T ERA
DSIC

50-219
354
355
363

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MAY 14 1980

Mr. William Hilger
63 Prospect Street
Jersey City, New Jersey 07307

Dear Mr. Hilger:

In reply to your letter of March 11, 1980, to the Nuclear Regulatory Commission, enclosed are excerpts from the following reports: WASH-740, WASH-1224, WASH-1250, WASH-1400, NUREG-0020 (Vol. 4, No. 1), NUREG-0480, NUREG-0512, NUREG-0517, NUREG/CR-1060, and the Final Environmental Statement related to operation of Oyster Creek Nuclear Generating Station. The full reports may be purchased from:

GPO Sales Program
Division of Technical Information
and Document Control
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

or

National Technical Information Service
Springfield, Virginia 22161

Information on service areas and current costs of the Oyster Creek and Salem nuclear stations may be requested from the operating utilities, Jersey Central Power & Light Company and Public Service Electric & Gas Company, respectively.

You asked about nuclear plants to be built in New Jersey in the next decade. Under construction are Units 1 and 2 of the Hope Creek nuclear station on Artificial Island in the Delaware River estuary about 7.5 miles southwest of Salem, New Jersey. Unit 1 is scheduled for operation in 1985 and Unit 2 in 1987. There is a construction permit for Unit 1 of the Forked River nuclear station on a site shared with the unit of the Oyster Creek nuclear station, about nine miles south of Toms River, New Jersey, and about three miles west of Barnegat Bay.

Sincerely,

HR Denton

Harold R. Denton, Director
Office of Nuclear Reactor Regulation

Enclosures:
As stated

8008170 060

P

THEORETICAL POSSIBILITIES AND CONSEQUENCES OF MAJOR ACCIDENTS IN LARGE NUCLEAR POWER PLANTS

A Study of Possible Consequences if Certain Assumed Accidents, Theoretically Possible but Highly Improbable, Were to Occur in Large Nuclear Power Plants

WASH-740

UNITED STATES ATOMIC ENERGY COMMISSION

March 1957

THIS COPY DOES NOT INCLUDE THE APPENDICES

Foreword

This report to the Commission contains an account of a study undertaken by the Division of Civilian Application, at the direction of the General Manager, to gain a more comprehensive understanding of the potential public hazards of nuclear power reactors.

All technical phases of the project were performed by a study team composed of staff members of the Brookhaven National Laboratory, with assistance of consultants and others from elsewhere. Principal contributors were:

Dr. Clifford K. Beck
Dr. Frederick P. Cowan
Mr. Kenneth W. Downes,
  Project Director
Dr. Joseph A. Fleck, Jr.
Dr. J. B. H. Kuper
Mr. James McLaughlin
Mr. Irving Singer
Mr. Maynard Smith

The study was carried out under the guidance of a Steering Committee composed of scientists and engineers of the Atomic Energy Commission staff and the Brookhaven National Laboratory. Members were:

Dr. Clifford K. Beck, AEC,
  Chairman, Steering Committee
Dr. Walter D. Claus, AEC
Mr. Kenneth W. Downes, BNL
Mr. Merril Eisenbud, NYOO
Dr. Clark Goodman (replaced by
  Mr. Howard Hembree, AEC)
Mr. Edwin A. Lamke, AEC,
  Secretary
Dr. Gerald F. Tape, BNL
Dr. Clarke Williams, BNL

Valuable assistance throughout the study was also rendered by Mr. Joshua Z. Holland, AEC, and in some of the technical phases by Mr. Raymond O. Brittan, Argonne National Laboratory, and Dr. Everitt P. Blizard, Oak Ridge National Laboratory.

Many other staff members, consultants and advisors, including members of the Advisory Committee on Reactor Safeguards, also rendered valuable assistance in the study.

Table of Contents

UNITED STATES

ATOMIC ENERGY COMMISSION

WASHINGTON 25, D. C.

March 22, 1957.

DEAR MR. DURHAM: There is transmitted herewith a report of a study of the possible consequences in terms of injury to persons and damage to property, if certain hypothetical major accidents should occur in a typical large nuclear power reactor.

More than two score leading experts in the sciences and engineering specialties participated in this study.

We are happy to report that the experts all agree that the chances that major accidents might occur are exceedingly small.

This study constitutes a part of the Commission's continuing effort on a broad front to understand and resolve this problem of possible reactor hazards so that we may proceed with an expanding atomic energy industry with full confidence that there will be few reactor accidents and that such as do occur will have only minor consequences. This effort and the work of translating the results into affirmative, concrete safeguards for protection of the public will, of course, be continued and expanded.

Since the beginning of the reactor program the experts and the Congress and the public and the Commission have all been concerned with the causes of and the possible magnitude of damage from reactor accidents and with means of prevention. The subject was considered important enough to command four of the 60-odd sessions of the International Conference on the Peaceful Uses of Atomic Energy in Geneva eighteen months ago, which, as you will recall, we initiated. One conference paper in particular gave estimates of the theoretical magnitude of damage. In May of last year, Dr. Libby presented to your Committee some estimations of the possible extent of harm and damage should a major accident occur.

This study has taken the form in which it is now presented to you as a means of responding to the Committee's specific request of last July 6. To produce such a study, it was necessary to stretch possibility far out toward its extreme limits. Some of the worst possible combinations of circumstances that might conceivably occur were included in the hypotheses in order that we might assess their consequences. The study must be regarded only as a rough estimation of the consequences of unlikely though conceivable combinations of failure and error and weather conditions; it is not in any sense a prediction of any future condition.

This has been a difficult study to make. There has fortunately been little reactor accident experience upon which to base estimates. Nuclear reactors have been operated since December 2, 1942, with a safety record far better than that of even the safest industry. More than 100 reactor years of regular operating experience have been accumulated, including experience with reactors of high power and large inventories of fission products, without a single personal injury and no significant deposition of radioactivity outside of the plant area. There have been a few accidents with *experimental* reactor installations as contrasted with the perfect record of safety of the regularly operating reactors. But even these accidents did not affect the public.

This record which shows that safe operation can be achieved is due to skillful design, careful construction, and competent operation.

Looking to the future, the principle on which we have based our criteria for licensing nuclear power reactors is that we will require multiple lines of defense against accidents which might release fission products from the facility. Only by means of highly unlikely combinations of mechanical and human failures could such releases occur. Furthermore, the

Government and industry are investing heavily in studies to learn more about the principles of safe reactor design and operation.

Framing even hypothetical circumstances under which harm and damage could occur and arriving at estimations of the theoretical extent of the consequences proved a complex task.

To make the study we enlisted the services of a group of scientists and engineers of the Brookhaven National Laboratory and of another group of experts to serve as a steering committee. Through recent months these men have met with many additional expert advisors to test out judgments on the estimates arrived at.

We are not aware of such a study having been undertaken for any other industry. We venture to say that if a similar study were to be made for certain other industries, with the same free rein to the imagination, we might be startled to learn what the consequences of conceivable major catastrophic accidents in those other industries could be in contrast with the actual experience in those industries.

Remembering that this study analyzes theoretical possibilities and consequences of reactor accidents, we might note here the judgments presented on (1) possible consequences of major accidents and (2) the likelihood of occurrence of such major reactor accidents.

The portion of the study dealing with consequences of theoretical accidents started with the assumption of a typical power reactor, of 500,000 kilowatts thermal power, in a characteristic power reactor location. Accidents were postulated to occur after 180 days of operation, when essentially full fission product inventories had been built up.

Three types of accidents which could cause serious public damages were assumed. Pessimistic (higher hazard) values were chosen for numerical estimates of many of the uncertain factors influencing the final magnitude of the estimated damages. It is believed that these theoretical estimates are greater than the damage which would actually occur even in the unlikely event of such accidents.

For the three types of assumed accidents, the theoretical estimates indicated that personal damage might range from a lower limit of none injured or killed to an upper limit, in the worst case, of about 3400 killed and about 43,000 injured.

Theoretical property damages ranged from a lower limit of about one half million dollars to an upper limit in the worst case of about seven billion dollars. This latter figure is largely due to assumed contamination of land with fission products.

Under adverse combinations of the conditions considered, it was estimated that people could be killed at distances up to 15 miles, and injured at distances of about 45 miles. Land contamination could extend for greater distances.

In the large majority of theoretical reactor accidents considered, the total assumed losses would not exceed a few hundred million dollars.

As to the probabilities of major reactor accidents, some experts held that numerical estimates of a quantity so vague and uncertain as the likelihood of occurrence of major reactor accidents have no meaning. They declined to express their feeling about this probability in numbers. Others, though admitting similar uncertainty, nevertheless ventured to express their opinions in numerical terms. Estimations so expressed of the probability of reactor accidents having major effects on the public ranged from a chance of one in 100,000 to one in a billion per year for each large reactor. However, whether numerically expressed or not, there was no disagreement in the opinion that the probability of major reactor accidents is exceedingly low.

Some of the reasons for this belief follow:

First, industry and government are determined to maintain safety and protect the health and property of the public from nuclear hazards. The Congress has authorized and we in the Commission are carrying out a program of close and careful regulation and inspection. Thus the potential hazard of this new industry has been recognized in advance of its development and brought under a strict system of safety control before the occurrence of the incidents which in other fields have marked the birth of new industry and have subsequently led to control.

Secondly, the challenge of this new and important venture in man's application of the forces of nature has attracted able and energetic men into the work of assuring safe design and operation.

In the third place, multimillion dollar efforts in research and development, both public and private, are directed toward identifying and solving safety problems. We know of no other industry where so much effort has been and is being spent on the definition and solution of safety problems.

Fourthly, the cost to the industry and government of reactor accidents, even of a minor nature, would be very high—much higher than for accidents in other industry. Self-interest, therefore, as well as public interest dictates avoidance of accidents.

To sum up, the report affirms that a major reactor accident is extremely unlikely. To reduce the matter of assumed hazards to comparative numbers, let us take the most pessimistic assumptions used and apply them to a case of 100 power reactors in operation in the United States.

Under these assumptions, the chances of a person being killed in any year by a reactor accident would be less than one in 50 million. By contrast the present odds of being killed in any year by an automobile accident in the United States stand at about one in 5,000.

We are not surprised by the contents of the report, nor are we made complacent. The report serves to identify areas where continued research and development are needed, and areas where emphasis is needed in the further development of our regulatory program. It gives renewed emphasis to our belief that our research and development program and our regulatory program in the nuclear power field must continue with vigor to the end that the "conceivable" catastrophe shall never happen.

We would appreciate your regarding the attachment as an "advance" report. It is being reviewed for editorial and mechanical errors and omissions. Copies of the report as corrected will be furnished to you at an early date.*

Sincerely yours,
(Signed) HAROLD S. VANCE,
Acting Chairman.

Enclosure: "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants"

HON. CARL T. DURHAM,
Chairman, Joint Committee on
Atomic Energy,
Congress of the United States.

**Editors Note:* In the attached report, this review has been made and the errors which were all relatively minor, have been corrected.

Introduction

It might be supposed, because the essential fuel in a nuclear power reactor is the same as that in atomic bombs, that gross malfunctioning in power reactors could possibly lead to a devastating explosion similar to those produced by A-bombs. Such is not the case. Under no conceivable circumstances can accidental nuclear explosions in power reactors cause significant direct public damage beyond the boundaries of the exclusion areas around such installations.

There could be explosive nuclear energy releases in power reactors, or chemical or physical energy releases from components or auxiliary systems, sufficient in magnitude to destroy the reactor, possibly break the various containment structures within which it is housed and wreck the auxiliary machinery. Such an accident would constitute a real threat to the life of personnel within the facility and could result in complete loss of the expensive installation. Nevertheless, little hazard to the general public would ensue from the explosion itself.

There is, however, another hazard to the general public which could cause extensive loss of life and damage to property. This is the possibility of radiation exposure and contamination, if the fission products stored up in the reactor should be released. It is possible to conceive of accidents which would release the accumulated fission products from a large nuclear reactor in a finely divided state so that a significant portion of them would become airborne and subject to atmospheric dispersal over wide areas. Injury or death could result to people from exposure to the direct radiation from these materials, or from ingestion of portions into the body. Settling out of these materials could cause both further hazard to health and costly contamination damage to property. Death at distances of many miles and injury and property damage for hundreds of miles could conceivably occur.

Fortunately, radiation intensity from most fission products released from a reactor decreases rapidly. The possibility of total release is exceedingly remote, and among those products most likely to be released are those which decay most rapidly. In no conceivable way could fission products from a reactor be distributed rapidly and uniformly over large areas. The major threat to the safety of people remote from the site of release would not be instantaneous; periods up to hours and even days after release would be available within which to avoid the full effects of radioactivity from the fission products.

It must be clearly recognized, however, that major releases of fission products from a nuclear power reactor conceivably could occur and that a serious threat to the health and safety of people over large areas could ensue.

An overall appraisal of the actual magnitude of hazard to the public arising from operation of a nuclear power reactor revolves around the best possible answers to four essential and difficult questions:

1. What is the likelihood that fission products might be released?
2. What are the factors and conditions which would affect the distribution of released materials over public areas?
3. What are the levels of exposure or contamination which cause injury to people or damage to property?
4. If releases of fission products should occur, what deaths or injuries to people and costs in damaged property could ensue?

Succeeding sections of this report are devoted to consideration of these questions.

It is important to recognize that the magnitudes of many of the crucial factors in this study are not quantitatively established, either by theoretical and experimental data or adequate experience. Appraisal must rest on the judgment and considered opinions of the most knowledgeable persons in the field. At various places in the report note will be made where important components are particularly uncertain, but it must be remembered continuously that this entire study hardly constitutes more than an identification of the factors which are important, the best appraisal of these factors currently possible, and a rough approximation of the magnitudes of the composite results.

There are many essential and significant qualifications and uncertainties in the conclusions contained in this report. If separated from these qualifications and uncertainties, the conclusions would lose their validity. However, we believe that the study, if taken in perspective, gives an order-of-magnitude frame of reference, and defines tentative boundaries for this problem.

More definitive information on estimated factors would probably tend to reduce the estimates of damages, though in a few instances the converse might be true. There are a few less usual weather conditions which occur perhaps 5 percent of the time and which could yield estimated damages outside the range of the figures stated here. Therefore, this study does not set an upper limit for the potential damages; there is no known way at present to do this. It does indicate the range of hazards from highly improbable catastrophic reactor accidents which might occur under all except a small percentage of most unusual combinations of circumstances.

Part I

The Probability of Catastrophic Reactor Accidents

The probability of occurrence of publicly hazardous accidents in nuclear power reactor plants is exceedingly low.

This single statement, re-emphasized, would suffice to report this portion of the study, except for the essential importance of this central fact of "low probability" to comprehension of the overall public hazard of power reactors. The significance of damages consequent to accidents cannot be appraised independently of the probability of the accidents.

One fact must be stated at the outset: no one knows now or will ever know the exact magnitude of this low probability of a publicly hazardous reactor accident. In trying to establish some estimation of this quantity, three possible approaches might be used:

1. Operate enough reactors for sufficient length of time to obtain an indication of the accident probability.
2. Give careful consideration and approximate numerical values to all separate factors which would either prevent or cause such an accident, then try to calculate, or guess, the composite result of these factors and hence the likelihood of occurrence of accidents.
3. Obtain a weighted average of the best judgments and judicious opinions of the most experienced and knowledgeable experts in the field.

None of these approaches is satisfactory. Even when combined, they are at the present time still unsatisfactory.

Indications from Cumulative Experience to Date

Nuclear reactors have been operated since December 2, 1942, with a remarkable safety record. We have accumulated more than 100 reactor years of experience with large routinely operated reactors without any accidents.[1] This record of safety, although highly reassuring, does not afford a dependable statistical basis for estimating the probability of occurrence of serious reactor accidents in the future.

In this initial period of power reactor experience, types of reactors, detailed reactor designs, and operating patterns are all experimental and variable.

There are factors both on the side which would lead toward confidence that our "no accident" experience will continue, and on the converse side. On the one hand, we attempt to provide wide margins of safety because of our limited knowledge of accident potentials of reactors. The new and glamorous field challenges and attracts the most expert and competent people. The Government has had and continues to have a substantial safety research program. Experience almost certainly will lead to safer design. On the other hand, since many reactor types are being developed more varied safety problems may exist than would be the case in fewer types. Accident free experience could lead to complacency. Lengthening reactor life could lead to hazards not otherwise encountered (cumulative radiation damage to components). Competitive pressures could furnish incentives to reduce margins of safety.

[1] All the half-dozen "runaway" incidents (Chalk River, Borax, EBR-1, etc.) experienced thus far, either inadvertent or planned, have occurred in research or experimental test reactors—in contrast to the steadily operating power reactors considered here. No one has been injured, and no fission products have been released "off-area." Hence, the accidents are not in the category of concern in this study.

