UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, D. C. 20555

May 7, 1980

The Honorable Victor Gilinsky
Commissioner
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Dr. Gilinsky:

This letter is in response to your letter of December 18, 1979, in which you raised several questions about the ACRS letter of December 11, 1979, concerning the pause in licensing.

1. In its letter of December 11, 1979 the Committee said:

> "The ACRS believes that the risk to the public health and safety which is posed by the operating nuclear power plants is comparable to or probably smaller than the risk posed by other existing methods of generating the same quantity of electricity. The ACRS also believes that this risk is comparable to or less than that posed by many other technological activities of society."

You have asked to "know the Committee's technical basis for the risk comparison with other methods of electricity generation." The attachment to this letter, which was prepared by three ACRS Fellows, provides some details of the technical basis for this ACRS opinion. In brief, there have been a number of studies during the past several years in which the health effects of various methods of generating electricity have been assessed and compared. Such comparisons include quantitative evaluation of the occupational and public health impacts of each of the steps (e.g., mining, transportation, production) involved in the different methods of electricity generation, and evaluations of the different ways (e.g., respiratory illness, cancer, genetic consequences) in which each of these impacts manifests itself. However, all such studies are subject to large uncertainties due to their incomplete nature and to limitations on our knowledge of the health effects of various pollutants and the probabilities of serious accidents.

Air pollution due to combustion of fossil fuel represents a potentially very large health effect which includes many complex factors. Only a few epidemiological studies provide the basis for current risk estimates from such air pollution, and these studies are subject to controversy. However, it is clear that carcinogens, mutagens, and toxic substances of various kinds are emitted in large quantities from the combustion of coal, and the bulk of expert opinion is that a substantial, albeit uncertain, effect on health can result. The application of modern airborne pollutant controls would reduce this risk.

Essentially no risk estimates are available for large accidents from hydroelectric generation. However, knowledge of the failure rate for large dams, of the limitations of safety criteria used in dam design, and of the potentially very large number of fatalities which could result from the failure of various dams, indicates that the expected value, measured in terms of fatalities per MW-year, should not be insignificant. The generation of electricity from liquefied natural gas should fall in a category similar to that for hydroelectric generation.

Of course, the risks of major economic difficulties or even war which are associated with the use of oil are difficult to assess, just as are the risks of nuclear weapons proliferation from the use of LWRs. Also, the increase in atmospheric CO_2 concentration due to combustion of fossil fuels is unavoidable. Its effect upon the temperature of the earth, agreed to by nearly all experts, and the consequent effects are uncertain, but potentially catastrophic. Such risks were not explicitly factored into the available published risk comparisons or into the ACRS comment. The difficulty of including genetic effects or the potential for depriving society of access to the use of land and other resources further complicates such assessments.

Coal, oil, and nuclear plants all introduce risks from the acquisition of fuel, over and above occupational risks for which data exist. While estimates exist for the risk from the tailings of uranium milling operations, the ACRS is not aware of quantitative studies of chronic risks to the public health from the mining of coal, for example, from acid mine drainage. While considerable emphasis has been given to the need for careful, long-term disposal of high-level radioactive waste in the future, relatively little attention has been given to risks from the ongoing disposal of large quantities of solid wastes from coal-fired plants, and such risks have generally not been included in risk comparisons.

For plants to be constructed, nuclear and nonnuclear, a comprehensive comparison should allow for all contributions to risk, including those resulting from the acquisition of materials of construction, the fabrication of components, and the construction of the plant. Also, any risk comparison should allow uniformly for anticipated improvements in safety for each type of plant. However, the ACRS letter of December 11, 1979 referred to those LWRs whose construction is nearly complete; hence, a comparison of the risks from operation of such plants with the risks from operation of existing or newly completed coal, oil, or hydroelectric plants is probably relevant to your question.

In each study summarized by the ACRS Fellows, the risk to the public health and safety arising from the operation of nuclear power plants was assessed to be smaller than the risk posed by other existing (coal and oil) methods of generating the same quantity of electricity. Only if relatively pessimistic assumptions regarding nuclear safety are employed, is the risk of nuclear energy comparable.

For example, one estimate [1] of the health effects of producing 10^{10} kWh of electricity in 1975 gave the following results:

From Coal:	Estimated deaths	10-200
	Estimated disabilities	300-500
From Oil:	Estimated deaths	3-150
	Estimated disabilities	150-300
From Natural Gas:	Estimated deaths	0.06-0.3
	Estimated disabilities	4-27
From Nuclear:	Estimated deaths	1-3
	Estimated disabilities	8-30

The recent study by the Committee on Nuclear and Alternative Energy Systems of the National Academies of Science and Engineering considered the period 1985-2010 and arrived at similar conclusions.[2]

The ACRS has noted some of the constraints and shortcomings in such studies, such as the lack of actuarial data and the uncertainties in the epidemiological models employed. In all the studies reported, the estimated risk due to catastrophic nuclear accidents was based on WASH-1400 and is subject to large uncertainties. However, since the contribution of nuclear accidents to the estimated deaths and disabilities is extremely small, this contribution would have to be increased by a factor of about five hundred in order to make the total risk from nuclear comparable to that from coal. The next six to twelve reactors to be ready for operation are at sites which are neither the most remote nor the most densely populated. The ACRS expects the consequence calculations of WASH-1400 to be roughly applicable, although a conservative view might lead to use of an additional factor to allow for differences of opinion on the effectiveness of evacuation, the effects of low level radiation, etc. The conservative application of a factor of 20 to the probability of core melt and a factor of 5 to the consequences as estimated in WASH-1400 would still leave the health and safety effects of these LWRs smaller than or comparable to those estimated for oil or coal.

2. You have stated, "I would also like an explanation of the relevance to decisions on prospective operating licenses of the comparison with other technical activities." The ACRS believes that it is relevant to consider the risk from electricity generation in some broader societal context for a variety of reasons. All technological activities are not equally beneficial to society, nor do they pose equal risks. Nevertheless, an examination of comparative risks provides insight into the risk levels society has accepted, tolerated, or imposed; it also provides a partial insight into where the limited resources of society can be spent in a more nearly optimum fashion to reduce risk. Studies by Sinclair [3], Morlat [4], and Schwing [5], among others, provide some good examples of disparate societal expenditures to reduce risk.

