendices A through G inclusive. That methodology takes into account: on-site employment; multiplier employment; and employment resulting from increased discretionary income spending (p. 36 and appendices, pp. 161-294).

5. Safety Goal Treatment - No safety goals are considered implicitly of explicitly.

6. Goal Formulation Criteria - Appendices A through G are replete with decision criteria employed in Jobs and Energy's economic analysis. However, since these decisions do not relate directly to nuclear safety, or indeed to the safety of any of the energy options considered, there is little interest in their further discussion here.

7. Risk-Cost-Benefit Considerations - Jobs and Energy has a highly detailed and systematic cost-benefit analysis. For example, Appendix C describes in detail the cost-benefit analysis of the conservation scenario (p. 227 et seq.). Thirty-four measures were included in the corresponding conservation scenario, which were chosen from a list of well over 100 residential energy conservation and solar energy opportunities.

VIII. COMPARATIVE REVIEW

Table 1 presents an overall comparative summation of certain attributes of the seven books reviewed, insofar as each book relates to the concepts of safety goal formulation presented in the paper by Mattson et al. on, "Concepts, Problems and Issues in Developing Safety Goals and Objectives for Commercial

Table 1. -- Summary of Selected Review Aspects Related to Risk Assessment and Safety Goal Formulation as Found in Seven Institutional Studies on Nuclear Power and Alternative Sources of Energy

REVIEW ASPECT ↓ / STUDY REVIEWED (Short Title) →	1. Nuclear Moratorium (IEA/ORAU)	2. Issues & Choices (MITRE)	3. The Next 20 Years (Rff)	4. America's Future (Rff)	5. Energy in Transition (NRC/NAS)	6. Energy Future (Harvard)	7. Jobs & Energy (CEP)
1. Risk[+] Definition							
a. Explicit	--	--	--	--	X	--	--
b. Implicit	X	X	X	X	--	X	X
2. Fuel Cycle Coverage							
a. All elements	X	X	--	--	X	--	--
b. Power generation	X	X	X	X	X	X	--
c. Some other elements	--	--	X	X	--	X	X
3. Risk Assessments							
a. Nuclear	QN	QN	QL	QL	QN	QL	QL
b. Coal	QN	QN	QL	QL	QN	QL	QL
c. Other fossil	QN	--	QL	QL	QN	QL	--
d. Solar, hydro & other	QL	--	--	QL	QL	QL	QL
4. Risk Assessment Methodology							
a. Mathematical models	X	--	X	--	X	--	--
b. Judgmental assessments							
(i) by explicit rationale	X	X	X	X	X	X	--
(ii) by assertion	--	X	--	--	--	X	X
5. Safety Goal Treatment							
a. Explicit goals and forms*	X	--	--	--	X	--	--
b. Only indirect information	--	X	X	X	--	X	--
6. Goal Formulation Criteria**							
a. Direct information	X	--	--	X	X	--	--
b. Indirect information							
(i) Safety improvement possibilities	--	X	--	--	X	--	--
(ii) Social acceptance issues	X	X	X	X	X	X	--
(iii) Other	X	X	X	X	X	X	--
7. Risk-Cost-Benefit Considerations[++] in Comparing Energy Options							
a. Risk comparisons	X	X	--	X	X	--	--
b. Cost comparisons	X	X	X	X	X	X	X
c. Benefit comparisons	--	--	--	--	X	--	X
d. Tradeoff considerations							
(i) Risk-cost tradeoffs	--	--	X	--	X	X	--
(ii) Risk-cost-benefit tradeoffs	--	--	--	X	X	--	--

[+]The treatment of "risk" may include social, economic and other environmental values at risk as well as safety and health effects.

[++]Costs and benefits include more than dollar impacts; regarding societal interests, costs are any adverse impacts and benefits are any desirable impacts.

*With attention to goal forms proposed by Mattson et al. (op. cit., pp. 11-15).

**With attention to decision criteria for evaluating alternative goal formulations proposed by Mattson et al. (op. cit., pp. 5-10).

LEGEND:

X Denotes information present for the review aspect.

-- Denotes information absent or insubstantial for the review aspect.

QN Quantitative risk assessment.

QL Qualitative risk assessment.

NOTE: When many risk assessments were made, the authors generally used both quantitative and qualitative modes; accordingly, the tabular notations, QN or QL, denote the reviewer's impression of the more dominant mode.