Factors For and Against a Major Accident

It is very difficult to determine whether a reactor of one type is safer, overall, than one of another type. It is easy to point out superior safety features and inferior ones in any one type compared with those in another type. Safety depends on the combination of many complex and interrelated factors and overall comparison of one reactor type with another depends on value judgments which are difficult to define quantitatively.

To estimate the *absolute* safety of a given reactor, or of reactors in general, or to estimate the quantitative probability that an accident will occur is more difficult, and more uncertain, by several orders of magnitude, than is the relative comparison of reactors.

In principle, it should be possible to identify each factor, positive or negative, involved in the safety of a reactor, assign some measure of the magnitude of its effect and some probability of its functioning (or failing to function), then derive a net weighted composite measure of the margin of safety, or of the probability of catastrophic accident in a given time.

On the positive side would be such factors as:

1. In no reactor, so far as is known, will a single equipment failure or a single operating error lead to a fission product-releasing accident (even within the containment structure). If such condition were recognized, it would be rectified. In the vast majority of cases, multiple separate malfunctioning events are a necessary prerequisite to a serious accident.
2. Most reactors are inherently stable, e. g., most reactors possess prompt negative temperature or power coefficients (any increase in these factors is accompanied by a decrease in reactivity, hence, any excursion tends to reach some limiting value, rather than indefinitely increasing power).
3. In heterogeneous (solid fuel) reactors, the fission product inventory accumulates within the solid fuel matrix from which escape is prevented not only by low mobility of these fission products in the solid fuel but also by the metallic surface cladding. Melting or violent damage must occur before fission products can be released into the reactor vessel. In homogeneous (solution or slurry fuel) reactors, the possibility of continuous removal of the fission products offers some compensation for the lack of confinement provided within the fuel elements of other types.
4. Every power reactor will be provided with an adequate primary containment vessel enclosing the reactor core within which fuel and fission products reside. This, in turn, is surrounded by massive radiation shields for biological protection of workers.
5. All power reactors now considered for construction in populated areas are provided with "vapor shells" designed to contain all fission products that might be released in any credible accident.
6. Seventy-five or eighty percent of the fission product elements are solids at ordinary temperatures and, unless opening of the outer vapor shell is caused or accompanied by an event which vaporizes and violently disassembles the core materials, most of the fission products would be expected to remain attached to fragments of fuel elements or to settle out on nearby structures.
7. Should fission products be released from the containment shell, not only the physical state of the materials, but also a complex variety of environmental meterological and other factors, having various probabilities of occurrence, would govern the subsequent pattern of dispersal. Probabilities of progressively unfavorable combinations of conditions become progressively lower, so that likelihood of highly unfavorable combinations is extremely low.

On the negative side, account would have to be taken of such factors as:

1. Many power reactor systems will operate under high pressures. High pressure systems are subject to failure.
2. The cumulative effect of radiation on physical and chemical properties of materials, after long periods of time, is largely unknown. Eventual serious failures may occur.
3. Various metals used in reactors such as uranium, aluminum, zirconium, sodium and beryllium, under certain conditions not at present clearly understood, may react explosively with water, also present in many reactors. During incidents of abnormal operation resulting perhaps in melting of some of the metals in contact with water and under the influence of radiation, chemical reactions of enough violence to rupture the containment vessels, with release of the fission products, could occur.
4. After initial operation, many of the vital components become inaccessible for inspections. In non-nuclear plants, serious accidents are often averted through detection of incipient failure.
5. Much remains to be learned about the characteristics and behavior of nuclear systems.

Listing of such items, in both positive and negative tabulations, could proceed at length. However, it should be clear already that, even if all the significant factors relevant to safety were known, it would be essentially impossible to assign dependable quantitative values to their respective probabilities of functioning and to derive therefrom a reliable indication of the margin of safety under operating conditions likely to exist.

The Best Judgment of the Most Knowledgeable Experts

Many outstanding leaders in reactor technology and associated fields were consulted in the course of this study. It is their unanimous opinion that the likelihood of a major reactor accident is low. There is a general reluctance to make quantitative estimates of how low the probability is. There is a common aversion to attachment of quantitative estimates to a phenomenon so vague and uncertain as the probability of occurrence of catastrophic accidents, particularly since such assignment of numerical estimations conveys an erroneous impression of the confidence or firmness of the knowledge constituting the basis for the estimate. Also, some hold a philosophic view that there is no such thing as a numerical value for the probability of occurrence of a catastrophic accident; that such a thing is unknowable.

Thus, many decline to make even order-of-magnitude guesses of the probability of catastrophic reactor accidents. On the other hand, a few have ventured to express their confidence of the extremely low probabilities of occurrence of such accidents by stating numerical, order-of-magnitude estimations. An indication of the range of these is illuminating.

Should some unfortunate sequence of failures lead to destruction of the reactor core with attendant release of the fission product inventory within the reactor vessel, however expensive this would be to the owners, no hazard to the safety of the public would occur unless two additional lines of defense were also breached: (1) the integrity of the reactor vessel; and, (2) the integrity of the reactor container or vapor shell.

Accidents of sufficient violence to breach these successive lines of defense occurring concurrently with progressively unfavorable combinations of dispersive weather conditions have decreasing probabilities of occurrence.

Thus, the probability of public hazards from reactor accidents may be considered in terms of a sequence of events, each being prerequisite to the situation arising from succeeding events, and each having a lower probability of occurrence than its predecessor. As indicated above, the numerical estimates ventured here represent an attempt to express in numerical terms the degree of feeling held by some of our advisors for the remoteness of the possibilities of occurrence of the various accidents described. It should be emphasized that these numbers have no demonstrable basis in fact and have no validity of application beyond a reflection of the degree of their confidence in the low likelihood of occurrence of such reactor accidents.

Their estimates for the likelihood of destruction or major damage to the reactor core with significant internal release of fission products, but no release outside the reactor vessel, ranged from one chance in 100 to one in 10,000 per year for each reactor.

Their estimates for the likelihood of accidents which would release significant amounts of fission products outside the reactor vessel but not outside the containment building (the contained accident) ranged from one chance in 1,000 to one in 10,000 per year for each reactor.

Finally, their estimates for the likelihood of accidents which would release major amounts of fission products outside the containment (the major release accident) ranged from one chance in 100,000 to one in a billion per year for each reactor.

Taking the most pessimistic of these estimates for the major accident, assuming that 100 reactors are in operation in the United States, and making the unrealistic assumption that each accident of the type defined would kill 3,000 people, there would be one chance in 50 million per year that a person would be killed by reactor accidents. For comparison, the chance of a person in the United States being killed by automobile accidents, assuming that each person has an equal likelihood of being among the 40,000 killed, is about one in 5,000 per year.

Safety Through Safeguards

Detailed evaluation of the safety of a reactor before approval is given for its operation may not lead to any better estimations of accident probabilities than those yielded by other considerations, but it does furnish added confidence that accident probabilities are indeed exceedingly small. In fact, the confidence of many persons in the low probability of accidents is due in large part to the application of these evaluation procedures.

Three aspects of these procedures contributing to minimization of public hazards from reactor accidents are worthy of mention:

1. Knowledge that safety evaluations and reviews are prerequisite to operation approval insures attention to and emphasis on safety aspects of a facility at all stages of the design.
2. The detailed safety analysis and evaluation by experts on the Commission staff, with assistance as necessary from consultants and advisors, including the Advisory Committee on Reactor Safeguards, assures that at least one independent review is given to each reactor facility in addition to that given by the designers.
3. As a part of the pre-evaluation procedure, careful analysis must be given to establishment of the accident of maximum proportions considered to be credible for each reactor facility, and demonstration must be made that adequate safeguards are provided the public against this eventuality.

Thus, since there is protection against "credible" accidents, no damages to the public will occur unless "incredible" accidents take place. It must be recognized, of course, that errors in judgment can be committed, with resulting occurrence of what was believed to be an "incredible" accident. Nevertheless, the consistent and rigorous execution of these procedures for every reactor warrants a considerable degree of confidence that safeguards against serious accidents have been incorporated, and that the probabilities of such occurrences are small.

Part II

Assumptions Used in the Damage Studies

It has been concluded that there is some remote but quantitatively uncertain possibility that a major reactor accident might occur. The immediate question then follows: What could be the extent of consequent damages? The remaining sections of this report devote attention to this question. Consideration is restricted to estimation of the damages to the public. No attempt has been made to appraise the hazard or damage to the facility itself or to its personnel.

To evaluate the hazardous consequences to the public of a reactor accident of major proportions, many features must be further described relating to the size and location of the reactor, its fission product inventory and the portion released, the conditions of release and the features of its delivery to public areas. In this section of the report, brief definitions and descriptions of those situations and features considered pertinent are recorded. Details of the technical foundations for these assumptions and specifications, and mathematical manipulations to arrive at estimates of the consequences thereof, are contained in various appendices as indicated.

Two comments are appropriate at this point. (1) Conditions and specifications described below are chosen to be representative of a "generalized" power reactor situation. Specific reactor situations will vary somewhat from the one described herein; however, use of the generalized reactor and site is adequate to permit a reasonable evaluation of general public liabilities. (2) The assumptions and specifications are chosen to be on the pessimistic side, i.e., result in higher damage estimates. This is due to an attempt to be on the safe side where uncertainties exist in present knowledge but no deliberate safety factors have been introduced.

Typical Reactor

The reactor considered is a 500,000-kw thermal (100,000 to 200,000-kw electrical) steadily operating, power producing type, having an average fuel reloading (and fission product eliminating) cycle of 180 days. Accidents assumed in this study, described later, are postulated to have occurred near the end of the 180-day cycle, when fission product inventory would be maximum. Research and test reactors and reactor experiments are excluded from consideration. A leak- and pressure-resistant containment building of the usual type is assumed to surround the reactor.

Fission Product Content of the Reactor

For the 500,000-kw thermal reactor, 180 days of operation, the fission product inventory would be approximately $4x10^8$ curies, when measured 24 hours after an accident (or shutdown). Decay of the fission products as well as their composition was taken into consideration for calculation of direct radiation exposures or contamination due to deposition. Special attention was given to the volatile fission products, xenon, krypton, bromine, and iodine and to strontium. The latter two are biologically the most hazardous.

Typical Location

The reactor is assumed to be located near a large body of water, most likely a river, and about 30 miles from a major city. As in many sites proposed to date, a site boundary of 2,000-foot radius is postulated.

Population Distribution

Distributions of populations around reactors would differ considerably in detail from one site to the next. However, many general features would be remarkably similar, especially at large distances. Each reactor site would be in an area of low population density, a large city would be located about 30 miles away and the density of population would increase from the reactor toward the city. If the total population enclosed within a circle of radius R centered at the reactor is calculated for distances to the city, it develops that the total population within given radial distances is remarkably alike for all reactor sites now in use or proposed. This population can be expressed by the equation: $P = 200R^{2.83}$, where R is in miles.

At distances beyond the city, the average population density decreases and a different expression must be used. Average population density over the entire United States is about 55 people per square mile. Reactors, however, are likely to be built in more populated areas, such as in the northeast, where the average runs about 500 per square mile. Therefore, the assumption is made that the population density beyond the city is constant, and averages 500 people per square mile. For most situations these assumed population distributions are on the conservative side, i.e., in hardly any likely place would the population be underestimated, and in most places they overestimate the number of persons in areas which may be affected by a reactor accident.

For some types of accidents, the high population density in the nearby city needs to be calculated independently of the general treatment described above. In these cases, it was assumed that the city located 30 miles from the reactor has a population of about 1,000,000 persons spread uniformly over a region having a diameter of about 10 miles. Where the existence of the city contributes significantly to the calculated damages, city damages are listed separately.

Characteristics of Released Products

Accidents of greatest concern would be those which resulted in release and subsequent atmospheric dispersal of fission products from the reactor. The characteristics of the fission products at the time of release would have a great influence on their subsequent dispersal. Two factors having the greatest impact in determining the effect of distribution due to various meteorological conditions would be the size of the particles contained in the release and the temperature of the radioactive cloud at the time of release. These factors could, of course, vary from one reactor accident to another and undoubtedly would be highly dependent upon the particular accident. For the purpose of this study two choices were made for each factor, each choice being considered as probable and also illustrative of widely different conditions. For temperatures of release, the two *chosen* conditions were characterized by "hot" and "cold," the temperatures being 300° F. (temperature of steam at a pressure sufficient to rupture the containment vessel) and 70° F. (normal atmosphere temperature), respectively. For particle size two distributions were assumed, one centered about one micron and the other seven microns in diameter, these being representative of fumes and industrial dust, respectively. Experience does not permit a better definition of the particle size; it does, however, lend credibility to these two choices.

Mechanism of Distribution

Assuming that a release had occurred, consideration must then be given to the assumed existing weather conditions and to other factors that might influence the rate and pattern of distribution of the released materials. Numerous variables here could combine into an almost infinite variety of situations. It is possible (see appendix I) to obtain an indication of the range of damages from calculations on a reasonably small number of cases by limiting the number of meteorological variables to those having major influences and choosing one or two appropriate values for each.

The meteorological variables selected are: weather—(a) dry and (b) rain (0.02 inches per hour over the whole area affected); atmospheric stability—(a) typical daytime lapse with a wind speed of 5 m/sec (12 mph) and (b) night-time typical inversion with a wind speed of 3 m/sec (7 mph) up to 50 meters height and 15 m/sec (35 mph) above; height of cloud rise—(a) cold release, zero, (b) hot release, 860 meters during lapse, 400 meters during inversion (appendix E). It should be noted that the conditions assumed in any given case existed continuously for the duration of the case and the area affected.

It should be noted here that exceedingly little is known about the details of atmospheric distribution, even if the characteristics of the materials under consideration and the many environmental factors involved could be stated with great confidence. Nevertheless, use of these approximate average values, above, does give reasonably dependable general indications of the results to be expected in a large majority of possible situations.

Tolerance Levels for Personal Injury

Personal injury might result from exposure of personnel to the radioactive cloud released during the postulated accidents. Personal injury might also arise from exposure to deposited fission products. In the latter case, ample time often would be available to permit evacuation from contaminated areas before serious injury would occur. In appraising the hazard to individuals who might be exposed, it would be necessary to define the probable extent of injury caused by various doses of radiation. This is an exceedingly complex matter (appendix D). Using the best advice available and considering various biological effects such as ingestion, external and internal radiation problems, and the special problems arising from particular fission product isotopes having special biological importance, the following ranges, as described in appendix D, were adopted:

	Equivalent whole body gamma radiation	*Concentration of released fission products to give equivalent exposures*	
		Volatile FP's (curie-sec/m³)	*Gross FP's (curie-sec/m³)*
A. Lethal exposure..	Over 450r	Over 350 .	Over 400
B. Injury likely.....	100 – 450r	80 – 350..	90 – 400
C. Injury unlikely, but some expense may be incurred; observation required.	25 – 100r	10 – 80...	10 – 90
D. No injury or expense.	Less than 25r [1]	Less than 10.	Less than 10.

[1] 25r in one exposure or 50r in three months.

The first column indicates the equivalent whole-body gamma radiation adopted as the basic criterion to define the several categories. Columns two and three have been calculated for these same criteria in terms of units used to estimate the effect of passage of the radioactive cloud. While these values are believed to be the best obtainable at the present time, many of the factors used in deriving them are highly uncertain. It should be noted that personal injury is considered to have occurred only in the first two categories. Expense might be incurred for exposures in the third category, but only for examination, observation and incidentals, not actual personal injury.

Degrees of Land Contamination

By far the largest dollar cost to the public of a major reactor accident would result from contamination of land areas by deposited fission products. Inhabitants of portions of the areas affected would have to be evacuated to avoid serious exposure. Access to various areas might be denied for different lengths of time, and the subsequent use of land for agricultural purposes might be curtailed, with possible loss of standing crops. The same basic exposure-injury criteria listed above (column 1) were used also for determining the consequences of land contamination. Details of calculations are shown in appendix D. In the case of land contamination, the existence of specific isotopes, especially strontium-90, must be considered very carefully. The severe restrictions that might be imposed on farming arise almost entirely from the existence of this particular isotope.

To estimate the potential loss arising from problems of land contamination both the number of persons and the area affected were calculated. In some instances the costs were evaluated by associating them with an average cost per person. In the particular cases associated with farm restriction an average cost per square mile was used.

The categories chosen, and costs assumed for each are:

Range I.	Evacuation of personnel — immediate	$5000/person
Range II.	Evacuation of personnel — orderly and in a reasonable time	$5000/person
Range III.	Restrictions on land and outdoor activity	$ 750/person
Range IV.	Crop and farm restriction	$25,000/sq. mile

The criteria used in establishing these ranges are described in appendix D. It should again be emphasized that they are based on meager data.