   If the risks from operating nuclear power plants to individuals or society were large compared to those posed by other ongoing technological activities of similar societal benefit, and if one had anticipated that the licensing pause would produce a significant reduction in this larger than "normal" risk, one might need some compelling motivation in order to grant additional operating licenses without a pause, even for interim operation at medium power levels for testing purposes. On the other hand, if society is routinely accepting, tolerating, or imposing risks from other ongoing activities which are much larger than those from light water reactors of current design, this fact should provide one significant input into the decision making involved in the pause.

   The ACRS believes that society continues to accept large, acute and chronic risks from other technological activities; risks which are larger than those posed by LWRs. For example, dams which have been judged to be hazardous by the U.S. Army Corps of Engineers remain full of water and the operation of many dams has been tolerated, on at least an interim basis, even though the estimated likelihood of failure lay between 1 in 1000 and 1 in 100 per year. A similar situation exists for many thousand seismically substandard large buildings in Los Angeles and elsewhere. There are many other examples of substantial technological risks to be found throughout the United States, particularly from the storage and the disposal of hazardous chemicals.

   In its letter of December 11, 1979, the Committee said:

   > "The ACRS has, in the past and again since the Three Mile Island accident, recommended that the NRC and the nuclear industry take major steps to improve the safety of nuclear power reactors. The ACRS believes that it is proper that nuclear power be safer than other comparable technologies. The Committee has sought this goal. It believes that the country wants a higher level of safety for nuclear reactors and is willing to pay for it. The ACRS also believes that the country wants a higher degree of assurance as to the level of safety which is being attained."

3. In its letter of December 11, 1979, the Committee said in part:

"While the ACRS believes that interim licensing of the next six to twelve nuclear power reactors for operation on the same basis as is now being accepted for currently operating reactors would not pose undue risk to the public health and safety, the ACRS favors the consideration of additional improvements in their safety on a case-by-case basis, as recommended by the President's Commission."

You have stated, "I would like to know what the Committee takes into account in defining 'undue risk.'"

The use of the term "without undue hazard" and "without undue risk" by the Atomic Energy Commission and the ACRS dates back more than two decades. The phrase, "without undue risk" was incorporated into Section 50.35(a) of 10 CFR 50, Code of Federal Regulations, more than fifteen years ago. The AEC Regulatory Staff provided a largely legalistic discussion of the meaning of "without undue risk" to the Atomic Safety and Licensing Hearing Boards for Malibu (Docket 50-214) and Fort St. Vrain (Docket 50-267) in 1966 and 1968, respectively.

In 1973, in connection with the publication of WASH-1270, "Anticipated Transients Without Scram for Water-Cooled Power Reactors," the Regulatory Staff proposed as a safety goal that the chance of a serious accident with consequences in excess of 10 CFR 100 be no greater than one in a million per reactor year for a large population of reactors. This philosophy was incorporated in part into the Standard Review Plan and was stated to the Congress by L. Manning Muntzing, the then Director of Regulation, without adverse comment by the Atomic Energy Commission itself.

As you know, during hearings of the Joint Congressional Committee on Atomic Energy on March 2, 1976 you stated that there had never been an explicit quantitative safety standard set by the Congress, by the AEC, or by the NRC, and that you thought there was a need for such a standard. The ACRS was asked by the Joint Committee on Atomic Energy to comment on this statement. The ACRS response of April 12, 1976 stated in part:

"The ACRS believes it will be difficult to establish such safety standards and that it will be impossible to apply them without considerable reliance on engineering and scientific judgment. The ACRS has endorsed the development of a simple probabilistic risk standard as a reasonable starting point with full recognition that there are various degrees of seriousness in postulated accidents and that, for the long term, a relation between acceptable probability and consequence may be needed. Also, there

> does not currently exist a well-defined means for factoring uncertainties pertaining to the estimation of low probability events into decisions using a quantitative probabilistic safety standard.
>
> "The ACRS believes that, for reactors to be constructed in the next several years a probability of less than one in a million per reactor year for an accident having serious consequences to the public health and safety is suitable as an interim objective."

The minutes of the April 1976 ACRS meeting show that the Committee agreed that a "serious" accident would be one having consequences equivalent to that of a fatal crash of a loaded commercial aircraft. It is noted that the Congress did not react unfavorably to the ACRS interim objective.

In its letter of December 11, 1979, the ACRS used the term "undue risk" in connection with the possible interim licensing of the next six to twelve nuclear power reactors. The ACRS does not yet have the benefit of systematic evaluations of the reliability of systems important to safety for each reactor in question, i.e., evaluations which the ACRS has recommended in the past and which the NRC is initiating now. Nevertheless, the Committee believes it unlikely that even those persons living closest to any of the reactors under consideration would be subject to a risk greater than 10^{-5} per year of early death from exposure to a large quantity of radioactive material following a serious accident, if those reactors meet the current post-TMI requirements. The Committee would expect this risk to be still lower from interim operation at limited power as recommended for consideration in its letter of December 11, 1979.

The ACRS anticipates that similar probabilities are applicable for the chance of a sizable population group receiving a large collective dose due to a major release of radioactive material.

While the ACRS has favored and continues to recommend that measures, as practical, be taken to mitigate potentially serious accidents, the ACRS believes that society has not in the past prohibited activities which pose the potential for low probability-high consequence events and that society is not and should not be so risk averse to such events that it incurs substantially greater risks or loses major benefits as a result.

In its letter of May 16, 1979 to Chairman Hendrie, the ACRS recommended that the Nuclear Regulatory Commission develop quantitative safety criteria for nuclear reactors. In its letter of February 14, 1980 to Chairman Ahearne on siting, the ACRS recommended that the NRC develop an overall safety policy. The Committee continues to believe that the definition of "no undue risk" represents a major policy decision which the Nuclear Regulatory Commissioners should take and present to the Congress and the nation to approve or disapprove.