Nuclear Power." Table 1 employs the same 7 categories used in reviewing each of the seven books: risk definition; fuel cycle coverage; risk assessments; risk assessment methodology; safety goal treatment; goal formulation criteria; and risk-cost-benefit considerations.

The judgments reflected in Table 1 are those of the present reviewer. An X is placed in the appropriate element of the chart where the particular book provides at least a modicum of attention. Each book necessarily presents a variety of shadings of such attention. Where there is no appreciative relevance, a double dash (--) is entered on Table 1.

A few explanatory remarks are in order. First, it must be understood that the treatment of "risk" may include social, economic and other environmental values at risk as well as safety and health effects. However, the principal emphasis in reviewing these studies has been on the more conventional connotation of safety and health effects although harmonization of safety goals with other societal interests and national objectives is regarded as highly important (see Mattson et al., pp. 9 and 17-20). Second, costs and benefits include more than dollar impacts; regarding societal interests, costs are any adverse impacts and benefits are any desirable impacts. In this sense, the book, Jobs and Energy, is directed entirely to the question of the benefits in the form of jobs to be associated with nuclear and non-nuclear energy options. However, as risks per se are not considered explicitly (although unemployment is an implicit risk) Jobs and Energy is of value to a comparative analysis of safety and health risks only insofar as the treatment of benefits would be germane to a harmonization of safety goals with other societal interests or national objectives. Third, the explicit goals and forms considered have been selected to be compatible with those of the reference report by Mattson et al. Fourth, decision criteria for evaluating alternative goal formulations have also been selected so as to be compatible with the reference report.

The seven review aspects are, for the most part, self explanatory or self evident, particularly when considered in conjunction with the preceeding four considerations of the previous paragraph.

"Risk definition" is subdivided into explicit and implicit definitions. It will be observed from Table 1 that only one book, Energy In Transition, offers explicit definitions of risk.

"Fuel cycle coverage" is subdivided into all elements and some elements. A degree of reviewer judgment is involved in this categorization since the majority of the books at least mention the major fuel cycle elements but only three consider all elements in depth and those three limit their consideration primarily to nuclear and coal fuel cycles.

"Risk assessments" is meant to reflect substantial statements regarding the risks to be associated with nuclear, coal, other fossil and other fuel sources. The latter category includes solar, hydro-electric, etc.

The "risk assessment methodology" category is subdivided into mathematical models and judgmental assessments. The latter is in turn subdivided into explicit rationale and by mere assertion. Two of the books are noted as having some risk judgments provided by assertion and still other risk judgments are accompanied by explicit rationale.

The safety goal treatment is subdivided into explicit goals and indirect information. Even the two books shown as presenting explicit goals should be understood to present those goals more often than not, in an indirect context, particularly in its conclusions and recommendations. None of the books specifically studied safety goals per se. The subject of risks was universally approached from the standpoint of what the risk was rather than what it ought to be.

Goal formulation criteria are subdivided into direct information and indirect information. The latter category in turn is further subdivided into safety improvement possibilities and social acceptance issues. Some thought was given to including yet a third subdivision "other," but that category was so inexplicit and its relevance to the seven books so uncertain as to dictate its exclusion.

The final category "risk-cost-benefit considerations" is subdivided into risk, cost and benefit comparisons (three subcategories) and tradeoff considerations. The latter subdivision is further subdivided into risk-cost tradeoffs

and risk-cost-benefit tradoffs. A true risk-cost-benefit tradeoff in the economic sense was to be found more implicitly than explicitly. Indeed, the categorizations of the seven books in the four subcategories is, to a certain extent, arbitrary in that to a point all books made certain comparisons of these considerations, whereas tradeoffs were approached gingerly, if at all. All these categorizations reflect the reviewer's judgment as to the significance of the comparisons and tradeoffs.

IX. CONCLUSIONS

In the reviewer's opinion, four conclusions stand out when conducting an overall comparison and assessment of the seven books reviewed, insofar as they pertain to the goals and objectives of the reference paper by Mattson et al.

The four conclusions are: (1), none of the seven books reviewed presents a comprehensive description, recommendation or selection of safety goals -- rather, most of the studies attempted to detail probable risks; (2), risk-cost-benefit tradeoff analysis in formulating safety goals would be consonant in whole or in part with the explicit or implicit methodologies employed or recommended by the majority of the seven books; (3), the majority of the books recognized and emphasized the importance of social, that is public, participation in the safety goal decision process; (4), those same books implicitly, if not explicitly, concur that one of the vital decision criteria in choosing between nuclear and other energy options is the social acceptability of risks to safety and health.

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