Reactor Accidents Assumed

Three types of reactor accidents were considered necessary for this study in order to indicate the range of public hazard which could result and to delineate the influence of the important variables as described above on the magnitude of these hazards. The three "typical" cases selected are:

A. *The Contained Case*

In this accident, it is assumed that all of the fission products from the 500,000-kw (thermal) reactor, after 180 days of operation, are released from the core and distributed uniformly throughout the interior of the containment building. None is assumed to escape. The fission products are assumed to decay at their natural rate, with no attempt at decontamination, etc., after the accident. Hazard to the public would arise from the direct gamma radiation from the fission products dispersed inside the containment building. One inch of steel shielding by the walls of the building is assumed. The site boundaries are 2,000 feet from the reactor.

B. *The Volatile Release Case*

In this case it is assumed that all of the volatile fission products in the reactor (500,000-kw (thermal) after 180 days), i.e., xenon, krypton, iodine, bromine and 1 percent of the strontium are released from the containment building and are subsequently dispersed, with characteristics and meteorological conditions as described and specified above. See appendix A.

C. *The 50 Percent Release Case*

In this case, it is assumed that 50 percent of all fission products in the reactor (500,000-kw (thermal) after 180 days) are released from the containment building and are subsequently dispersed, with characteristics and meteorological conditions as described and specified above. See appendix A.

Each of these arbitrary cases represents a highly pessimistic assumption. Certainly more catastrophic releases of the Contained and the Volatile types are not possible. In the third type, it is conceivable that more than 50 percent of all fission products could be released, but this is considered to be so far in the realm of incredibility as not to merit consideration.

Part III

Estimated Consequences of the Assumed Reactor Accidents

In this part of the report, there is presented a brief summary of the calculated damages obtained from each of the assumed accidents, together with brief observations and pertinent comments on the results obtained in the respective cases. Reference is made to appendices H and I, of part IV, for more complete tabulation of results.

CASE I—THE CONTAINED CASE

The assumption is made that all of the fission products are vaporized and dispersed within the containment shell. There is no release to the atmosphere. Damage to the public would then result from direct exposure to gamma radiation. The following tabular summary shows personal injuries and evacuation costs beyond the 2,000-foot boundary of the reactor site.

PERSONAL INJURY

	Assuming evacuation in 2 hours (persons)	*Assuming evacuation in 24 hours* (persons)
Lethal exposure	0	0
Injury likely	0	6
Injury unlikely, but expense likely.	1	15

EVACUATION COSTS

Number of People	*Area*	*Cost*
67	1.8 sq. mi.	$335,000

Observations and Remarks

1. The above results would be the maximum possible for this type of accident in that all fission products would be involved and no shielding except the container is assumed.
2. Under the best conditions, namely, prompt evacuation of nearby personnel, no personal injury would be likely. The public loss would be due entirely to evacuation costs and payments for denial of use of land. This can be measured in the hundreds of thousands of dollars.
3. Under less favorable conditions, namely, slower evacuation, a small number of personal injuries might be expected.
4. Use of the typical site and population distribution is less satisfactory for this case since nearby population variations from site to site are larger than the numbers of people affected. The method does, however, give an order-of-magnitude.
5. For smaller site boundaries, larger numbers of people would be affected, especially in the injury category. However, with proper combinations of distance and shielding no loss to the public would be involved.

CASE II—THE VOLATILE RELEASE CASE

Here it was assumed that, because of a breach in the container or failure to close all openings, all volatile fission products would be discharged to the atmosphere at the time of the accident. Four different situations of meteorological conditions and two particle size distributions were considered. Furthermore, separate indication is given for releases which include 1 percent of the strontium inventory and for those which do not.

A full summary of the calculated damages is contained in appendix I. The following table contains a brief summary to indicate the magnitude and range of the consequences.

The Volatile Release Case

Personal Injury

A. *Lethal exposure*	*Persons*	*Conditions at release*
Minimum	2	Temperature lapse
Maximum	900	Temperature inversion, 1μ particles

Assuming that (1) the particle size distributions are equally probable, and (2) the distribution of weather conditions is as stated in appendix I, then lethal exposures would be less than five people for those accidents which might occur during about one-half of the time or less than 300 people for those accidents which might occur during about three-fourths of the time.

B. *Injury likely*	*Persons*	*Conditions at release*
Minimum	10	Temperature lapse, 7μ particles
Maximum	13,000	Temperature inversion, 1μ particles

Using the same assumptions as under A, the number of persons injured would be less than 20 people for those accidents which might occur during about one-half of the time or 2,000 people for those accidents which might occur during about three-fourths of the time.

Property Damage

II. *Evacuation*	*Persons*	*Area (sq. mi.)*	*$ Millions*	*Conditions*
Minimum	0	—	—	Temperature lapse, dry
Maximum	41,000	28	205	Temperature inversion, rain

Under the same assumptions as under A, the number of persons requiring evacuation would be less than 1,000 for accidents which might occur during about two-thirds of the time or 6,000 for those accidents which might occur during about nine-tenths of the time.

III. *General restrictions (due to Sr)*	*Persons*	*Area (sq. mi.)*	*$ Millions*	*Conditions*
Minimum	20	1	0.01	Temperature lapse, dry, 1μ
Maximum	235,000	350	177	Temperature lapse, rain, 1μ

Under the same assumptions as under A, the area placed under general restrictions would be less than 50 sq. mi. for those accidents which might occur during about three-fourths of the time.

IV. *Agricultural Restrictions (due to Sr)*	*Area (sq. mi.)*	*$ Millions*	*Conditions*
Minimum	3	0.1	Temperature lapse, dry, 1μ
Maximum	3,500	90.	Temperature lapse, rain, 1μ

Under the same assumptions as under A, the area placed under agricultural restrictions would be less than 500 sq. mi. for those accidents which might occur during about nine-tenths of the time.

Observations and Remarks

1. The number of personal injuries is highly dependent upon existing weather conditions at the time of the accident. Few lethal exposures would occur during daytime conditions. Exposures of large numbers of persons would occur during temperature inversions, typical of night-time conditions.
2. Except when strontium accompanies the release, property damage would range from essentially none to approximately two hundred million dollars. Without strontium, there would be no restrictions on agriculture.
3. The presence of strontium would add severe restrictions on land use both for general activity and for agricultural purposes. Decontamination would also be required within certain city areas. The net effect would be to increase the property damage and personal dislocation costs to a maximum of about 400 million dollars.

CASE III—THE 50 PERCENT RELEASE CASE

In this case it is assumed that 50 percent of all fission products would be released into the atmosphere and subsequently dispersed according to assumptions described earlier. Appendix I contains a summary of the personal injuries and property damages calculated for the variety of conditions considered. The following table contains a brief summary to indicate the magnitude and range of the consequences.

Personal Damage

A. *Lethal exposure*	*Persons*	*Conditions at release*
Minimum	0	Hot release at any time
Maximum	3400	Cold release, 1μ particle size, temperature inversion

Assuming that (1) hot and cold releases are equally probable, (2) particle size distributions are also equally probable, and (3) the distribution of weather conditions is as stated in appendix I, then lethal personal exposures would be less than 10 for accidents which might occur during about three-fourths of the time.

B. *Injury likely*	*Persons*	*Conditions at release*
Minimum	0	Hot release at any time
Maximum	43,000	Cold release, 1μ particle size temperature inversion, dry

Using the same assumptions as under A, the number of persons injured would be less than 100 for accidents which might occur during about three-fourths of the time.

Property Damage

II. *Evacuation*	*Persons*	*Area (sq. mi.)*	*\$ Millions*	*Conditions*
Minimum	0	0	0	Hot, temperature inversion
Maximum	460,000	760	2300	Cold, 1μ, temperature inversion, rain

Using the same assumptions as under A, the number of persons to be evacuated would be less than 50,000 for accidents which might occur during about three-fourths of the time.

III. *General restrictions*	*Persons*	*Area (sq. mi.)*	*$ Millions*	*Conditions*
Minimum	0	0	0	Hot, 1μ, dry
Maximum	3,800,000	8200	2800	1μ, rain

Using the same assumptions as under A, the area placed under general restrictions would be less than 1,200 sq. miles for accidents which might occur during about three-fourths of the time.

IV. *Agricultural restrictions*	*Area (sq. mi.)*	*$ Millions*	
Minimum	18	0.5	Hot, 1μ, day, dry
Maximum	150,000	4,000.	Hot, 1μ, day, rain

Using the same assumptions as under A, the area placed under agricultural restrictions would be less than 10,000 sq. miles for accidents which might occur during about 93 percent of the time.

(The numbers above are from different cases and hence are not additive.)

Observations and Remarks

The numbers shown in the previous summary are calculated on the basis of what we believe to be the best available assumptions, data and mathematical methods. As has been stressed elsewhere, there is considerable uncertainty about many of the factors, techniques and data, so that these numbers are only rough approximations. Where information is sufficiently complete we have chosen values to represent the most probable situation but where high degrees of uncertainty exist we have chosen values believed to be on the pessimistic (high hazard) side. The results shown would be quite sensitive to variations in some of the factors which were used. As an example, the amount of fission products actually retained in people's lungs might be quite different from the amount assumed and this difference would change all the personal injury numbers greatly.

In addition, there could be weather conditions which, when combined with other imaginable extremely adverse conditions, could result in damages greater than the maximum considered in this study.

The damages calculated for the assumed 50 percent fission product release would vary widely depending upon weather conditions and assumed temperatures of the released materials.

The lethal exposures could range from none to a calculated maximum of 3,400. This maximum could only occur under the adverse combination of several conditions which would exist for not more than 10 percent of the time and probably much less.

Under the assumed accident conditions, the number of persons that could be injured could range from none to a maximum of 43,000. This high number of injuries could only occur under an adverse combination of conditions which would exist for not more than 10 percent of the time and probably much less.

Depending upon the weather conditions and temperature of the released fission products for the assumed accident, the property damage could be as low as about one-half million and as high as about $7 billion. For the assumed conditions under which there might be some moderate restrictions on the use of land or crops (Range IV), the areas affected could range from about 18 square miles to about 150,000 square miles.

WASH-1224

COMPARATIVE RISK-COST-BENEFIT STUDY OF ALTERNATIVE SOURCES OF ELECTRICAL ENERGY

A COMPILATION OF NORMALIZED COST AND IMPACT DATA FOR CURRENT TYPES OF POWER PLANTS AND THEIR SUPPORTING FUEL CYCLES

DECEMBER 1974

EXCERPT

UNITED STATES ATOMIC ENERGY COMMISSION
DIVISION OF REACTOR RESEARCH AND DEVELOPMENT

WASH-1224 UC-11
WASH-1224 UC-13
WASH-1224 UC-41
WASH-1224 UC-81

COMPARATIVE RISK-COST-BENEFIT STUDY OF ALTERNATIVE SOURCES OF ELECTRICAL ENERGY

A Compilation of Normalized Cost and Impact Data for Current Types of Power Plants and Their Supporting Fuel Cycles

December 1974

Office of Energy Systems Analysis
Division of Reactor Research and Development
United States Atomic Energy Commission

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price $3.20

CHAPTER 1

INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

The role of energy in sustaining and advancing civilization is fundamental and pervasive. It is difficult to identify a single artifact or activity of modern society which does not involve, either directly or indirectly, an expenditure of energy beyond that associated with man's muscular exertions.

In general, the production of a quantity of useful energy, such as a kilowatt-hour of electricity, involves several dimensions of cost:

(a) the diversion of conventional labor, material, and capital resources, all of which are normally reflected in the market price of energy;
(b) the consumption of a quantity of a nonrenewable fuel resource, thus precluding its use in the future;
(c) degradation of natural and manmade environments, including disruption of natural material, energy, and biological balances, and damage to man-made structures and materials.
(d) impacts on human health and safety.

Recently, popular attention has been drawn to the last two of these cost groupings, as evidenced by the staggering proliferation of energy and environmental studies in the past few years.

Concern over environmental impacts of producing electrical energy has often focused on very narrow aspects of individual electrical energy production systems,* such as thermal effects of discharge heat from power plants, mining impacts, and air pollution. For this reason, the quantitative environmental literature on electrical energy production is, to a large extent, fragmentary and redundant.

A more balanced and coherent view requires that costs and impacts throughout entire fuel cycles be identified, quantified, normalized and compared on a consistent basis. As part of a continuing analysis of the role of nuclear power in providing the Nation's energy requirements, the Division of Reactor Research and Development of the United States Atomic Energy Commission has undertaken such an assessment -- the "Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy."

*The terms "electrical energy production system" and "fuel cycle" are used synonomously in this report.

Purpose and Scope

The purpose of this study is to provide a quantitative basis for making comparisons of societal costs across and within alternate electrical energy production systems. The principal tasks in achieving this goal are to assign internal and external costs of the alternate systems to a common unit of electrical energy produced (kilowatt-hours) and to express such costs, where possible, in consistent units (dollars). Fuel cycle material balances provide the central format for assembling and normalizing data, and provide the quantitative link between an impact or cost anywhere in the system, and a corresponding quantity of electrical energy (benefit) produced.

Such information could provide a preliminary basis for numerous ancillary comparisons and cost-benefit tradeoffs, including: (a) comparisons of total costs (internal plus external) of producing electrical energy from alternate fuels; (b) comparisons of external and internal costs for each process step within each fuel cycle, in order to determine which steps are the most environmentally offending, and in order to measure the cost-effectiveness of abatement measures; (c) comparison of external costs of alternative methods for the same functional step in a given fuel cycle; and (d) comparison of the total costs associated with alternative energy strategies, or mix of fuels, to meet a given energy demand projection over a period of time; and (e) coherent judgements regarding abatement measures, which, while reducing an impact at one stage in an energy system, may increase impacts at another.

The following restrictions and assumptions serve to further define the scope of the Study.

- The study is confined to electrical energy. A more comprehensive assessment would include all forms of end use energy ("total energy"). Benefits and costs of substituting electrical energy for other forms are not addressed, although the coefficients developed in the course of this study can be useful in such analyses.

- The study is restricted to electrical energy production, and embraces entire fuel cycles, and their residuals. Questions regarding electrical energy use are not addressed, although alternative electrical energy use patterns may have significant environmental and economic differences.

- Attention is restricted to modern, commercial size, baseload power plants and their supporting fuel cycle facilities, and to those systems based on technologies whose commercial application is proven. The analysis includes only those systems expected to make major contributions to base load power production in the near term, i.e. the next ten or fifteen years. Systems considered are those based on coal, residual fuel oil, natural gas, nuclear fission (LWR) fuels, and hydroenergy. Although two types of advanced nuclear fission reactors -- the HTGR and the LMFBR -- are expected to make significant contributions to base load power by the end of this century, these concepts are not addressed quantitatively in this report. Electricity generation using gasified coal is similarly excluded.

. The study is restricted largely to quantification of the environmental and human impacts of the energy systems under normal operating conditions. Certain classes of routine industrial accidents, for which reliable statistics are available, are treated, however. Large, hypothetical accidents at a nuclear power plant are excluded, since other concurrent USAEC studies are addressing this topic.

. "Benefit" in this study is defined as a quantity of electrical energy, e.g., one kilowatt hour. No attempt is made to determine the absolute societal value of electricity. That is, the question addressed is not whether a unit of electrical energy should be produced, but instead how it should be produced.

"Risks" are treated as "costs" in this study: the product of the probability of an undesirable event (per unit of electrical energy) times the consequences of the event.

"Costs" include both "internal" and "external" costs. Internal costs are those costs already borne by electricity consumers. Internal costs are already imbedded in the price of electricity (mills/kWhe) and include the conventional components -- labor, materials, and costs of capital. External costs are the environmental and human impacts not accounted for in the price of electricity.

With the definitions of benefit, risk, and cost established above, the study reduces to a comparison of total costs to produce electricity by alternative fuels.

. Much of the information assembled in this report is based on aggregate national data. In this sense, the assessment assumes a national homogeneous model, at the expense of displaying regional variations in unit costs, impacts, engineering and economic constraints, local utility company practice, site-specific considerations, and the like. For example, in order to properly burden a quantity of electrical energy with coal mining impacts, it is necessary to assume production fractions from surface and underground mining techniques. Although the unit impacts of production methods are disaggregated and displayed separately in the body of the report and in other supporting materials,* production fractions representative of the current national pattern (~50% underground, ~50% surface) are assumed for the purpose of constructing summary tables. The same general approach was taken in several other elements of the assessment.