4. You concluded your letter of December 18, 1979, as follows:

> "I must add that in reflecting on your advice on what does and does not 'pose undue risk' I am reminded of a meeting we had with the Committee soon after the Three Mile Island accident on whether or not to suspend operations at the plants with B&W reactors. No member of the Committee thought it necessary or desirable to suspend operation at these plants. The NRC staff later decided that a more conservative approach was required and recommended that the plants be shut down for necessary modifications. This difference in outlook is evident again today."

The ACRS wishes to make several observations in regard to this comment:

- It is to be expected that separate groups or individuals forming independent judgments on matters of safety will differ.

- During the last fifteen years, the ACRS has frequently been more conservative than the Regulatory Staff and the Commissioners themselves. This was true in 1965-66 when the ACRS recommended major improvements in pressure vessels, ECCS and primary system integrity. It was the case when in 1966 and the thirteen succeeding years the ACRS recommended the development and implementation of measures to mitigate core melt accidents. It was the case when in the late 60's and 70's the ACRS recommended improvements in design and increased preparedness measures beyond the low population zone for highly populated sites accepted for reactor construction. It was the case on Three Mile Island, Unit 2 with regard to instrumentation to follow the course of accidents. And it has been the case for the last few years in the Committee's efforts to put life into the program for research to improve reactor safety.

- No member of the ACRS had a technical basis for recommending shutdown of the B&W reactors based on the information available to the ACRS during its meeting in April 1979. During the days following the April ACRS meeting, the NRC Staff decided it was sufficiently concerned about the probability of a transient leading to a stuck open relief valve in B&W reactors that it would recommend reactor shutdown and a few specific modifications. The ACRS was not asked a second time and in view of further developments has not provided any opinion on the need for these specific actions on the time scale utilized. However, the Committee believes that there exists a large body of ACRS recommendations to which the NRC Staff and the Commission have responded far more slowly than the Committee believes was prudent.

The ACRS, therefore, does not agree with your conclusion, if you are suggesting that the NRC Staff or the Commission has generally adopted a more conservative position than the Committee.

Additional comments by Members H. W. Lewis and P. G. Shewmon are presented below.

Sincerely,

Milton S. Plesset

Milton S. Plesset
Chairman

Additional Comments by Members H. W. Lewis and P. G. Shewmon

The Committee has gone on record here with an estimate of 10^{-5} as an upper limit to the risk per year of early death for those living closest to a reactor. This number is based on no study of which we are aware, and we are dismayed that the Committee should invent an important number after the Commission has expended so much time, effort, and money to have this risk calculated as well as one could (Reactor Safety Study, WASH-1400). These calculations, such as they are, yield numbers two to three orders of magnitude smaller as best estimates of this risk.

After the above comments were written, the Committee also adopted the section assessing the risk from the next six to twelve reactors, and repeated the previous performance by inventing factors of twenty and five for accident probability and consequences, respectively. These are called conservatisms, but are, in fact, multiplicative factors with no solid basis. I believe that a Committee of the eminence and stature of this one has the responsibility to use in its reports only numbers which have an agreed scientific base, or at least, where this is lacking, to justify the estimate. Had these factors been chosen in the other direction, a righteous uproar would have ensued. I believe that if the Committee is going to adopt a position revising the WASH-1400 risk upward, it should do so as a result of a deliberate review of the current position. The only such review so far (The Risk Assessment Review Group) specifically eschews such a revision.

In addition, the Committee was asked to provide the "technical basis for the risk comparison with other methods of electricity generation." To be responsive to such a request, the comparison must be made even-handedly, and it is wrong to penalize or exalt any method. It is not proper to arbitrarily penalize nuclear power just because some calculations make it appear so much safer that one is embarrassed. Yet in the case in the previous note the Committee has chosen not only to assess the nuclear risk to a person living right next to a reactor (while not doing the same for alternate methods), but has then, on top of that, multiplied the nuclear risk by a factor of one hundred to one thousand. In this case the factor is "only" one hundred, but it is just as arbitrary, and does not lend itself to an objective answer to the question to which this letter was supposed to be responsive.

Attachment:
"A Survey of Risks of Alternative Fuel Cycles," by ACRS Fellows, J. M. Griesmeyer, D. H. Johnson, W. E. Kastenberg, April 28, 1980.

REFERENCES:

1. L. D. Hamilton and A. S. Manne, "Health and Economic Costs of Alternanative Energy Sources," IAEA Bulletin, 20, pp 44-57, August 1978.

2. National Research Council, "Energy in Transition 1985-2010," Final Report of the Committee on Nuclear and Alternate Energy Systems, 1979.

3. C. Sinclair, P. Marstrand, P. Newick, "Innovation and Human Risk: The Evaluation of Human Life and Safety in Relation to Technical Change (Centre for the Study of Industrial Innovation, London, 1972).

4. G. Morlat, "Un modele pour certaines decisions medicales," Cahiers du Seminaire d'Econometrie, Centre Nationale de la Rech erche Scientifique, Paris, 1970.

5. R. C. Schwing, "Technological Forecasting and Social Change," 13-333 (1979).

A SURVEY OF RISKS OF ALTERNATIVE FUEL CYCLES

28 APRIL 1980

ACRS Fellows:
J. M. Griesmeyer
D. H. Johnson
W. E. Kastenberg

ABSTRACT

Difficulties in assessing the risks imposed by different electricity generation techniques are presented. Specific aspects of the coal, oil, hydroelectric, and nuclear fuel cycles which are difficult to quantify are discussed. This is followed by a review of five recent comparative analyses. The results of these studies are compiled and presented as broad health effect assessments. Review of these studies indicates that the assessed risks of nuclear power are less than or equal to those of the primary alternatives. When the unquantified risk components are then considered, this relative assessment becomes more qualitative, but does not appear to change.

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1. INTRODUCTION

The generation of electrical energy has become an integral part of our society, resulting in both positive and negative impacts. Because of changing resources, energy options are subject to evolution which in turn bring about changing impacts on society. An essential ingredient in the formulation of responsible policy regarding choices of energy is an identification and quantification of their impacts for currently deployed and future options.