The bases for normalization of costs and impacts are 1000 MWe of electrical generating capacity, or the annual operation of one 1000 MWe unit at 75% capacity factor (6.57 billion kWhe).** All fuel cycle parameters are normalized to these quantities through equilibrium fuel material balances. The resulting evaluation is a static comparison of costs and impacts associated with alternate energy systems. It is recognized, however, that the overall problem of ranking alternatives is a time dependent one, and that alternatives must be regarded as changing mixes of energy sources or energy strategies, rather than as individual, isolated sources. The development of static impact coefficients, the central task of this study, is a prerequisite of the broader assessment of comparing energy strategies.

1.2 SUMMARY AND CONCLUSIONS

Summary

For purposes of making gross comparisons, representative costs and impacts of alternative electrical energy production systems† were assembled and normalized to 6.57 billion kilowatt hours (kWhe), the annual energy produced by one 1000-MWe unit operating at 75% capacity factor. Systems considered were those based on coal, oil, natural gas and nuclear fission fuels.†† Attention is restricted to modern, commercial size, baseload power plants and their supporting fuel cycle facilities, and to those systems based on technologies whose commercial application are proven. Although two advanced reactor types, the HTGR and the LMFBR, are expected to make significant contributions to base load power production by the end of the century, this study includes a quantitative appraisal only of the current generation of power reactors -- the LWRs. Emphasis of the report is on quantifying effects throughout the respective fuel cycles, from fuel extraction to power generation, as conceptualized

*and are available to the reader in substituting his own assumptions.

**Some impacts and costs are related to a unit of electrical energy produced (kWhe), while others are related to power capacity (MWe).

†The terms "electrical energy production system" and "fuel cycle" are used synonymously in this report.

††The hydro-energy system is discussed qualitatively in Chapter 3. Little quantitative information is developed, since relatively little additional hydro capacity is expected to be installed.

in Fig. 1.1. Where possible, non-conventional costs were reduced to a common basis (same unit of electrical energy produced) and to common units (dollars), thus rendering them comparable and, perhaps, additive.

The information assembled and normalized in this report emerged from an extensive literature survey aimed at quantifying numerous individual impacts and costs. In most cases, the individual impacts and costs displayed in this report are derived quantities. Individual items of data were rarely found in the desired format, that is, restricted to the particular impact or cost under consideration and normalized to a unit of electrical energy produced or to a unit of production capacity. For each item addressed, considerable manipulation -- disaggregation, interpretation, averaging, normalization -- was necessary to reduce the quantity to consistent and meaningful information. In several cases, only source terms, e.g., pollutant emission rates, are presented. Ideally, one would reduce all such quantities to ultimate impacts in consistent damage units to permit their display as added costs.

Table 1.1 summarizes comparative data for the alternate fuel cycles normalized to production of 6.57 billion kWhe or to a generating capacity of 1000 MWe.* The format of Table 1.1 warrants some explanation. First, much of the data represents sums over the individual fuel cycle process steps. Chapters 3 and 5 give similar data for each process step, permitting the reader to make comparisons among process steps of individual fuel cycles or among similar process steps (e.g., mining) across competing fuel cycles. Further, it is recognized that the organization of a table such as Table 1.1 can prejudice and distort a comparative assessment.** In this regard, great care was taken to present an objective set of impacts and costs, assembled in a coherent, but uncontrived, matrix. Entries in Table 1.1 are arranged to conform roughly to the four conceptual groupings of costs and impacts established in the Introduction: (a) conventional costs; (b) consumption of nonrenewable fuel resources; (c) environmental degradation; and (d) impacts on human health and safety.

The major categories of Table 1.1 are discussed briefly below.

Power Plant and Energy System Efficiencies

Power plant net thermal efficiencies for the fossil plants are essentially the same -- 38-39%. The LWRs, PWR and BWR, have somewhat lower net thermal efficiencies, ~ 32%, owing to their coolant temperature limitations.

*Some impacts and costs are related to a unit of production, while others are related to system capacity.

**e.g., the grouping of data under descriptive headings, the selection of "typical" or "representative" parameters, the omission of impacts not quantifiable, etc.

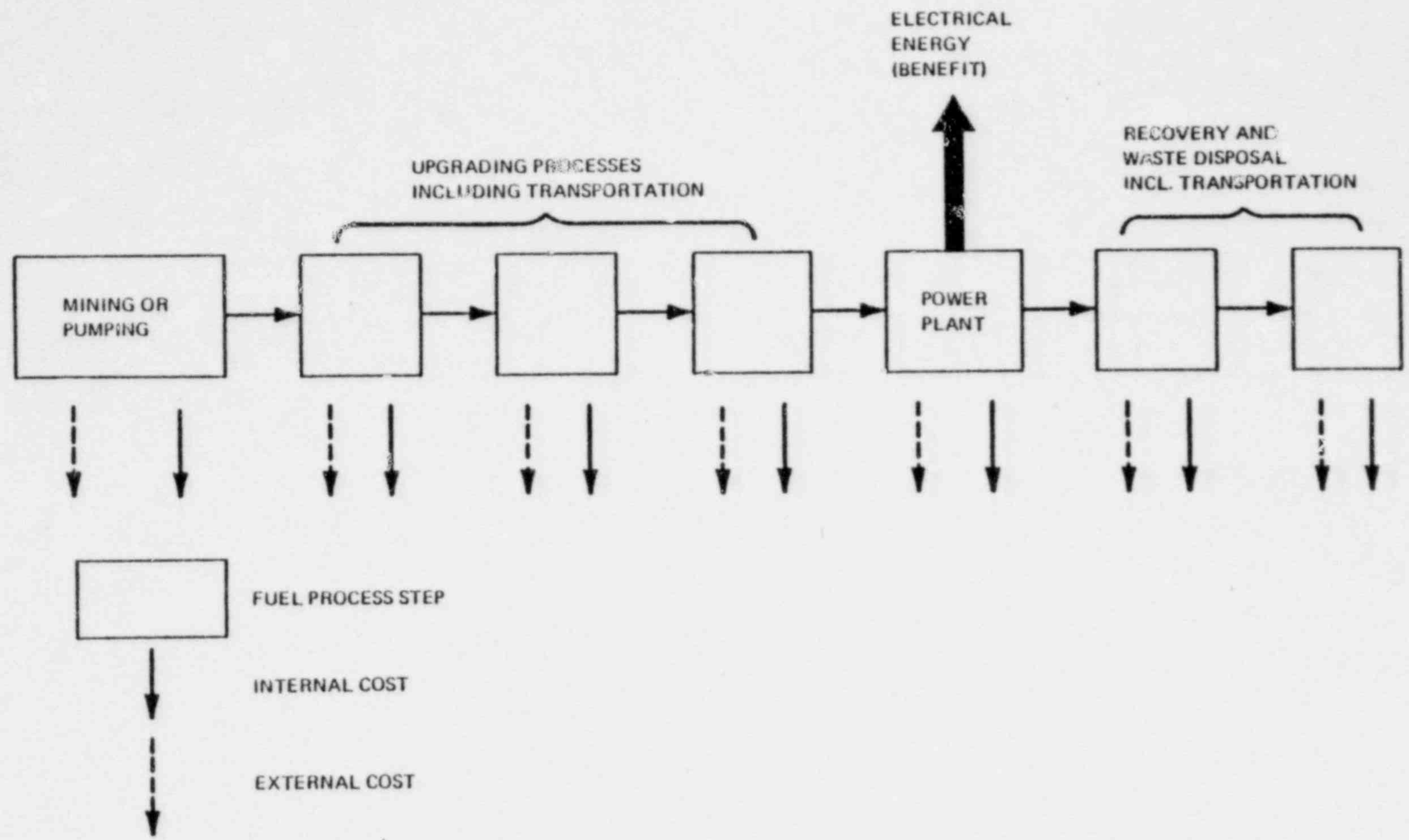


FIG. 1.1 SCHEMATIC OF A FUEL CYCLE (ENERGY PRODUCTION SYSTEM)

TABLE 1.1 COMPARISON OF COSTS AND IMPACTS OF ALTERNATE ELECTRICAL ENERGY PRODUCTION SYSTEMS*

Basis: 1000 MWe Power Plant, 75% CF
6.57×10^9 kWhe

	Coal	Oil	Gas	LWR
POWER PLANT AND ENERGY SYSTEM EFFICIENCIES				
Electrical Energy (billion kWhe/year)	6.57	6.57	6.57	6.57
Power Plant Heat Rate (BTU/kWhe)	8,900	8,830	9,110	10,850
Power Plant Thermal Efficiencies (kwe/kw_t, %)	38	39	38	32
Energy System Efficiency (kwh_e consumer/kwh_t input, %)	35	35	34	28
CONSUMPTION OF NON-RENEWABLE FUEL RESOURCES				
Power Plant Fuel Consumption (annual)	2.3M tons	10M barrels	64 B cubic ft.	~130 M tons U**
Fraction of Reserves Consumed (annual)	0.000006	0.0001	0.0004	0.0002
CONVENTIONAL COSTS (mills/kWhe)* **				
Plant	7.8	7.2	6.4	11.7
O&M	0.8	0.6	0.6	0.8
Fuel	9.8	27.4	36.0	6.0
Total	18.4	35.2	43.0	18.5
SELECTED ABATEMENT COSTS (mills/kWhe)* **	4.7	2.0	0.6	0.6
OCCUPATIONAL HEALTH AND SAFETY				
Occupational Health (MDL/yr)	600	U	U	480
Occupational Safety				
Fatalities (Deaths/year)	1.1	0.17	0.08	0.1
Non-Fatal Injuries (#/year)	46.8	13.1	5.3	6.0-7.0
Total Man-Days Lost (MDL/year)	9,250	1,725	780	900-1000
PUBLIC HEALTH AND SAFETY				
Public Health				
Routine Pollutant Release (MDL/year)	U	U	U	180-210

TABLE 1.1 CONTINUED

Basis: 1000 MWe Power Plant, 75% CF

	Coal	Oil	Gas	LWR
Public Safety				
Transportation Injuries				
Fatalities (Deaths/year)	0.55	U	U	0.009
Non-Fatal (Injuries/year)	1.2	U	U	0.08
Total Man-Days Lost (MDL/year)	3,500	U	U	60
ENVIRONMENTAL DEGRADATION				
Land				
Land Use, Inventory (acres)	22,400	~1,600	~3,600	~1,000
Land Use, Consumption (acres/year)	740	S	S	12
Air				
SO_2 release, w/o abatement (tons/year)	120,000	38,600	20	3,600
, w abatement	24,000	21,000	0	720
NO_x releases, w/o abatement (tons/year)	27,000	26,000	13,400	810
Particulate releases, w/o abatement (tons/year)	270,000	26,000	518	8,000
, w abatement	2,000	150	4	60
Trace Metals releases (tons/year)	0.5 Hg	1,500	U	S
Radioactivity releases (Ci/year)	0.02	0.00[illegible]	S	250-500 T
Thermal Discharge, power plant stack (billion kwh_t/year)	1.64	1.71	2.2	0
Water				
Cooling Water Use (billion gal./year)	263	263	263	424
Process Water Use (billion gal./year)	1.46	1.75	1.42	0.095
Radioactivity releases (Ci/year)	0	0	0	500-1000
Other Impacts (billion gal./year)	16.8	7.9	0	S
Thermal Discharge, power plant (billion kwht/year)	9	9	9	14

U ≡ Unevaluated; S ≡ Small; M ≡ Million; B ≡ Billion; T ≡ Thousand

*The number of digits shown is not generally indicative of precision. In many cases, several digits are retained merely for calculational purposes.

**About 99% of this figure is not irretrievably consumed; rather, it is available in the form of enrichment plant tails for use in breeder reactors.

***1980 dollars.

Overall energy system efficiencies include corrections for process heat and electrical energy requirements of the supporting fuel cycle operations. For all systems, process heat requirements for the supporting fuel cycle are negligible compared to the heat input at the power plant. Fuel cycle electrical energy requirements are also negligible, except for the diffusion-enrichment plant requirements for the LWR systems, which are of the order of 3 to 5% of the power plant output. Transmission losses are assumed the same for all systems.

The fossil fuel cycles have similar systems efficiencies -- $\sim$ 35%. The LWRs have lower system efficiencies, $\sim$ 28%, due both to their lower power plant efficiencies and their enrichment plant power requirements.

More detailed analyses of the overall fuel cycle energy balances are given in Chapter 5 and in the Appendix.

Consumption of Nonrenewable Fuel Resources

The availability of fuel at acceptable cost is a major consideration in selecting a power plant type. For example, fuel shortage offsets the environmental benefits of the natural gas system. Annual fuel consumption of each 1000 MWe plant is expressed in Table 1.1 as a fraction of reserves available for U.S. electric power production, at current extraction costs and with current extraction technology. Current alternative-use fractions were used to establish the reserve base available to the U.S. electricity production. Residual fuel oil (RFO) assumed to be available from Africa and Venezuela is included in the RFO reserve base.

Coal is seen to be the most abundant fossil fuel resource, natural gas the least. Foreign deposits place the RFO system on a par with the LWR systems.

Fuel resource data is given for each of the mineral fuels in Chapter 3, and reduced to equivalent quantities of electrical energy in Chapter 5.

Conventional Costs

Conventional costs are those definable costs already imbedded in the price of electricity to the consumer -- the costs for labor, materials, and use of money. They include the capital cost of power plant amortized over the life of the plant, plant operating and maintenance costs, and fuel costs. Fuel costs include costs incurred throughout the fuel cycle, including capital costs of fuel cycle facilities. These costs are ultimately transferred to the utility company and, together with utility company working capital changes associated with fuel, borne by the consumer.

Representative conventional costs, corrected for escalation to the year 1980, are shown in Table 1.1. The purposes of including conventional costs in this report are to show roughly the market competiveness of the alternate energy systems and to provide reference points for comparison of nonconventional costs. Where possible, costs associated with abatement and restoration measures have been separated from the conventional costs.

It should be recognized that conventional costs are quite sensitive to power plant location. Further, a number of factors cause such costs to vary with time -- routine inflation, abundance of fuel resources, capacity/throughput effects, legal and regulatory actions, technological maturity, etc.

Abatement Costs

Abatement costs in Table 1.1 include SO_2 removal from stack gases (coal), desulfurization of residual fuel oil, natural-draft evaporative cooling towers (all plants), near-zero radwaste systems (LWRs) and surface mined land reclamation. This is not, of course, a complete list.

Abatement costs in the coal cycle are the greatest, due to the large cost projected for SO_2 removal. The desulfurization of residual fuel oil is the dominant abatement cost in the oil cycle. The near-zero radwaste treatment systems add little to the LWR energy costs.

Environmental Degradation

Burden rates on the environmental receptors* -- land, air, and water -- are displayed in Table 1.1, with the intent of presenting crude measures of relative environmental impacts of the alternate energy systems. In most cases, these burden rates are merely source terms, i.e., emission rates normalized to a quantity of electrical energy produced. Ideally, these quantities would be reduced to incremental quantities of damage to ultimate receptors, such as natural flora and fauna, structural materials, crops, and the like. Dollar costs could then be assigned to units of damages. Owing largely to the lack of damage-function information for each pollutant-receptor combination, this procedure could not be followed rigorously.

Two aspects of land use are included in Table 1.1: land tied up or committed by the power plants and their supporting fuel cycle; and the land "consumed" annually, e.g.,

*Effects on human health and safety are frequently included in the term "environmental effects." In this study, human health and safety are considered separately. The next two sections deal, respectively, with occupational and public health and safety.

land disturbed by surface mining, land inundated by disposal of fuel cycle residuals. The coal fuel cycle has the greatest land impact, owing mainly to its mining operations and waste disposal. Inventory land requirements for the nuclear fuel cycles are magnified by exclusion-area requirements, but are still an order of magnitude less than that of the coal cycle.

Annual emissions of sulfur oxides, nitrogen oxides, particulates, radioactivity, heat, mercury, and vanadium to the atmosphere are shown in Table 1.1. The coal energy system releases greater quantities, per unit energy produced, of SO_2, NO_x, and particulates than do the other fossil systems. For purposes of comparison, electrical energy required for the gaseous diffusion enrichment of LWR fuel is assumed to be provided by a coal-fired plant, and prorated quantities of coal cycle pollutants are, accordingly, assigned to the LWR fuel cycle.* It is interesting to note that on this basis, the LWR cycle "emissions" of SO_2 and particulates are greater than those of the natural gas fuel cycle. Thermal releases to the atmosphere are about 15% of the total heat rejected by fossil power plants. There are, of course, no atmospheric thermal releases at nuclear power plants. Minute quantities of radioactive materials are routinely released from nuclear facilities to the atmosphere. These emissions are of primary concern to public health, and are discussed below, together with fossil pollutants, under the heading "Public Health and Safety."

Light water reactors, because of practical coolant temperature limitations, operate at lower thermal efficiencies and, therefore, reject more heat than modern fossil fuel plants of the same generating capacity. For this reason and because about 15% of the heat from fossil fueled plants is discharged into the atmosphere through the stack, LWRs discharge about 1/3 more waste heat to cooling water than do modern fossil fueled plants.

Process water use in the LWR fuel cycle is essentially negligible compared to that in fossil fuel cycles, due both to the nature of the processes themselves and to the relatively small masses and volumes of fuel materials involved. Chemical contamination of waterways is similarly small. Chemical contamination in the fossil system includes acid mine drainage in coal fields, black water from coal cleaning

*This is, of course, a purely arbitrary assumption, although the existing diffusion capacity is powered by coal-fired power plants. Notwithstanding recent publicity to the contrary, coal is not uniquely required for the production of enriched nuclear fuel. Some electricity (a few percent of the equivalent electrical energy yield of the nuclear fuel) is required, and any fuel which produces electricity will do.

plants; oil spills, ballast discharge, and refinery effluents in the oil system.

As discussed in Chapter 4, damage functions for each pollutant-receptor combination are not well established. Thus, any measure of damage costs, normalized to annual emission rate must be regarded as a gross preliminary estimate. Section 4.9 gives crude measures of the dollar costs imposed by damage from coal, oil, and natural gas plant SO_2 and particulate emissions. Section 4.10 presents estimates of dollar costs associated with impacts (largely consumptive water use) of waste heat rejection by natural draft wet cooling towers. Estimates of other damage costs -- associated with mine land disruption, oil spills and ballast discharge, and biological oxygen demand of refinery effluents -- are given in Section 4.11. All of these damage costs are summarized in Table 1.2. More detailed discussions are provided in the Appendix.

Occupational Health and Safety

Table 1.1 displays occupational health effects for coal and nuclear energy systems in units of man-days lost (MDL).

The dominant occupational health effect in the coal fuel cycle is coal workers' pneumoconiosis (CWP), or "black lung," a respiratory disease resulting from the accumulation of coal dust in the lungs of underground miners. An advanced stage of this disease is progressive massive fibrosis (PMF). Crude estimates of the frequency (normalized to 6.57 billion kWhe) of CWP cases, are compared to estimated occupational health effects in the light water reactor fuel cycles -- lung cancers among uranium miners due to inhalation of radon gas, and cancers resulting from occupational exposures at the reactor and reprocessing plants.*

It is estimated that on the order of one case of black lung can be attributed to the mining requirements associated with one 1000 MWe coal-fired plant per year.** By comparison, on the order of one malignancy would be expected in the light water reactor fuel cycles, per 1000 MWe plant, during the life of the plant (~ 30 years).

Occupational health is addressed in more detail in Sections 4.4, 4.6, 4.7 and in the Appendix.

Occupational injuries due to routine industrial accidents occur throughout the alternate fuel cycles. Table 1.1 gives injury rates, normalized to the annual operation

*6000 MDL is assigned to each malignancy; 1000 MDL is assigned to each case of simple CWP.

**Assumes 50% production in the power plant from underground mines. Also assumes that future U.S. coal mining health impacts, after implementation of the 1969 Act, will be similar to British experience.

of a 1000 MWe power plant. Injuries in the coal cycle exceed, by far, those in the other fuel cycles. About one occupational fatality per year can be attributed to each 1000 MWe coal fired plant. The dominant source of coal cycle injuries is underground mining.* The injury rates in the oil, gas, and LWR fuel cycles are roughly equivalent -- an order of magnitude below that of coal. Mining in the nuclear fuel cycles accounts for most of the injuries in these cycles. Because of the high energy content of nuclear fuels, nuclear fuel mining injury rates are much lower than those in coal mining.

Public Health and Safety

Public health effects of electricity production are extremely difficult to assess. Pollutant emission rates at the power plant or at a fuel process step in the supporting fuel cycle are first estimated. A thorough understanding of the process in question, and a careful description of the material flows involved in the process are normally sufficient to yield a fairly accurate emission rate, normalized to a given quantity of electrical energy produced. Transport of the pollutant through various pathways to man, or to alternate fates, must next be analysed. Factors involved in this step are local meteorology, hydrology, pollutant reconcentration mechanisms, pollutant loss mechanisms, biological uptake mechanisms, population distribution, and the life style, including diet, of the population. Human exposure levels and rates must then be assessed to determine dose. Finally, the health damage corresponding to this dose (using an appropriate dose-response function or coefficient) must be evaluated; and if warranted, a dollar cost may be assigned to the incremental health damage.

The establishment of dose-response relationships is at present the weakest link in this procedure. The relationships between health effects and pollutant concentrations (or dose levels) are generally established by epidemiological studies on statistical samples of the human population, or laboratory studies on animals. Animal studies require that results be scaled in some manner in order to estimate human effects.

Table 1.1 contains crude estimates of public health effects (in units of mandays lost)** of the routine radioactivity emissions from the nuclear fuel cycles. These figures are based on a very conservative dose-response coefficient of the order of ~0.0001 malignancy per rad, and the emission rates in curies per ton of fuel

*Occupational injury figures of Table 1.1 assumes 50% production from underground mines, 50% from surface mines.
**6000 MDL is assigned to each malignancy.

processed or per MWHe estimated in the present study. Section 4.4, the Appendix, and the footnotes of section 3.5 describe these calculations in more detail.

Unfortunately, human health hazards from fossil fuel pollutants are not as well understood and quantified as the health hazards from radiation. There is no dose-response data comparable in quality to therapeutic irradiation and atomic bomb casualty data and no linear dose-response model, both of which are so useful in estimating (however conservatively) radiation effects. Numerous measures of health effect have been investigated but no preeminent measure has emerged which is analogous to malignant neoplasm in the case of radiation. Toxicologic studies on animals have demonstrated that massive doses of specific chemicals such as sulfur dioxide may impair health. Likewise, chronic exposures of animals have demonstrated health effect. Correlations between various measures of human respiratory impairment, including death, and levels of air pollution have been observed during and following episodes of exceptionally high concentration of air pollutants. However, there is no information on the effect of individual exposure to specific pollutants during such episodes, and no dose-response relationship can be formulated. This same lack of exposure information plagues the attempt to establish pollutant-response correlations through study of chronic exposure. Several regression formulas have been developed which relate measures of mortality and morbidity to measures of general air pollution levels such as sulfur dioxide concentrations and concentrations of particulate matter. These formulae are of no use for the prediction of health effect as a function of pollution level because they have not been based on known and controlled populations, the exposure measures relate to concentrations made at several geographical locations but are not a measure of personal exposure, and the full spectrum of air pollutants is not represented in the equations. Although a quantitative comparison between radiation health effect and fossil air pollution health effect is an essential part of the comparison of nuclear and fossil fuel cycles, no quantitative estimate of fossil air pollution health effect, normalized to a unit of electrical energy produced, can be made at this time.

While it is not feasible, at this time, to normalize public health effects to a unit of energy produced, some perspective can be gained by comparisons of natural background levels, man-made exposures, regulatory standards, and broad ranges of pollutant concentrations known to result in some health effect. Figure 1.2 illustrates the comparisons for sulfur dioxide, nitrogen oxides, and whole body irradiation. The areas labeled "medically perceivable effects" are adopted from a recent University of California study.* Several tentative conclusions may be drawn from Figure 1.2.

*Hausknecht, D. Public Health Risks of Thermal Power Plants, University of California UCLA-ENG-7242 (May 1972).

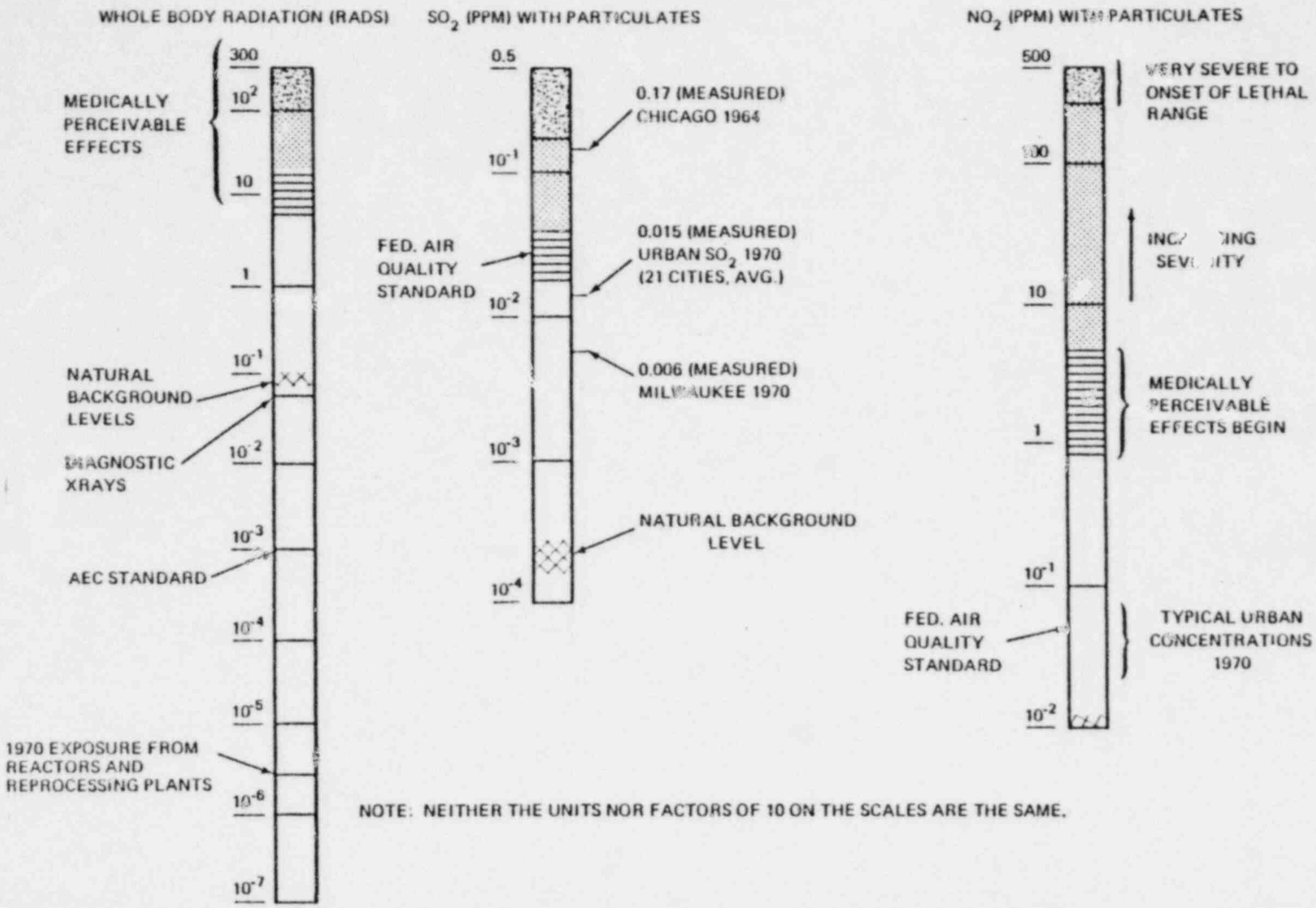


FIG. 1.2 COMPARISON OF POLLUTANT STANDARDS, BACKGROUND LEVELS, MANMADE EXPOSURES, AND HEALTH EFFECTS

(a) Environmental Protection Agency standards for SO_2 and NO_2, applicable to fossil-fired power plants and other man-made sources of these pollutants, are above natural background levels of these pollutants. Current USAEC regulations (10 CFR 20) for radiation exposure are about equivalent to doses from natural background sources. However, the new proposed "as low as practicable" guidelines (10 CFR 50, Appendix I), applicable to light water reactors, would restrict individual doses to orders of magnitude below that from natural sources.

When man-made and natural sources are added, the total levels permitted by regulations or guidelines are:

- about a factor of 100 over natural background for SO_2;
- about a factor of 4 over natural background for NO_2; and
- about a factor of 2 over natural background (10 CFR 20) or about a factor of 1.01 over natural background (10 CFR 50, Appendix I)* for radiation.

(b) As expected, ranges of medically perceivable effects are well above natural background levels for all three pollutants.

(c) With the exception of SO_2, the standards are well below the ranges of medically perceivable effects.

(d) Actual average annual radiation whole body exposures from nuclear power facilities in 1970 were several orders of magnitude below the existing standards (10 CFR 20) and natural background. Concentrations of fossil pollutants (together with background) were substantially above background levels in 1970.

The discussion above was restricted to effects on public health of routine pollutant releases from the energy system. Of concern also is public safety, more specifically, the hazards to the public from conventional accidents in transporting fuels.** Of the various process steps in the electricity production systems, fuel transportation is the dominant source of accident-risk to the public since it is in the transportation of fuel that the public comes in closest contact with the energy production system. Routine industrial accidents at power plants and fuel processing facilities usually affect only occupational personnel. Table 1.1 compares public injury rates associated with transporting fuel required for 1000 MWe coal-fired and LWR power plants.

---

*Proposed.

**Hypothetical, large scale-low probability accidents at power plants and supporting facilities are not addressed in this study.

Radiological and chemical risks associated with transporting fuels, which are orders of magnitude below risks of conventional impact-injury,* have been excluded.

Because of the large masses and volumes of fuel involved, coal transportation imposes a much more severe public safety hazard than transportation of nuclear fuels. Public injury rates in coal transportation are, in fact, comparable to occupational injury rates in coal mining. The transportation of coal for a 1000 MWe plant results in a statistical public death about every two years -- this almost entirely due to accidents at railroad grade crossings. Thus, about one third of the total fatalities attributable to the coal fuel cycle are public fatalities, the other two-thirds being occupational fatalities largely in underground mining.

A more detailed treatment of conventional injury rates in fuel transportation is given in the Appendix.

Nonconventional Costs in Perspective

Although normalized to the same quantity of electrical energy produced or production capacity, the quantities in Table 1.1 are in a variety of physical and nonphysical units. Quantities along a single row are, however, in consistent units, so that comparisons can be made across competing energy systems. Ideally, one wishes to reduce all such quantities to the same dimension, e.g., dollars, in order to make dissimilar categories of impact within each energy system comparable, and perhaps, additive, making possible comparisons of total societal costs across competing energy systems. For example, one might wish to compare the occupational radiological health impact in the LWR system to the conventional costs of producing electrical energy in this system.

Efforts to assign dollar values to non-conventional costs are highly preliminary, subjective, and generally imperfect. However, in several specific cases, it is possible to make gross assessments useful in making order-of-magnitude comparisons.

Table 1.2 compares conventional costs of producing electrical energy and several categories of environmental and human impacts which were reduced to dollar costs. This table represents the highest degree of summation and condensation considered feasible, useful, and appropriate in this study. The table aggregates numerous quantities derived and presented in a labyrinth of supportive materials in the main report and the appendices. Further condensation could lead to misinterpretation and gradual vitiation through succeeding generations of studies.

*USAEC, Nuclear Fuel Transportation Study (to be issued).

TABLE 1.2 COMPARISON OF CONVENTIONAL COSTS AND SOME EVALUATED NON-CONVENTIONAL COSTS OF ALTERNATE ENERGY SYSTEMS

Basis: Annual operation of one 1000 MWe Power Plant and Supporting Fuel Cycle (6.57 billion kWhe).
1980 dollars.

		Coal	Oil	Gas	LWR
Conventional Costs	($$10^6$/yr)				
Capital Plant		51	47	42	77
Fuel Cycle		64	180	237	39
O&M		5.4	4.0	3.7	5.2
Rounded Totals		120	231	283	121
Abatement Costs	($$10^6$/yr)				
Cooling Towers		3.6	5.9	7.1	2.4
Sulfur/SO_2 Removal		25.9	4.9	NA	NA
Strip-mined Land Reclamation		0.1	NA	NA	S
Near-Zero Radwaste		NA	NA	NA	1.2-1.8
Rounded Totals		30	11	7	3-4
Conventional & Abatement	($$10^6$/yr)	150	242	290	125
Abatement Component	(%)	20	5	2	3
Safety	($$10^6$/yr)				
Occupational[a]		0.46	0.086	0.039	0.05
Public[b]		0.18	U	U	0.003
Subtotal		0.64	>0.086	>0.039	0.053
Health	($$10^6$/yr)				
Occupational		0.03[c]	U	U	0.024[d]
Public		U	U	U	0.01[e]
Subtotal		>0.03	U	U	0.034
Total Human Health & Accident Costs	($$10^6$/yr)	>0.67	>0.086	>0.039	0.087

TABLE 1.2 -CONTINUED

Environmental Effects	($\$10^6$/yr)				
Water Base		0.4	0.4	0.4	0.6
Air Base		0.8	0.6	0.1	S
Land Base		0.2	S	S	S
Subtotal		1.4	1.0	0.5	0.6
Total Human & Env. Effects	($\$10^6$/yr)	2.1	1.1	0.5	0.7
Percent of Conv.	(%)	3	1	0.5	0.9

Key: U = unevaluated; NA = not applicable; S = small

Footnotes: (a) Conventional injuries in routine industrial accidents, including fatal and non-fatal injuries; 1 death = 6,000 MDL = \$300,000
(b) Conventional injuries in accidents in transporation of fuels; 1 death = 6,000 MDL = \$300,000
(c) Coal workers' pneumoconiosis (CWP)
(d) Radiological health effects, including lung cancers among uranium miners.
(e) Radiological health effects from routine emissions.