A measure of the negative impact of technical endeavors such as energy generation is the measure of risk. Although formal definitions of risk have been made [1-3], it is convenient here to be fairly general in its definition. In this discussion, risk is used as a measure of negative impact on society. It may be based on actuarial data (e.g., the number of people killed annually in automobile accidents) or it may be based on calculation using a model (e.g., the potential restriction of land use due to a nuclear reactor accident).

In this report, the current literature regarding the risks of conventional fossil fuel-electric and hydroelectric energy generation are summarized and compared to the risks due to conventional nuclear-electric generation. The major objective is to place the actual and potential risks of nuclear energy generation in perspective, so that they can ultimately be considered in the licensing process. This consideration might also include the allocation of limited economic resources. The use of a more expensive form of electricity production caused by increased licensing requirements which may not be cost effective could also lead to the unavailability of resources which could be used for risk reductions in other aspects of society.

Before proceeding with this summary and comparison, it is useful to comment on such an approach. The consideration of risks from electricity generation technologies in such a generic manner as advocated here should, at the least, provide a coarse measure for the comparison of the social costs of these options. If one option is denied, either through political decisions or due to lack of development of the resource or technology, its risks are replaced by risks from other options. It is important to note in this regard that even conservation may impose risk.

A prime difficulty in the study of energy related risks surfaces in the choice of an unbiased common denominator upon which to base the comparisons. Related difficulties include the lack of an established and accepted methodology for risk comparisons, the multidisciplinary nature of the problem, the different manifestations of the impacts for each option in terms of their associated health effects, and the enormous variance in the uncertainties in the risks of concern. It is fully expected that the treatment of these difficulties will provide the potential for disagreement in the general public as well as in the risk assessment community.

In Section 2, risks of the coal, oil, hydroelectric and nuclear fuel cycles are considered. Attention is given to problematic aspects which are the source of major uncertainties of assessing specific risks. Difficulties in establishing a common base of comparison of the diverse risks are discussed with detailed consideration given to specialized concerns such as the use of expected values for catastrophic phenomena.

Section 3 contains a summary of some recent assessments of the risks imposed by various alternative electricity generating options. The health effects are presented as ranges of expected values which encompass the individual analyses and generally represent accepted values. However, in light of the difficulties discussed in Section 2, the assessments necessarily contain omissions.

The final section of this report contains a brief summary, discussion and some concluding remarks regarding the risks associated with current electricity generating technology.

2. FUEL CYCLE RISK ASSESSMENTS

2.1 Introduction

An assessment of the risks from each electricity generating option must include consideration of the risks from each portion of the corresponding "fuel" (or full production) cycle. Only when such complete assessments are made and the uncertainties therein evaluated, can objective comparisons of the risks of energy options be made. As discussed below, such completeness may be an elusive goal; however, careful analysis of the quantified and unquantified risk contributors contained in recent analyses of various fuel cycles can provide insight into relative risks.

Elements of a fuel cycle that must be considered in a complete risk analysis would include, but not necessarily be limited to, fuel extraction, transportation, processing, conversion, and waste disposal. Each element may impact public health and safety, as well as the environment, through a variety of mechanisms; and common elements across fuel cycles will have different impacts.

2.2 Sources of Uncertainty: General

Nonrandom uncertainty is present in fuel cycle risk assessment because of the type and quality of the data involved, the nature of the component risks, the selection among and treatment of the varied impacts, and the selective omissions of component risks.

The analyses performed to date have utilized data that can be categorized as follows: a) those based on actuarial information and b) those based on models. In addition, some risks remain unquantified, either through omission of the parent hazards in the overall analysis or because of the lack of fundamental understanding of the particular phenomenon. The type of data used depends primarily on the nature of the risk.

One major aspect in the quantification of risk is a knowledge of human health effects. In particular, the health effects of fossil fuel plant emissions and the health effects of low level releases of radioactive material from nuclear plants contain uncertainty. A recent paper by Hamilton [4] reviews the major uncertainties in the health effects data for both types of emissions. In addition, Hamilton assesses the various criticisms of presently accepted health effects data, shows which are valid and which are not, and finally suggests areas where further research is necessary to reduce uncertainty.

An additional concern in the utilization of data involves its original source. The use of common sources, necessitated by the dearth of independent information on specific effects, raises the possibility of common fallacies cross-contaminating a selection of otherwise unbiased investigations. An example of this concern is found in the dependence in many risk analyses on the data compiled by a handful of investigators reflecting the health effects of air pollution from the burning of fossil fuels.

A related concern is the reliance upon a single analysis of a component risk across risk assessments. For example, the quantification of the risks associated with large accidential releases of radiation from nuclear power plants is commonly based on a single analysis [5] or variations on that analysis.

Three final comments are appropriate in a general discussion on uncertainties in risk analyses. First, at least one investigator [4] has indicated that the marginal health effects of additional energy generating units must be considered; specifically, ambient concentrations of sulfates, especially east of the Mississippi River, are close to levels where chemical damage is seen. Second, synergistic effects have not been adequately considered; for example, the increased use of coal may, through climatic change, influence the failure probability of hydroelectric dams by increasing the magnitude of the maximum probable flood. Third, there is always some uncertainty introduced in not knowing whether all contributions to risk in a given analysis are included; for example, that all sequences are included in determining the risks of accidents.

2.3 Problems in the Characterization of Risk

Risks from different technologies of electricity generation involve impacts which manifest themselves in a great variety of ways. The present paper will focus primarily on two such impacts: premature death and non-fatal disease/accidents. No comprehensive attempt is made to discount or convert, in some sense, other impacts such as land use restriction or resource diversion to equivalent deaths or disease. Health impacts from different hazard sources may vary according to the amount of time for effects to surface.

Demographic factors, such as the age distribution of a target population, which are dynamic variables, also enter into the analysis of risk and vary in importance among risk sources.

A difficulty in establishing a common denominator on which to base comparisons surfaces when the question of equity is approached. The receipt of direct, tangible benefits and some degree of control of the hazard suggests that occupationally encountered risks be considered separately from risks to the general public.

As risks to individuals are considered collectively by society, the degree to which that society is risk adverse may be defined. Thus, there is a logical division between individual and societal risks. One aspect of this division is perhaps exemplified by the current controversies surrounding the Zion and Indian Point nuclear power plants. It may well be that the units in question pose individual risks which are not significantly different from the "average" nuclear plant in the United States. However, the relatively large populations surrounding these units may necessitate engineered changes if the societal risk is considered excessive.

Society demands explicit attention be paid to hazards of catastrophic proportions, regardless of their probability of occurrence [6]. Each form of energy producing technology presents such hazards (e.g., in the use of coal or oil, climate modification from released CO_2 or extreme ecological modification from acid runoff and rain; for hydroelectric power generation, the rupture of a sizable dam near a large population center; in the use of natural gas, the release of LNG near a population center; and in the case of nuclear power, the release of substantial amounts of radioactive materials resulting in potentially large immediate, as well as delayed, health effects).

These risks, however, must be brought into the overall risk assessment framework (quantified to the extent possible), perhaps employing singular risk aversion factors.

Because of the diverse aspects of risk, expected (or average) values are often employed and they require careful interpretation. While the use of expected values may be informative in specific studies, any temporal or demographic variance, for example, will be obscured. However, the desire for simplicity in the use of a single number, whether standing alone or in a comparative analysis, may well be abandoned in favor of a more complete basis such as frequency-consequence plots for a spectrum of consequences.

2.4 Uncertainties in Current Risk Assessments of Available Fuel Cycles.

The specific uncertainties and omissions in currently reported risk assessments of available methods of generating electricity are listed below. These include fossil fuel, hydroelectric and nuclear generated power. No attempt is made to improve the quantification, and no claim is made as to the completeness of the present discussion. The objective here is to demonstrate that all presently available energy generation technologies pose some risk components that are unquantified or are subject to technical controversy.

2.4.1 Coal

Because of the great potential increase in its use, the health and environmental effects of coal utilization have been receiving increased attention [7,8]. In addition, the recent report from the Office of Technology Assessment [9] stated that if additional evidence confirms the present concerns, existing coal consuming facilities will be prime targets for emission regulations. Difficulties in assessing the risk from the use of coal include quantifying:

a) the chronic health effects (dose/response relationships) of the oxides of carbon, sulfur and nitrogen, radon gas, and particulates released at the power plant. The particulate fraction includes trace elements (e.g., vanadium, cadimum, uranium, thorium) as well as organic material.

b) the long-term effects of carcinogens, mutagens and toxic substances emitted in large quantities, including those imposed by long-range transport of sulfates and trace metals.

c) the long-term societal risks of atmospheric buildup of CO_2 and the risks to human health from acid rain.

d) the risks of contamination of groundwater from acid or alkaline mine water. Present neutralization techniques involve pH treatment which results in increased water hardness, perhaps introducing other risks.

e) the effect of dust, polycyclic organic material, CO_2, and sulfur compounds on coal mine workers. Actuarial data are available; however, the combined effect of new regulatory standards and an increased workforce will be difficult to assess due in part to the long characteristic time constant of the health effects.

f) the risks of groundwater contamination and other chemical releases from coal combustion waste (i.e., coal ash). This waste may represent one-half of the nation's noncombustible solid waste and industrial sludge (by weight) by 1985. The waste is chemically active and also contains radioactive trace elements whose daughters are gases (e.g., isotopes of radon).

g) the risks from mine waste impoundment practices. (In 1972 the failure of a mine waste dam killed 125 people.)

h) the health effects due to releases of chemical effluents from mine waste piles.

i) the multifacted effects from the competition of the entire operation of the coal cycle with local resources. For example, current reclamation efforts are sometimes less than successful due to the long time constant for ecological recovery and adverse rapid processes such as erosion. Health effects of such diversions of resources are difficult to quantify.

j) the marginal risks of a coal unit in a particular geographic location.

Note that of these concerns only the health effects related to (a) and (e) are addressed in the analyses reviewed in Section 3, and even then they are only partially considered.

2.4.2 Oil

In order to compare the risks of the oil fuel cycle with those of other energy options, the potential risks from the following activities must be determined: drilling, transportation, refining, utilization and waste disposal. Because the use of oil, in proportion to coal and nuclear, will steadily decline in the future, and because of the competition for its utilization as a transportation fuel, the risks attributable to its use as a power-plant fuel have received less attention.

Those aspects of the oil fuel cycle leading to uncertainy in risk include:

a) the health effects of the effluents (e.g., oxides of sulfur, carbon and nitrogen) released during normal operation of an electricity generating unit. The risks also include those discussed in the previous section concerning CO_2 buildup, acid rain and long-term effects.

b) the health and environmental risk associated with oil spills. Quantification of this effect requires an adequate model of man's food chain as well as other information.

c) the risks associated with the storage of oil near population centers. A major fire accompanied by unfavorable meteorological conditions could lead to catastrophic impacts.

d) the risks associated with extraction (e.g., health effects of water pollution from seepage and spills, and land subsidence). The latter is particularly important in regions of high seismicity, because it is thought that extraction of oil may increase the frequency of earthquakes.

e) the risks associated with oil tanker fires due to collisions in harbors and in coastal shipping lanes.

f) the sociopolitical risks, including war, associated with increasing demand for oil and its limited supply.

Only the health effects associated with the first concern above are addressed in the analyses reviewed in Section 3.

2.4.3 Hydroelectric

The utilization of dams for the generation of hydroelectric power involves risks which are characterized by a spectrum of consequences and frequencies. Difficulties in assessing the risks of hydroelectric power generation include:

a) the interpretation and use of actuarial data on dam failure. While historical evidence yields an average failure probability of $2\text{-}7 \times 10^{-4}$*/ per dam-year, additional assessments of individual dam designs are necessary to determine variance of this average [10,11].

b) the lack of information concerning the consequence of particular dam failures. It has been estimated that the failure of particular dams may have consequences of up to 250,000 deaths [12].

c) analyzing the synergistic effects of other dams or other technologies.