The limitations and uncertainties of the information displayed in Table 1.2 warrant further discussion. These qualifications do not, however, invalidate the major conclusions and findings of the study.

. Additive Costs

One of the tasks of the study was to reduce numerous quantities to a consistent basis (same unit of electrical energy produced) and to consistent units (dollars) in order to render them comparable and additive. All costs, internal and external, should be summed to obtain a total societal cost.

Adding any set of quantities to obtain a total requires that they not only be in consistent units, but also that they be (a) exhaustive and (b) mutually exclusive. Put another way, this means that one should include all of the costs, and that one should avoid counting something twice.

The categories and quantities of Table 1.2 are not exhaustive. One notable omission is the public health effect of airborne fossil pollutants, which, for reasons discussed in more detail in the text, could not be quantified. For this reason, the health subtotal for the coal system may be low by an order of magnitude.

Neither are the quantities of Table 1.2 mutually exclusive. For example, the conventional costs displayed may indeed contain components such as workers' compensation and insurance, tending to internalize occupational health and safety impacts. In many such cases an exact separation of costs could not be achieved.

Uncertainties

There are several degrees of uncertainty among the quantities presented in Table 1.2. Uncertainties increase, generally, as one moves from top to bottom and from left to right in Table 1.2. In general, it was found that small quantities were attended by the greatest uncertainty. This is understandable, since small quantities are frequently masked by large ones; the hazards of dealing with small differences between large numbers are well known among scientists and engineers. Fortunately, in the context of this report, small quantities are less important than large ones.

Conventional costs, the largest of the quantities presented, are the most accurately known. A band of plus or minus 15% is assigned to cover regional and local variances and uncertainties in escalating labor, materials, and money costs to 1980. Abatement costs, because they can be tied to specific equipment and procedures, are roughly as accurate as the conventional costs displayed.

Rates of occupational injuries in the coal cycle are considered quite accurate and representative. For example, statistical fluctuations in fatalities per million miner-hours appear very slight; the gradual reduction in mining injuries from 1955 to 1967 appears systematic, suggesting that such injuries may be regarded for practical purposes as deterministic and accepted. By contrast, injuries in uranium mining, because they are fewer, appear highly random. Accordingly, a broad confidence band of ± 50% is assigned to nuclear system injuries. Similar comments apply to public injuries in transporting coal and nuclear fuels.

Accidental injuries can be counted as discrete events and assigned to specific activities, e.g., mining, transportation, etc. By contrast, health effects are amorphous, difficult to define, and often impossible to assess quantitatively with current knowledge of dose-response characteristics. For this reason, health damage costs displayed in Table 1.2 should be regarded only as order-of-magnitude estimates based on the best available information. Radiological health impacts of nuclear power production are considered to be conservative, i.e., over-estimated, in that they are based on a linear dose-response extrapolation.

Life Values

Health and injury costs were assessed at $50 per man-day lost, leading to a life value of $300,000 if one assumes 6000 man-days lost per death. These are arbitrary figures, assigned to permit rough comparisons, and carry with them no implied comment on the absolute value of human life. The $300,000 per death figure is, however, in accord with several independent assessments. The reader may adopt his own values by scaling the health and accident costs of Table 1.2.

Summary of Limitations

To summarize, several limitations and shortcomings of Table 1.2 were discussed above:

- the costs tabulated do not form a complete set, nor are they mutually exclusive; for this reason, the table does not yield total social costs of producing electricity;

- in several categories, only very crude estimates of non-conventional costs could be made; in general it was found that small quantities are attended by the greatest uncertainty; and

- the unit costs of $50/MDL and $300,000/death, assigned more or less arbitrarily to permit comparisons of health impairment and injury costs with conventional costs, are highly subjective, and may be readily challenged on emotional and moral grounds.

None of these shortcomings, however, invalidate the major conclusions and findings of the study, reviewed in the next section. The salient point is that even drastic changes in the very small quantities in question will not propel these quantities to dominant importance.

Choice of life value, if applied consistently, will not distort the relative impacts of the competing energy systems. Further, whatever value is assumed, within reason, the health and injury costs will remain small compared to the conventional costs of producing electricity. Similarly, the large uncertainties in the environmental, health, and injury figures do not alter the conclusion that these costs are small compared to conventional costs. The same general argument could apply to overlaps and omissions in the Table.

Conclusions

1. Costs associated with human health and injury effects, both occupational and public, of new power stations and their respective prorated supporting fuel cycles, are small compared to conventional energy costs (less than 1%). This conclusion excludes public health effects of airborne fossil pollutants -- SO_2, NO_x, particulates, trace metals -- which could not be quantified.

2. Total non-conventional costs -- including health, injury, and environmental impacts -- are small compared to conventional energy costs (less than 3%).

3. In view of conclusions 1 and 2, ultimate fuel resource availability is apt to have greater influence, in making national choices among energy systems, than environmental considerations. Coal and nuclear fuels are the most abundant domestic fuels for electricity generation. This assumes that greater nuclear fuel utilization is achieved through the conversion of fertile nuclides to fissile nuclides, as in the fast breeder reactor. A host of factors affecting supply of residual fuel oil and natural gas make extensive, long-term base load use of these fuels doubtful.

4. Health and injury impacts are greater for occupational personnel than for the public.

5. Specific judgments concerning the cost effectiveness of various abatement measures cannot be supported by the data available. Although costs of abatement measures can be estimated with some degree of accuracy, corresponding incremental costs of damage avoided are difficult even to estimate by order of magnitude, owing to the lack of damage function (dose-response function) information.

6. The overall problem of ranking alternatives is a time-dependent one, and alternatives must be regarded as mixes of energy sources through time rather than as individual isolated sources. It is probable that all sources will be welcome to meet the rising demand for electrical energy. For this reason, a quantitative ranking or scoring among individual energy systems, based on static parameters, is unwarranted. However, some qualitative conclusions, based on the quantitative assessment summarized in preceding tables are in order.

. The natural gas system enjoys low plant capital costs, and incurs minimal environmental and human impacts. However, remaining domestic reserves are small, imports at acceptable costs are uncertain, and there is competition from alternate uses of this fuel, such as commercial and residential heating. Supply problems also face the residual fuel oil (RFO) system. Domestic yields of RFO are low (less than 10%) because of the incentive to maximize production of more valuable refinery ends; thus, a preponderant share of RFO consumed in the U.S. is imported, and foreign sources cannot be considered secure and permanent. Environmental and human impacts involved in the RFO system are large compared to those of the natural gas system, but substantially less than those of the coal system. Because of fuel supply related problems, and attending conventional costs, RFO and natural gas are expected to have diminishing roles in fueling new generating capacity after 1980.

. Coal, the most abundant of domestic fossil fuel resources, is the most severe environmental offender. This results largely from the sheer quantities -- masses and volumes -- of materials handled in the fuel cycle. Impacts of the coal energy system are more visible and, to some extent, more easily measured than those of other systems. In almost every category addressed, non-conventional (or external) costs are greatest in the coal system. Quantified external costs of producing electricity from coal are, however, less than 3% of conventional costs. Abatement costs, particularly SO_2 retention systems if proved feasible, may add as much as 20% to internal costs. However, the compelling fact is that coal is an abundant domestic fuel, and its environmental disadvantages are not likely to preclude its continued exploitation as a source of electrical energy.

. Nuclear fuels, including both fissile and fertile nuclides, are abundant domestic resources, and are expected to share, with coal, a major role in electrical energy production from 1980 through the year 2000 and beyond, provided reactors with substantially improved fuel utilization characteristics are introduced on a commercial scale. Gross, direct environmental impacts of extracting, processing, and transporting fuel -- so visible in the coal fuel cycle -- are essentially absent in the nuclear fuel cycles, because of the high energy content (on a mass or volume basis) of nuclear fuels. Similarly, nuclear power plants do not discharge large, visible quantities of airborne pollutants. The current generation of nuclear power plants -- the light water reactors -- discharge about one-third more heat to the environment than do modern fossil plants. Though relatively small in mass and volume, material flows and residuals in the nuclear fuel cycles are not without very substantial potential hazard. For this reason, nuclear systems are designed, fabricated, and operated with numerous safeguards, high performance radwaste systems redundancies, and with increasingly vigilant quality assurance programs and standards.

WASH—1250

THE SAFETY OF NUCLEAR POWER REACTORS
(LIGHT WATER-COOLED)
AND
RELATED FACILITIES

JULY 1973

EXCERPT

U.S. ATOMIC ENERGY COMMISSION

It must be emphasized that the preceding remarks pertain to the possibility of a weapon-like explosion. There could be explosive thermal, chemical or nuclear energy releases of considerably smaller magnitude in power reactors, although these are among the highly unlikely events which are prevented by design and safety features, as discussed in preceding chapters of this report. As noted in the report WASH-740 (Ref 1 - which will be the topic of the following section):

> "Even in the worst imaginable cases of nuclear runaway the energy release would be comparable only to a mild* chemical explosion. Chemical reactions occurring in the wake of a nuclear runaway might in fact contribute more energy than the runaway itself. If power reactors are located at sites similar to those now being proposed, the release of energy accompanying a reactor accident would constitute a negligible hazard to the public. The energy release is important only because it contributes to the possible extent of the fission product release."

8.2 WHAT ABOUT THE POSSIBLE EXTENT OF FISSION PRODUCT RELEASE? (WASH-740)

An answer to this question was needed in the early days of development of commercial nuclear power for use in estimating the amount of liability insurance that the industry might be required to carry. The answer obviously required some idea of the extent of damage that might be caused by a catastrophic nuclear power plant accident. Toward that end, the report, WASH-740 (Ref. 1), was prepared for the AEC by a study team of staff members of the Brookhaven National Laboratory, assisted by outside consultants. The report was published in March 1957, before any commercial nuclear power plants were in operation in the U.S.

The WASH-740 study estimated fatalities, injuries, and property damage (largely radioactive contamination of land) that might occur from the accidental release of fission products from a nuclear power plant under several sets of assumed circumstances. Referring only to the maximum consequence circumstances suggested by the study, the major underlying assumptions were: (a) 50% of the fission product inventory of a 500 MW (thermal) reactor could, in conceivable but highly unlikely accidents, be released to the atmosphere. Allowance for time to escape and to reach surrounding population areas was made by assuming a 24 hour decay period for the fission product inventory and (b) the release might occur under an adverse combination of conditions, including adverse weather conditions, which may prevail less than 10% of the time.

For the 50% fission product release case, the study estimated 0 to 3400 fatalities, 0 to 43,000 injuries, and from 18 to 150,000 square miles of land that might be placed under some form of general restrictions due to radioactive contamination. As indicated by the ranges,

*This is obviously a relative term.

injury to the public from a very large fission product release would, under circumstances that would prevail most of the time (e.g., relatively favorable weather conditions, prompt evacuation), not necessarily be large in magnitude. The upper limits refer to circumstances estimated to occur less than 10% of the time and are probably overstated due to the pessimistic assumptions involved.

The authors of WASH-740 used great care in placing their study and its results in proper perspective. Some critics of nuclear power have bypassed this perspective by using selected quotations from the report to support their points of view, while ignoring other portions that would not tend to do so. Critical reviews of books and articles that have used WASH-740 in this manner have been published (Ref. 2, pp. 355-396). The report has been cited by intervenors in connection with their opposition to the licensing of nuclear power plants. Some people interpret the report as a frightening revelation of the dangers of nuclear power. Thus, WASH-740 has gained some prominence, in a contentious sense, in the public eye.

In 1965, the AEC gave some thought to issuing an updated version of WASH-740, taking into consideration the large sizes of nuclear power plants then being designed or built, in comparison with the 500 MW thermal (about 160 MWe) plant originally assumed as a source of fission products (Ref. 3, pp. 347-348). No such report was issued. Given the assumptions used in WASH-740 and a larger number of fission products, one will inevitably calculate larger "upper limits" for the consequences. But WASH-740, in effect, used extreme fission product release values on an intuitive or judgmental basis, and a simple updating would have given little additional insight into the probability that such releases will occur from the plants currently in service. Consequently, the contemplated up-dating would have provided no insight into the magnitude of the population risk. Moreover, the quantitative assessment of such risk requires much more sophisticated methodology and much more detailed input data than were available for the original WASH-740 study, or for the contemplated updating. The evolving probablistic analysis methodology (Chapter 6.0) appears to offer the best path to meaningful assessment of accident probabilities and risks that may be associated with nuclear power plants currently in service. Such methodology is being developed for this and related purposes (See, Section 6.4.8, Chapter 6.0).

From the AEC point of view, WASH-740 served an important historical purpose at the time it was developed. In the intervening years, the information available, reactor safety systems and analysis techniques have all been upgraded considerably from those available when the WASH-740 study was made. This upgraded capability has been in routine use for many years, in connection with the licensing of nuclear power plants, for the assessment of a broad spectrum of assumed accident situations, and the ability of inherent design features and engineered safety systems of each specific plant to prevent or minimize harm, should such accidents occur (See Chapter 5.0).

NUREG-0252

THE ENVIRONMENTAL EFFECTS OF USING COAL FOR GENERATING ELECTRICITY

A. J. Dvorak, Project Leader

C. D. Brown B. G. Lewis
E. H. Dettman R. T. Lundy
R. A. Hinchman R. D. Olsen
J. D. Jastrow J. I. Parker
F. C. Kornegay E. D. Pentecost
C. R. LaFrance J. L. Saguinsin
W. S. Vinikour

EXCERPT

Manuscript Completed: May 1977
Date Published: June 1977

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

Prepared for
Division of Site Safety and Environmental Analysis
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Under ERDA Contract W-31-109-ENG-38

Available from
National Technical Information Service
Springfield, Virginia 22161
Price: Printed Copy $8.00 ; Microfiche $3.00

The price of this document for requestors outside of the North American Continent can be obtained from the National Technical Information Service.

1. INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

1.1.1 Background and Purpose

The National Environmental Policy Act of 1969 requires that an Environmental Statement be written prior to the construction of a nuclear power plant. The Nuclear Regulatory Commission's May 1975 Guide to the Format and Content of an Environmental Impact Statement (EIS) on a Nuclear Power Plant (Construction Permit) states:

> "The Environmental Statement should present a factual, impartially analytic, and detailed discussion of the anticipated environmental impacts of the proposed licensing action. The Statement should then establish, by means of a benefit-cost analysis, whether benefits that will result from operation of the proposed nuclear power plant will exceed the aggregate of the environmental, power-generating, and other costs or whether a more favorable balance can be achieved through available alternatives."

One alternative which must be considered within the EIS is the evaluation of an energy source other than nuclear. The forecasted availability of fossil fuels in conjunction with present technology indicates that coal is the primary alternative energy source for large electrical power plants.

This document is a survey of the health and ecological effects of the coal cycle. Environmental effects from cooling towers, thermal discharge, and other processes common to both nuclear and coal-fired power plants are not included.

1.1.2 Scope

The identification of health and ecological impacts of utilizing coal for generating electrical power requires an understanding of the entire coal cycle, which can be described chronologically as extraction → processing → transportation → combustion → waste. Each segment of the cycle is described, with emphasis placed on those topics where potential health and ecological impacts may occur. Underground and surface mining, coal processing, and transportation including rail, barge, slurry pipeline, truck, and conveyor are described. The descriptions include differences based on regional siting.

The physical and chemical characteristics of coal are not uniform within or between coal regions. Therefore, it was necessary to characterize coal from the Appalachian, Eastern Interior, Four Corners, and Powder River Regions (Fig. 1.1). A coal seam from each region was chosen and is described. The description includes the lowest, average, and highest Btu rating, sulfur content, and ash content; and, to a more limited extent, trace and heavy metal content. These data were used as inputs to predict potential effluents from the combustion process in a model plant, given a specific coal as the fuel.