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*/ Based on the period 1940-1972 the actual rate was 7 failures per 10,000 dams per year of height over 45 feet excluding waste impoundment dams; however, the definition of failure is subjective and varies from investigator-to-investigator.

d) analyzing the risks on human health posed by the environmental impact of the dam.

e) analyzing those risks associated with maintenance or utilization of the secondary benefits (e.g., recreational) of the dam.

2.4.4 Nuclear

The risks associated with commercial nuclear power have been the subject of extensive analyses. Such studies have identified specific problem areas; however, difficulties remain in fully quantifying the risks from the entire fuel cycle. These difficulties include:

a) the controversy over the biological impact of low level ionizing radiation which includes acute, long-term and genetic effects. Assessments to date have generally relied upon a linear - no threshold biological response to radiation; this model is generally accepted as being conservative for the present generation, has not been replaced by a best estimate model, and does not include genetic effects.

b) the consideration of both occupational (e.g., mining operations) and societal risk from low level radiation. This latter category is complicated by the necessity of modeling radioactive effluent transport, population distribution, plant and animal intake and buildup, and biological response to various chemical species and physical forms.

c) characterizing the contribution of high-consequence low frequency events and verifying the frequency of both high and low probability events.

d) identification of all important accident sequences. A related difficulty involves the identification of common mode and system interaction phenomena, operator error and intervention, and characterization of degraded reactor behavior.

e) assessment of the risks of long term waste disposal. Presently, for example, a narrow consequence model is typically assumed. A related uncertainty involves assessing the risks associated with all possible reprocessing decisions.

f) inability of quantifying the risk of hazardous material being diverted for alternative purposes.

The concerns (a) through (e) are treated to varying degrees of completeness in the analyses reviewed in Section 3; (f) is not addressed.

3. SURVEY OF SOME RECENT RISK COMPARISONS

3.1 Introduction

Regardless of the difficulties discussed in the previous section, there have been recent attempts to quantify and compare selected risks of various fuel cycles by different investigators. In this section an attempt is made to review several studies which compare selected risks for different energy systems. Before making any judgments on relative risk, it is important to note the following:

a) Each set of risk comparisons does not necessarily represent the risk of the total fuel cycles, but considers only selected contributions to risk. In some instances omissions are significant risk contributions, in others they may not be.

b) Although there may be some degree of self-consistency for each study (base-line data, etc.), there is a lack of consistency from author to author. It is assumed, for example, that for the degree of accuracy desired in this report, a simple scaling correction is appropriate to correct for differing assumed plant capacity factors.

c) Some contributions to risk are determined from actuarial statistics (e.g., mine accidents), while some are based on calculational models (e.g., catastropic nuclear accidents). Hence, there are different degrees of uncertainty associated with the component risks.

The studies reviewed are discussed below and are summarized in Table 3.1.

3.2 Comar and Sagan (1976)

In 1976, Comar and Sagan [13] presented the results of a study on the health effects of energy production and conversion for 1,000 MWe oil, coal, and nuclear power plants operating for one year (the assumed capacity factor is not given). The health effects considered are given as: premature occupational deaths, premature general public deaths and occupational injuries in terms of accident and disease. The various facets of the fuel cycle considered are extraction, transport, processing and conversion.

Long term effects such as atmospheric buildup of CO_2 and high level radioactive waste disposal are not included. For the most part, the results presented were obtained from the available literature and were not determined explicitly for the study.

There are several other points worth noting:

a) genetic effects due to fossil fuel combustion were not included.

b) the fossil fuel data did not discriminate between premature deaths occurring early in life and those due to persons with chronic disease, already at high risk.

c) the data used for fossil fuel were based on epidemiological studies.

d) low-level effects of radiation were based on the BEIR report of 1972 [14].

e) catastropic risks of the nuclear plant were based on the Rasmussen Study (WASH-1400, [5]), as it appeared in draft form.

3.3 Gotchy (1977)

In 1977, Gotchy [15] examined the health effects attributable to coal and nuclear fuel cycle alternatives. Estimates of mortality and morbidity were presented based on "present day" (1977) knowledge of health effects. Emission rates used were based upon fuel cycle facilities expected to go into operation during the period 1975-1985. The results are given as excess deaths per 0.8 gigawatt-year electric (GWye) (i.e., 1,000 MWe power plant operating at 80% of capacity for one year).*/

*/ During a recent (February 1980) Subcommittee meeting of the ACRS, Gotchy indicated that current refinements to the 1977 study do not change the assessed risks appreciably.

For nuclear energy, the health effects due to normal operation were taken from the "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed-Oxide Fuel in Light Water Reactors" (GESMO) [16] and Table 5-3 of 10 CFR 51 (updated to include the long-term impact of radon-222). The health effects due to accidental releases were obtained from WASH-1400 [5].

Dose-response relationships for fossil fuel combustion were obtained from the epidemiolgical studies of Lave and Seskin [17] and Winkelstein, et al [18]. Other assumptions included:

a) the use of actual population distributions within 80 km of several nuclear plant sites (also used for the coal plants),

b) actual meteorological data,

c) use of 3% sulfur coal, 12% ash for upper bound and 0.4% sulfur coal with 3% ash for lower bound,

d) 99% particulate removal from emissions,

e) 75% plant capacity factor,

f) 10% per hour oxidation rate for conversion of sulfur oxides to sulfates.

3.4 <u>Hamilton and Manne</u> (1978)

In 1978, Hamilton and Manne [19] attempted to estimate the excess morbidity and mortality for various technological and population alternatives due to air pollution from a 1000 MWe fossil fuel power plant within 80 km of the plant. Using these results, they also estimated the excess mortality and morbidity to calculate the health effects associated with the total production of electric power in the USA in 1975.

The results were obtained using the Biomedical and Environmental Assessment Division (BEAD) models developed at Brookhaven National Laboratory. Dose-response functions for fossil fuel were based on the Lave and Winkelstein data and on a linear extrapolation for the radiation dose-response function.

3.5 Hamilton (1979)

In a series of papers, Hamilton [4,20] has reviewed the Brookhaven work using BEAD models for various contributions to risk from coal and nuclear power plants. This work differs from the Hamilton and Manne paper discussed above in that it considers the use of low rather than high sulfur coal in future electricity generation. Furthermore, this work includes other aspects of the coal and nuclear fuel cycles such as processing, waste management, etc.

In examining Hamilton's work, it should be noted that the results for coal neglect the potential risks due to solid wastes (both the carcinogenic components and the radioactive dose due to radon gas and radium). The results for nuclear utilize the WASH-1400 risk estimates for catastrophic accidents.

3.6 CONAES (1979)

One of the more comprehensive attempts to compare the risks of various energy options is the recent study by the Committee on Nuclear and Alternative Energy Sources (CONAES) of the National Research Council [21]. Although the final report is published, the supporting documents concerning risk are still in preliminary form. A detailed description of the models and data used will be described in the final CONAES supporting documents.

3.7 Results

The results of the five studies reviewed above are presented in Table 3.1. All entries in the Table have been linearily scaled to reflect the production of 10^{10} Kwh of electric power. (This scaling was considered appropriate for the degree of accuracy desired here). Table 3.2 indicates the range of assessed values for the five studies. The large variance in the nonfatal effects is due in part to interpretation. The studies summarized in Tables 3.1 and 3.2 indicate that the assessed risks of nuclear power are less than or equal to the assessed risks of coal or oil. The omissions in Table 3.1 indicate that those particular facets of risk were not addressed or not differentiated to reflect occupational versus general public effects.

The studies reviewed did not consider to the same degree the risks associated with hydroelectric or natural gas plants. Hamilton and Manne [19] estimated 0.2 deaths and 20 disabilities per 10^{10} Kwh of natural gas generated electricity. For an equivalent amount of natural gas generated electricity, the review of the literature by Comar and Sagan [13] estimated occupational fatalities to be 0.065-0.32 and occupational injuries to be 4.5-27. However, its transport as liquified natural gas (LNG) gives it the potential for a series of high consequence events which may not be of low frequency when compared to nuclear fuel cycle risks. This risk has not been included in the assessments.

The environmental risks of a hydroelectric power plant do not lend themselves to quantitative analysis and are difficult to compare to fossil-fuel and nuclear cycle risks. This energy source also has a significant contribution to public risk because of potential high consequences (up to ten or hundreds of thousands of deaths) accompanied by relatively moderate frequency (10^{-4} per dam-year on the average) events.

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TABLE 3.1

HEALTH EFFECTS OF THE USE OF COAL, OIL AND NUCLEAR POWER (normalized to 10^{10} Kwh)

fuel

oil

Consequence	COMAR and SAGAN (1)	GOTCHY (2)	HAMILTON and MANNE (3)	HAMILTON (4)	CONAES (5)
occupational deaths	0.16-1.5	--	--	--	--
general public deaths	1.14-114	--	--	--	--
total deaths	1.3-116	--	3-150	--	--
occupational disease/accidents	14.77	--	--	--	--
general public disease/accidents	--	--	--	--	--
total disease/accidents	14.77	--	150-300	--	--

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TABLE 3.1 (con't)

HEALTH EFFECTS OF THE USE OF COAL, OIL AND NUCLEAR POWER (normalized to 10^{10} Kwh)

fuel

coal

Consequence	COMAR and SAGAN (1)	GOTCHY (2)	HAMILTON and MANNE (3)	HAMILTON (4)	CONAES (5)
occupational deaths	0.62-5.7	0.50 - 10.9	--	--	4-6
general public deaths	1.8-127	20.3-158	--	--	3-304
total deaths	2.4-133	21-169	10-200	13.5-16	7-310
occupational disease/accidents	30-143	--	--	--	--
general public disease/accidents	--	--	--	--	--
total disease/accidents	30-143	--	300-500	88	61-152

TABLE 3.1 (con't)

HEALTH EFFECTS OF THE USE OF COAL, OIL AND NUCLEAR POWER (normalized to 10^{10} Kwh)

fuel

nuclear

Consequence	COMAR and SAGAN (1)	GOTCHY (2)	HAMILTON and MANNE (3)	HAMILTON (4)	CONAES (5)
occupational deaths	0.11-0.98	0.51	--	--	0.3-0.5
general public deaths	0.01-0.18	0.33-1.98	--	--	1.5
total deaths	0.13-1.16	0.84-2.49	1-3	1.35	1.8-2.0
occupational disease/accidents	4.6-15	--	--	--	--
general public disease/accidents	--	--	--	--	--
total disease/accidents	4.6-15	--	8-30	26.2-30.9	15.2-22.8

Footnotes:

(1) reflects review of literature (1975 technology)

(2) expected effects of facilities to go into operation during 1975-1985

(3) estimated health effects for electricity production in the U.S. (1975 technology)

(4) update of Hamilton and Manne to reflect use of low sulfur coal

(5) expected effects during 1985-2010

TABLE 3.2

RANGE OF ASSESSED HEALTH EFFECTS
(normalized to 10^{10} Kwh)

	OIL	COAL	NUCLEAR	NATURAL GAS
deaths	1.3-150	2.4-310	0.13-3	0.065-0.32
disease/accidents	14.77-300	30-500	4.6-30.9	4.5-27

4. SUMMARY AND CONCLUSIONS

4.1 Summary

In this report, an effort has been made to discuss some of the difficulties associated with performing risk analyses and to present in a unified manner results from a selected group of recent risk assessments. The former aspect is discussed in Section 2 proceeding from a presentation of the concerns associated with assessing comparative risks in general, to a sketch of specific areas of uncertainties surrounding the health effects of current technologies capable of providing significant amounts of electricity.