The combustion, combustion wastes, and airborne combustion emissions are predicted for a model 1000-MWe coal-fired power plant. The description of this plant includes ancillary structures, daily and annual fuel requirements assuming a 70% capacity factor, coal storage piles, and wastes generated. These data vary because the model coal plant is hypothetically sited within each of five regions of the United States--the Northeast (Northern Appalachian), Southeast (Southern Appalachian), Midwest (Eastern Interior), Southwest (Four Corners), and the Pacific Northwest (Fig. 1.1). Table 1.1 lists the source of coal for each regional site. Justification for selecting several sites includes the need to consider separately the different physical characteristics and chemical composition of the coal from mines that would supply these sites, and the contrasting agricultural systems and natural ecosystems among regions. Sites were selected based on existing and potential nuclear power plant sites. Annual fuel requirements are quantified based on (1) characteristics of the coal supplied, and (2) an assumed 70% capacity factor.

Each model plant is assumed to be equipped with electrostatic precipitators for fly ash removal and, if high-sulfur coal is used, flue-gas desulfurization limestone scrubbers for SO_2 reduction. These two pollution control technologies, their expected efficiencies, and the resultant by-products and/or wastes are described according to the geochemistry of the fuel.

Fig. 1.1. Regions in the U. S. Producing Coal for the Model Plants and the Five Model Plant Sitings. Adapted from Ref. 1.

Table 1.1. Coal Sources for Each Regional Plant

Plant Site Region	Coal Source	Coal Seam
Northern Appalachian	Pennsylvania	Pittsburgh
Southern Appalachian	Eastern Kentucky	Upper Elkhorn #3
Eastern Interior	Illinois	Illinois #5
	Wyoming	Anderson, Canyon, and Wyodak-Anderson
Four Corners	Arizona	Wepo
Pacific Northwest	Wyoming	Anderson, Canyon, and Wyodak-Anderson

The annual fuel requirements are used to quantify, by region on a yearly basis, the following: (1) land area disturbed due to mining, (2) potential transportation requirements, (3) amount of waste generated from processing the coal, (4) non-airborne wastes produced from combustion, such as fly ash, slag, and bottom ash, (5) by-products from pollution control technology, and (6) ultimate airborne emissions with varying pollution control of stack gases and particulates. The terrestrial and aquatic impacts associated with each of the above are discussed to the detail that a regional analysis allows. Ecological impacts associated with airborne primary pollutants such as SO_x, NO_x, and heavy/trace metals are oriented towards agricultural systems, forest products, soil, and aquatic systems. Impacts are quantified where published data permit.

The occupational and public health impacts are identified for each of the six coal cycle components listed. Occupational health effects such as accidents in coal mines, black lung disease, and public health effects associated with transportation accidents (including railroad crossings) are quantified for a given annual tonnage of coal. Public health effects resulting from the dissemination of power plant air pollutants are discussed, including a consideration of variation among individuals in response to air pollutants. Quantitative information is presented on mortality regarding the projected emission output for the model plant. Morbidity is treated qualitatively.

1.1.3 Selected Coal Supplying Regions

The location and coal reserves of the regions selected as sources of coal for the model plants are briefly described in the following paragraphs.

Appalachian Region (Northern and Southern). This region covers an area of about 70,000 square miles and extends about 800 miles (north to south) from Pennsylvania to Alabama.[1] Approximately one-fifth of the nation's identified coal reserves can be found in this region.[1] Coal reserves in the Appalachian Region can be divided into two areas of concentration, the northern and southern. The states of Ohio, Pennsylvania, West Virginia, eastern Kentucky, and smaller portions of Virginia and Tennessee make up the northern part.[1] Estimates of reserves indicate a total of over 14 billion tons of surface reserves and nearly 95 billion tons of underground reserves.[2]

The southern part of the Appalachian Region is concentrated in Alabama.[1] Here the coal reserves have been estimated at almost 3 billion tons--1.7 billion tons of underground reserves and 1.2 billion tons of surface reserves.[2]

Eastern Interior Region. This region lies within a structural basin and includes southern Illinois, southwestern Indiana, and western Kentucky,[1] and contains over 71 billion tons of underground reserves with nearly 18 billion tons of strippable reserves.[2]

Powder River Region. This region is located in southwestern Montana and northeastern Wyoming.[1] This region contains over 59 billion tons of strippable coal reserves.[2]

Four Corners Region. This region lies within the Colorado Plateau and includes part of the states of Arizona, Colorado, New Mexico, and Utah.[1] Two estimates of the surface reserves of the Four Corners Region are over 3.7 billion tons[2] and over 4.8 billion tons.[1]

1.2 SUMMARY

This document estimates the environmental impacts of electricity generation by conventional coal combustion. The estimates are made by using a model 1000-MWe coal-fired power plant assumed to operate at a 70% annual capacity factor. The model plant is hypothetically sited within each of five geographic regions of the United States--the Northeast (Northern Appalachian Region), Southeast (Southern Appalachian Region), Midwest (Eastern Interior Region), Southwest (Four Corners Region), and the Northwest (Pacific Northwest Region). The Eastern Interior Region is treated for two different cases. In one case the model plant uses nearby high-sulfur Illinois coal; in the other, low-sulfur Wyoming coal. The model plant in the Pacific Northwest Region also uses Wyoming coal. Each of the remaining sites is supplied coal from mines assumed to be located within a 200 mile radius of the model plant site. The annual coal requirement for each model plant is used to quantify the impacts from extraction, transportation, combustion emissions and combustion waste disposal. Each model plant is equipped with an electrostatic precipitator assumed to remove 99.5% of the particulates from the stack effluents. Three regional plants, the Northern Appalachian, Southern Appalachian, and Eastern Interior (using Illinois coal), are assumed to burn coal containing sulfur concentrations which will cause the stack effluents to exceed the New Source Performance Standard (NSPS) of 1.2 lbs $SO_x/10^6$ Btu even if the coal is cleaned before combustion. Therefore, limestone scrubbers with an assumed 90% SO_2 removal efficiency are used to meet the NSPS at these three sites. The by-products from the various pollution control methods are quantified for all sites.

The environmental effects considered at each regionally sited model plant are limited to those effects that are primarily associated with using coal to generate electricity by conventional combustion. Therefore, the effects of cooling towers, thermal discharges and other processes common to both nuclear and coal-fired power plants are not included. Although the purpose of the report is to present the environmental effects of using coal as an alternative to nuclear/stream-generated electricity, comparisons between the two technologies are not made. The information contained in this report is derived from an extensive literature survey and should serve as a functional data base for comparisons of the impacts of using coal to the impacts of using other fossil fuels or nuclear power to generate electricity.

Table 1.2 summarizes the quantifiable environmental impacts of a 1000-MWe coal-fired power plant with a 70% annual capacity factor in each of five geographic regions in the U. S. Data were rarely found in the desired format and in some cases considerable manipulation and extrapolation were necessary to achieve consistency among all sites. The assumptions and calculations used for this study are presented in either the text or appendixes. Table 1.2 contains a summary of the quantifiable impacts of the major coal cycle phases: extraction, processing, transportation, combustion wastes and combustion emissions, each of which is discussed briefly below.

1.2.1 Extraction

The annual coal requirement (ACR) is derived by assuming that each 1000 MWt plant requires 2666 MWt, operates at 70% capacity and burns coal of a known Btu content. All of the ACR for the Four Corners plant and the two model plants using Wyoming coal is extracted by surface mining. The coal supplied to the remaining three plants is an equal mixture of surface- and deep-mined coal.

The land disturbed annually by surface mining is directly affected by the Btu content of the coal, the thickness of the coal seam and the method of surface mining. Contour strip mining disturbs an area much greater than the area underlain by the seam of coal being extracted. Depositing the overburden on the downslope side along the outer edge of the exposed coal will at least double the land area directly disturbed. The total acreage directly disturbed annually would therefore increase from the estimated 165 and 195 acres (Table 1.2) to 330 and 390 acres for Northern and Southern Appalachia, respectively, if this disposal method is employed. The second factor to consider when calculating land disturbance is the length of time between mining and the establishment of a productive postmining land use. Estimates on the length of this time period vary from three years in the East to ten years or longer in the West.

Surface mining completely destroys the existing vegetation in the stripped area. Topsoil (if not segregated) and other suitable plant growth materials originally near the surface are generally placed at the base of the spoil. Until the land is reclaimed, topography is altered, fauna are displaced, and former land uses such as wildlife habitat, cropping, or grazing are eliminated.

Environmental impacts to aquatic systems will be essentially similar in all eastern coal regions (e.g., Appalachian and Eastern Interior Region). Aquatic impacts in these regions will be the result of acid mine drainage (due primarily to oxidation of iron pyrites) and erosion-induced siltation. Effects of these pollutants on aquatic communities of receiving streams have historically been severely adverse throughout the eastern coal regions. While the perturbations have been highly site specific and variable, the biological effects of mine effluents to aquatic systems have usually been observed as decreased productivity and diversity, temporally and spatially altered species composition, and altered succession patterns. Heavily polluted systems have been reported to be virtually sterile.

Recently promulgated State and Federal guidelines and standards for reclamation and effluent limitation will minimize the deleterious effects of coal extraction effluents in the East (assuming prompt implementation and strict enforcement), such that the assumed coal production for the model 1000-MW power plant should not result in significant degradation of aquatic systems.

Information describing the aquatic impacts of western coal mining is limited; however, it is clear that due to fundamental differences in climate, hydrology and coal chemistry, the environmental impacts to aquatic systems will be different than those found in eastern coal regions. The virtual absence of acid-forming substances (i.e., pyrite) along with the generally alkaline nature of the overburden and soils suggests that acid drainage, with associated toxic elements common in the East should be minimal at western mines. Research results that are available concerning impacts from western mines suggest that increased salinity of surface or groundwater systems is due to soluble salts from mine spoils. This is one water quality problem that can be expected in both the Southwest and Wyoming. Soluble salts of calcium, magnesium, and sodium have comparatively low toxicities, so that chemical impacts to indigenous aquatic biota should be minor. However, since most coal deposits in the West are located in arid or semiarid environments with sparse vegetation, highly erodable soils and questionable reclamation potential, the

Table 1.2. Annual Environmental Impacts Associated with a 1000-Megawatt Coal-Fired Power Plant with a Load Factor of 0.70, Located in Five Regions of the U. S.

Impacts	Northern Appalachian	Southern Appalachian	Eastern Interior (Illinois Coal)	Eastern Interior (Wyoming Coal)	Four Corners	Pacific Northwest
Extraction						
Coal source *(Table 1.1)*[a]	Pittsburgh seam (PA)	Upper Elkhorn No. 3 (KY)	Illinois No. 5 (IL)	Anderson, Canyon Wyodak-Anderson (WY)	Wepo Formation (AZ)	Anderson, Canyon Wyodak-Anderson (WY)
Btu content of coal *(Table 5.2)*	13,800	14,200	11,400	8,200	11,600	8,200
Coal ash content (%) *(Table 6.5)*	3.6	3.9	5.2	6.0	5.2	6.0
Sulfur content of coal (%) *(Table 6.6)*	1.26	0.9	2.45	0.45	0.6	0.45
Annual coal requirements (10^6 tons) *(Table 6.4)*	1.91	1.84	2.29	3.19	2.25	3.19
Land disturbed annually by surface mining (acres) *(Table 7.1)*	165	195	190	30	100	30
Occupational accidental deaths (persons/yr) *(Table 7.5)*	0.82	0.58	0.95	0.29	0.20	0.29
Processing						
Refuse produced annually (10^6 tons) *(Table 6.4)*	0.69	No coal processing	0.69	No coal processing	No coal processing	No coal processing
Land preempted annually for refuse disposal (acres)[b]	16	--	16	--	--	--
Transportation and Storage						
Fatalities per year *(Table 9.1)*	0.14	0.18	0.11	1.45	0.16	0.15
Land preempted annually for coal storage (acres) *(Table 10.1)*	4.0	3.8	4.8	6.7	4.7	6.7
Wastes Collected from Combustion and Emission Abatement						
Bottom ash (tons/yr) *(Table 6.5)*	14,000	14,000	24,000	40,000	23,000	40,000
Fly ash (tons/yr) *(Table 6.5)*	54,000	56,000	95,000	153,000	92,000	153,000
Land preempted by ash ponds (acres)	20-30	20-30	20-30	20-30	20-30	20-30
Land preempted annually for ash disposal (acres)[b]	1.5	1.6	2.7	4.5	2.6	4.5
Limestone scrubber sludge (10^6 tons/yr) *(Table 6.8)*	0.24	0.18	0.46	No scrubbing	No scrubbing	No scrubbing

Table 1.2. Continued

Impacts	Northern Appalachian	Southern Appalachian	Eastern Interior (Illinois Coal)	Eastern Interior (Wyoming Coal)	Four Corners	Pacific Northwest
<u>Wastes Collected from Combustion and Emission Abatement</u> (cont.)						
Land preempted annually for scrubber sludge[b] disposal (acres)	7	6	14	--	--	--
<u>Combustion Emissions</u>						
Sulfur oxides (tons/yr) *(Table 6.6)*	4800	3300	11,200	30,700	27,000	30,700
Nitrogen oxides (tons/yr) *(Appendix A)*	9900	9900	9900	9900	9900	9900
Particulates (tons/yr) *(Table 6.5)*	280	280	485	765	460	765
Trace elements (tons/yr) *(Table 6.8)*						
Arsenic	0.55	0.20	0.23	0.04	0.07	0.04
Barium	0.88	0.95	0.67	2.56	0.53	2.56
Cadmium	--	--	0.18	0.03	0.03	0.03
Chromium	0.55	0.42	0.73	0.16	0.24	0.16
Cobalt	0.24	0.19	0.31	0.08	--	0.08
Lead	0.38	0.28	2.65	0.05	0.31	0.05
Manganese	0.23	0.27	0.87	0.18	0.[illegible]1	0.18
Mercury	0.34	--	0.33	0.10	0.09	0.10
Selenium	1.02	0.82	0.60	0.26	0.62	0.26
Vanadium	0.67	0.56	0.78	0.37	0.21	0.37
Zinc	0.80	0.52	5.56	1.61	0.38	1.61
Public deaths/10^6 persons *(Table 12.1)*						
Winkelstein-based estimate Even distribution of population	2.8	5.4	2.8	3.0	3.7	2.6
Population concentrated in most heavily exposed 400-600 mi^2	9.7	26.8	8.2	8.4	15.7	8.8
Lave-Seskin-based estimate Even distribution of population	1.7	3.3	1.7	1.8	1.9	1.6
Population concentrated in most heavily exposed 400-600 mi^2	6.1	16.7	4.9	4.8	8.2	5.1

[a]Information in italics indicate location of the data in the text.

[b]Assumes that each acre at the disposal site contains 25 acre feet of waste material (refuse, ash and scrubber sludge).

possibility of erosion-induced sedimentation of streams could be substantial if the applicable laws concerning reclamation and water quality are not strictly enforced.

The two major human health impacts from mining treated in this report are fatal accidents and coal worker's pneumoconiosis (black lung). The accident fatality rate for underground coal mining is higher than for any other occupation examined by the National Safety Council. Ninety percent of the fatal coal mining accidents in the last 40 years occurred in underground mines. The accident fatalities per year per million tons of coal mined are 0.54 for underground mines and 0.09 for surface mines.

Coal workers pneumoconiosis (CWP) is a generic term applied to a group of occupational diseases of the lung caused by inhalation of coal dust. There are two types of CWP--simple and complicated. The estimates of cases attributable to the model plant (0.6 simple and 0.006 complicated) are based on the assumption that mines supplying coal to the model plants achieve a respirable coal dust limit of 2 mg/m^3.

1.2.2 Processing

The problems associated with the refuse from coal cleaning (gob and slurry) are essentially limited to the Eastern Interior and Appalachian Regions since western coals generally are not cleaned. Of the target states designated as coal suppliers for the model 1000-MWe plant, coal from Pennsylvania and Illinois are cleaned, producing 1904 tons of refuse per day for each model plant. Thus, 694,960 tons will be produced annually over the 30-year life of the plant, and a maximum of 21 million tons of refuse will require disposal.

Substantial adverse impacts, including air pollution, water pollution, and damage to aesthetic value can occur if gob piles and slurry lagoons are not properly engineered and reclaimed. However, if conscientious reclamation and pollution abatement procedures are followed in accordance with State and Federal regulations, the detrimental impacts to terrestrial and aquatic ecosystems can be negligible (e.g., short-term and reversible). The major long-term impact to terrestrial systems may be that the disposal area (480 acres/plant/30 years) can only be returned to limited land uses such as wildlife cover, pasture, or recreation.