Five recent studies, which primarily compared the health effects of the use of coal and nuclear energy, are summarized in Section 3. In light of the aforementioned difficulties in assessing the risks of any fuel cycle, these studies are recognized as estimating only portions of the total risks. Nevertheless, the estimated health effects were normalized in an approximate manner and tabulated as broad appraisals with minimum critique of the individual assessment methodologies. From the combination of these effects, the assessed risks of the nuclear power cycle, when discussed in terms of expected values, are comparable to or less than its alternatives.

4.2 Discussion

In order to assess and compare the health and environmental risks of the available methods for generating electricity, the uncertainties (such as those discussed in Section 2) should be evaluated. Although the results of incorporating these uncertainties into the assessments and comparisons contained in Section 3 would at best be qualitative, they can be considered in a relative sense.

Uncertainties in actuarial as well as health effects data (or models) may increase or decrease assessed risks; uncertainties due to a lack of the ability to quantify effects which lead to the omission of risk components can only increase assessed risks. Furthermore, risk assessments may be more sensitive to unquantifiable effects than to uncertainties in data. Before any conclusions can be stated, some of the more important uncertainties should be discussed.

With respect to fossil fuel combustion, the damage function (dose/response relation) of air transported sulfates is not well known. Morgan, et. al. [22] estimated a mean function value of 3.7 deaths per 10^5 people/mg of sulfate/m^3 of air which had a low confidence level (95% confidence interval 0-11.5). Atmospheric CO_2 buildup and acid rain are real phenomena which have potentially catastrophic consequences; but, the corresponding links between assaults on the ecosphere and human health are poorly understood and unquantified at present. Groundwater contamination from mine water runoff or from coal combustion waste is a serious hazard and also is not quantified. These two unquantified risks may have a more profound effect on fossil fuel assessed risks than the uncertainty in the damage function described above.

With respect to nuclear energy, there are several important uncertainties to consider. Despite the well known controversy, the hazard function of low level radiation is better known than that of airborne sulfates. The identification of all important accident sequences, and the characterization and verification of the contribution to risk of specific sequences, is a common concern to all risk analyses. The 1977 Ford/MITRE study [23] concluded that the frequency of core melt with breach of containment as predicted in WASH-1400 may be low by as much as a factor of 500; however, that report goes on to say:

> It is significant that even under such extremely pessimistic assumptions, the fatalities [expected value] are less than the high end of the range of estimated deaths associated with [the normal operation of] coal-fired power plants.

More recently, the 1979 Resources for the Future Report [6] stated:

> If all the electricity generated in 1975 had come from coal, the total number of associated fatalities (including coal miners and members of the general public) would have ranged between about 200 and 4,000. . . . If, however, the electricity had been generated from nuclear sources, total fatalities which might have resulted have been calculated at between 60 and 900 (... this includes an evaluation of accident probabilities which is 100 times higher than the controversial Rasmussen Report - partly because of subsequent criticisms of the margin of error assumed originally in that report and partly because of the accident in early 1979 at the Three Mile Island nuclear plant, which involved at least some problems that had not been anticipated). Even without continued improvements in nuclear technology and operating practices, which might be expected in the wake of the Three Mile Island accident, the range of estimates for health threats is substantially lower for nuclear than it is for coal - although the two overlap.

It is also important to discuss the relative uncertainty between fuel cycles. A recent report by the Environmental Protection Agency [24,25] using an upper bound technique, identified the routine operation of coal-fired power plants in urban areas as a potentially significant source of added radiological risk to society, possibly greater than existing nuclear plants. Note that for the nuclear fuel cycle the largest occupational radiological risk exists for uranium mining and milling.

The risks due to the long term storage of nuclear waste have not been adequately quantified; however, this same statement can be applied to the wastes from the coal cycle. A major risk which has not been quantified for coal is the potential contamination of groundwater due to the large projected volume involved, its chemical properties and the lack of an acceptable disposal plan. A second risk contributor for coal ash is the release of radioactive materials. Pigford [26] compared the potential hazard from radioactive trace elements in stored coal ash with the ingestion toxicity of nuclear power waste; he estimated that for a given amount of delivered electricity, the radiotoxicity of the high-level reprocessing waste from a PWR becomes less than the radiotoxicity of coal ash initially containing 24 ppm uranium after 500 years, and less than that of coal ash initially containing 1 ppm uranium after 30,000 years. Unreprocessed spent nuclear fuel retains a toxicity higher than that of ash from the former class of coal until 100,000 years have passed.

A recent concern is the risk of nuclear weapons proliferation and the effect on world peace and stability. Although the benefit of a secure energy supply may offset this risk to some degree, both effects are unquantifiable at this time. The dominant factors determining these risks are sociopolitical in nature, so that any attempt to compare them with direct public health and environmental risks at this point is beyond speculation. A similar statement can be made concerning the risks involved with the growing competition for a diminishing supply of oil on a global scale. As world demand and dependence on any resource that is unequally distributed geographically grows, be it coal, oil or uranium, such risks will necessarily develop. Therefore, the conclusion drawn in this report will necessarily reflect only direct health and environmental risks.

The risks arising from the use of hydroelectric power and the burning of oil have received a lesser amount of attention. Only site specific studies will reduce the uncertainties in assessing the risks of dam failure. These risks appear at present to have catastrophic potential but are unquantified.

The oil fuel cycle shares many common hazards with the coal cycle. The inclusion of potential catastrophic events can only increase the assessed risks.

4.3 Conclusion

It appears that the actual risks of the nuclear fuel cycle are less than or equal to those of its major alternatives: coal and oil. This conclusion is based upon the following considerations:

a) the assessed risks (expected values) of the nuclear fuel cycle are less than or equal to those of coal and oil,

b) the effect of uncertainties (with respect to both data and unquantified risk components) on these assessed values appears to be smaller for the nuclear fuel cycle, and

c) the analysis, while far from complete, of the risks of the nuclear fuel cycle relative to analyses of alternative cycles are more comprehensive.

Uncertainties appear to be largest for hydroelectric energy production, which exhibits both large scale ecological impact and the potential for high consequence - moderate frequency events at specific sites.

The conclusion stated above excludes sociopolitical derived risks, such as nuclear proliferation or war over liquid fuel supplies, which are at present unquantifiable and at best speculative.

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