Three health impacts to persons outside the mining industry can result from the disposal of gob and slurry: acid mine drainage can decrease water quality, coal waste ignition can increase air pollution, and waste dams can fail and cause flooding.

1.2.3 Transportation and Storage

Railroads, barges, slurry pipelines and trucks are considered as the alternative transportation modes to bring coal to the model plant. The impacts to terrestrial and aquatic ecosystems from coal transportation alternatives depend upon future developments in the transportation systems. Operational impacts of existing facilities are small, but major perturbations could result from new construction or upgrading of present facilities. Land clearing, trenching, bridge construction and grade preparation would destroy terrestrial vegetation and may produce erosion resulting in the siltation of benthic habitats within aquatic ecosystems. Although the intensity and type of transportation development will vary among different regions, no unacceptable regional impacts should occur, since mitigating measures are available for protection of the aquatic communities, and construction activities are usually of short duration.

Estimates of railroad right-of-way per 1000-MWe coal-fired power plant range from 1148 to 2213 acres. Slurry pipeline construction disturbs 12 acres per mile of 18 inch pipe and the pumping stations occupy 0.5 acres per mile of pipe.

The accident fatalities presented in Table 1.2 for each model plant are exclusively for rail transportation; however, fatalities expressed on a 1000-MWe coal-fired power plant basis are presented in the report for the other transportation alternatives. Rail fatalities are calculated assuming 2.4 accident fatalities per million freight train miles, a unit train capacity of 10,000 tons of coal, the ACR, and round trip distances for each plant. Calculated accident fatalities ranged from 0.11 to 1.45 per plant per year.

The area required for coal storage at each plant site varies from 3.8 to 6.7 acres. Infiltration water and runoff from these piles contain coal fines, humic acids, and inorganic ions, and may be acidic for eastern and midwestern coals. The terrestrial effects of such additions to the surrounding environment will usually be localized, i.e., immediately beneath or immediately adjacent to the storage piles. These effects likely include leaching of soil nutrients and breakdown of soil structure. Placement of an impermeable layer (e.g., clay) on the ground before stockpiling can reduce adverse effects of infiltration water, but will tend to increase runoff.

The aquatic effects of runoff can be more severe than the terrestrial effects. Low pH, abnormal ion concentrations, and particulate matter can have adverse effects on the benthic, planktonic, and fish populations of surface waters. These effects of runoff will be more pronounced in regions of high rainfall. In areas where rainfall is low, or during relatively dry seasons, fugitive dust from the coal storage piles will contribute to local air quality degradation, and dust suppression by means of water and/or chemical sprays may be necessary.

1.2.4 Wastes Collected from Combustion and Emission Abatement

Wastes collected from combustion and emission abatement include fly ash, slag or bottom ash, and scrubber sludge. Slag is that portion of total ash which melts to a viscous fluid at burner operating temperature, and bottom ash is the remainder of the ash which does not melt and is too heavy to be entrained in the flue gas (fly ash). The type of combustion unit, cyclone or pulverized-coal, influences the partitioning of the total ash content of the coal into bottom ash or fly ash. A pulverized-coal burner with 20% of the total ash content becoming bottom ash during combustion is assumed for all model plants. The remaining coal ash in entrained in the flue gases as fly ash, 99.5% of which is collected by electrostatic precipitators. The amount of bottom and fly ash generated during combustion depends on the ash content of the coal. Scrubber sludge is a precipitate chemically formed when SO_2 in the flue gas comes in contact with a limestone slurry; the sludge, composed mainly of calcium sulfite, calcium sulfate, and water, is dewatered to about 50% solids and transferred to settling ponds. Limestone scrubber sludge is produced only at the model plants burning coal containing sulfur concentrations that would produce effluents exceeding the NSPS for SO_x.

The disposal of combustion waste (precipitator fly ash, bottom ash, slag), and scrubber sludge (where flue-gas desulfurization is required), is currently a major problem in conventional coal combustion. Seepage from ash and sludge dewatering ponds can add potentially toxic elements and salts to the surrounding soil, vegetation, groundwater, and eventually, surface waters. Utilization of fly ash in roads, building products, and as a soil amendment is not extensive, nor have the environmental effects of such utilization been investigated to the extent that recommendations can be made. Ultimate disposal of the ash is usually in landfills and mine sites. Such disposal does not necessarily isolate the waste from the biosphere, since rainfall onto these sites and/or rising and falling water tables can result in leaching of potentially toxic elements into the surrounding soils and groundwater. In areas of high rainfall, the potential for adverse effects arising from runoff and seepage to ground and surface waters is greater than in semiarid or arid regions. On the other hand, in drier regions, salts and potentially toxic elements that seep into the surrounding soils will tend to remain in the soils, moving into root zones during the process of evapotranspiration of soil water. This tendency can result in adverse effects, such as uptake of toxic elements into forage, and accumulation of salts in or on the soil, leading to a decrease in the productivity of the land.

Waste from flue-gas desulfurization (sometimes called limestone scrubber sludge) is thixotropic even after dewatering, and is unsuitable for landfill without additional treatment (e.g., addition of chemical fixatives or mixing with fly ash). The sludge also contains a high concentration of calcium sulfite, which could drastically lower the oxygen concentrations in surface waters receiving effluent from the sludge ponds, unless the effluent is treated to reduce its oxygen demand. Decreasing the dissolved oxygen content of surface waters can result in inconsequential to severe impacts to aquatic life.

1.2.5 Combustion Emissions

Three major conventional combustion emissions, SO_x, NO_x and particulates, are quantitatively determined for pulverized-coal combustion at each model plant. The calculated sulfur oxide emissions (Table 1.2) are well below NSPS limits at the three eastern sites employing flue gas desulfurization. Nitrogen oxides emissions are assumed to be constant at all sites. Certain potentially toxic trace elements tend to condense preferentially onto the smallest particulates, which generally escape even the most efficient electrostatic precipitators. The 11 elements listed in Table 1.2 are the only elements for which partition factors (necessary for the calculation of emissions) were found in the published literature.

The ecological analysis performed in this report indicates that SO_2 is the only gaseous emission from the model plant that may have measurable impacts on terrestrial ecosystems at the regional sites. These potential quantifiable impacts would be in the form of acute or chronic visible injury to vegetation. Animals, in general, are about an order of magnitude less sensitive to SO_2 than plants and in most cases would not exhibit direct, acute injury symptoms to any of the SO_2 doses predicted in this report.

The ecological effects of SO_2 for the various model plant locations are site-specific to the extent that the magnitude depends on: 1) frequency of worst-case meteorological conditions (plume fumigation during inversion breakup) at the site, 2) sulfur content of the coal burned at a particular model plant, and 3) presence or absence of SO_2 scrubbers on a particular model plant.

The hypothetical situations summarized below are presented in order of increasing severity of potential impacts based on the factors enumerated above, plus the possible occurence of inoperative scrubbers.

At all sites, when the model plant is operating under assumed normal conditions (i.e., scrubbers if present, operating at 90% SO_2 removal efficiency) and when typical meteorological conditions prevail, the projected total ambient levels of SO_2 and NO_x within a 5-km radius of the model plant will meet all applicable National Primary and Secondary Ambient Air Quality Standards and no measurable impacts of SO_2 to biota should be encountered. This does not preclude the possibility of direct or secondary long-term effects of any of the primary pollutants on any biota. This caveat applies, as well, to all of the hypothetical situations discussed below.

The SO_2 doses in the vicinity of model plants with operating scrubbers (Eastern Interior plant using Illinois coal, Northern and Southern Appalachian plants, under worst-case meteorological conditions, would be below the injury threshold for sensitive vegetation, and no measurable impacts are anticipated.

The model plants without scrubbers (Eastern Interior using Wyoming coal, Four Corners, and Pacific Northwest) operating normally under worst-case meteorological conditions could result in doses of SO_2 capable of causing threshold levels of visible injury (chlorosis or necrosis of foliage) to vegetation in the SO_2 sensitive category in an area not exceeding about 5 km^2. Such fumigation episodes would occur about 10 times per year in the Four Corners and Pacific Northwest Regions and about 25 times per year in the Eastern Interior Region. Actual injury to vegetation would occur only if the plants were growing under the most sensitive environmental conditions and stage of plant maturity.

If worst-case meteorological conditions were to coincide with a period during which the scrubbers were inoperative at the Eastern Interior plant using Illinois coal and the Northern and Southern Appalachian plants, SO_2 doses capable of causing extensive visible (acute) injury to some vegetation within an area of about 5 km^2 in the plant vicinity could occur. At all three sites vegetation in the SO_2-sensitive category could exhibit injury symptoms ranging from threshold levels to severe, depending on species and condition. At the Eastern Interior plant, vegetation in the SO_2-intermediate category could sustain threshold injury.

The impacts to aquatic ecosystems from gaseous combustion emissions result primarily from acidification of the receiving water by acid precipitation formed from SO_x and NO_x. The potential for acidification of surface water is greatest in areas where the natural buffering capacity of the water is low. Areas with acidic soils and igneous rock outcrops, such as the Adirondack Mountains in New York and similar areas in New Hampshire and Maine, are subject to surface water acidification. In addition, the dilute alpine lakes and headwater streams in the Cascade Mountains of Washington and Oregon, and a small igneous region in the Appalachian Mountains in North Carolina have been identified as areas of potential acidification. However, most aquatic ecosystems in the U. S. have sufficient alkalinity to buffer acidic inputs and the potential for impacts to broad regional areas is low, except as noted above.

The assessment of the terrestrial impacts of trace element emissions resulting from coal combustion is extremely difficult because very little is known about the behavior of trace elements in terrestrial ecosystems. The approach taken in this study was to model emission dispersal and deposition, and to make conservative assumptions about trace element behavior, thus creating a worst possible case. The analysis was limited to eleven elements, As, Ba, Cd, Co, Cr, Hg, Mn, Pb, Se, V and Zn.

Even when the model plant emission is at the maximum allowed by the Federal New Source Performance Standard for particulates (0.1 lb/10^6 Btu), the impacts to vegetation are expected to be minimal. Trace element impacts to livestock and other animals could not be quantified. However, cadmium and selenium are believed to have the greatest potential for adversely affecting animals. Because of the magnification of some trace elements in the food chain, higher carnivores and man have the greatest chance of injury.

The potential for enrichment of specific trace elements in aquatic ecosystems from coal combustion emissions appears low. An analysis of hypothetical aquatic systems suggested that availability of dilution water prevents the enriched concentrations of selected trace elements from exceeding the water quality criteria and the toxicity threshold of most aquatic organisms. Although the background concentration of some specific trace elements in surface waters is high in some streams within the United States, no general regional problems were identified with respect to trace element inputs from a single coal-fired power plant.

It cannot be assumed that the release of trace elements into the atmosphere from coal combustion will always result in negligible impacts. The potential for impacts is obviously greater in areas already subject to heavy trace element accumulation from other sources. Our understandings of deposition rates, routes and rates of transport from terrestrial to aquatic systems, chronic toxicity levels, and synergistic or antagonistic effects of trace elements are very poor and any effort to disregard trace element contamination of surface waters is clearly unwarranted.

1.2.6 Public Deaths

Section 12 of this report contains a qualitative discussion of the human health effects which may result from exposure to coal combustion products at greater than threshold levels. Threshold being defined as that quantity of a specified agent that an organism is able to metabolize, detoxify, or excrete without biological consequences.

The quantitative estimates of mortality associated with the model plants are based on the long-term effects of two effluents, SO_x and particulates. The two independently derived projection models used for this analysis take the form of absolute risk. The model taken from Lave and Seskin relates total mortality to two independent pollutants measured simultaneously: sulfate ion ($\mu g/m^3$ $SO_4^=$) and total suspended particulates ($\mu g/m^3$ TSP). The second model is on data from Winkelstein's study of mortality related to total suspended particulates. The models utilize an input mortality schedule of sex and age-specific death rates and project the death rates to be expected under the increment of pollution with a simple linear equation. Mortality estimates are given for two population distributions. The estimate based on the assumption that the population (10^6 persons) is evenly distributed ranges from 1.6-3.3 persons with the Lave-Seskin estimate to 2.6-5.4 persons with the Winkelstein estimate (Table 1.2). The range assuming a population concentrated in the area receiving the highest pollution dose, $\sim$ 600 mi^2, is 4.8-16.7 persons with the Lave-Seskin estimate and 8.2-26.8 persons with the Winkelstein estimate.

Several major assumptions are necessary to achieve quantitative mortality estimates. The model plant produces an effluent stream where the ratio of SO_2 and other gas-phase effluents to particulates differs markedly from the uncontrolled plants from which field studies have thus far been based. The use of only one or two components (SO_x and/or TSP) of the effluent stream as indicators of pollution exposure, assumes constancy in the unobserved components. The biologically effective TSP dose from the model plant is assumed to be 3.5 times the estimated emission level. This inflation is necessary because electrostatic precipitators are less efficient at removing respirable particulates than the more visible and less harmful larger particulates.

References

1. "Synthetic Fuels Commercialization Program," Draft Environmental Statement, ERDA-1547, Energy Res. and Develop. Admin., U. S. Dep. of Interior, Dec. 1975.

2. "Demonstrated Coal Reserve Base of the U. S., by Sulfur Category on January 1, 1974," Mineral Industry Survey, Bur. of Mines, U. S. Dep. of Interior, 1975.

WASH-1400
(NUREG 75/014)

CALCULATION OF REACTOR ACCIDENT CONSEQUENCES

APPENDIX VI
to
REACTOR SAFETY STUDY

EXCERPT

U.S. NUCLEAR REGULATORY COMMISSION
OCTOBER 1975

Available from
National Technical Information Service
Springfield, Virginia 22161
Price: Printed Copy $12.00 Microfiche $2.25

Second printing

Section 13

Calculated Results with Consequence Model

This section is directed towards the calculation of the probability versus magnitude of the consequences of an accident at one of the first 100 commercial light water reactors. Before discussing these calculations, it is necessary to establish the framework for the calculations, with regard to the health effects described in section 9 and also the sampling scheme for the meterological data. In order to understand the model, it is also helpful to do some parametric studies with a uniform population, thereby eliminating one variable. With this groundwork laid, the basic risk calculations are described followed by some additional calculations giving greater perspective on the results. Finally, there is a discussion of the overall uncertainties in the results.

13.1 MEDICAL FRAMEWORK

As was frequently noted in section 9.2, the selection of dose-mortality criteria depend, to some extent, on the temporal pattern of dose to different organs and the relative magnitudes of the doses to different organs. This section shows a series of hypothetical calculations to provide this basis and to contribute to the understanding of the health effects model.

Figures VI 13-1 through VI 13-4 show (1) the external dose from the passing cloud, including a shielding factor of 0.75, (2) the external dose from ground contamination within a 24-hour time period[1] after deposition, including a shielding factor of 0.33, and (3) the dose, as a function of time, from internally deposited radionuclides to the bone marrow, the lung, the regenerative cells of the lower large intestine[2] and the thyroid. The relative magnitudes of the doses from the three exposure modes and the temporal distributions of the internal doses are self-evident; they are discussed in section 9.2.

For the critical time periods (specified in the appropriate sections of section 9.2), the contributions of the major radionuclides are shown in Fig. VI 13-1 et seq. The dose contributions are for radionuclides released from the containment and include any contribution from their radioactive daughters. The reader should also note that the graphs are logarithmic with respect to dose. The radionuclide contributors are ranked in descending order and in general "others" contribute less than about 5% of the total dose. The relative importance of certain radionuclides will be discussed later after presentation of similar calculations for the late health effects.

At any distance from the reactor, the external doses from the passing cloud, the external dose from ground contamination, and the dose from internally deposited radionuclides are all approximately proportional to the concentration of radionuclides in the air near the ground at that distance. This airborne concentration as a function of distance from the reactor is strongly influenced by the prevailing stability and wind speed especially within 20 miles of the reactor. However, for a given release category, the relative magnitudes of the three doses and the time-dependence of the internal dose are basically independent of distance and weather within this region since (1) they are all approximately proportional to the same variable, (2) the time periods after release are short, so that differences in radioactive half-life do not become significant, and (3) the deposition velocities (and washout coefficients) of 1-micron particles and iodine are equal so that all radionuclides except the noble gases are uniformly depleted from the plume. Furthermore, the noble gases are negligible contributors to dose within this region. Therefore, the temporal behavior of doses is shown in Fig. VI 13-1 et. seq. for only one distance (0.5 mile) from the reactor and only one weather type (stability category A, 0.5 m/sec, or 1.1 mph) for a large, cold, ground-level release.

[1]For shorter time periods, the dose from ground contamination is approximately proportional to the time period.

[2]For brevity in section 13.1 the regenerative cells in the lower large intestine will be referred to as the gastrointestinal tract.

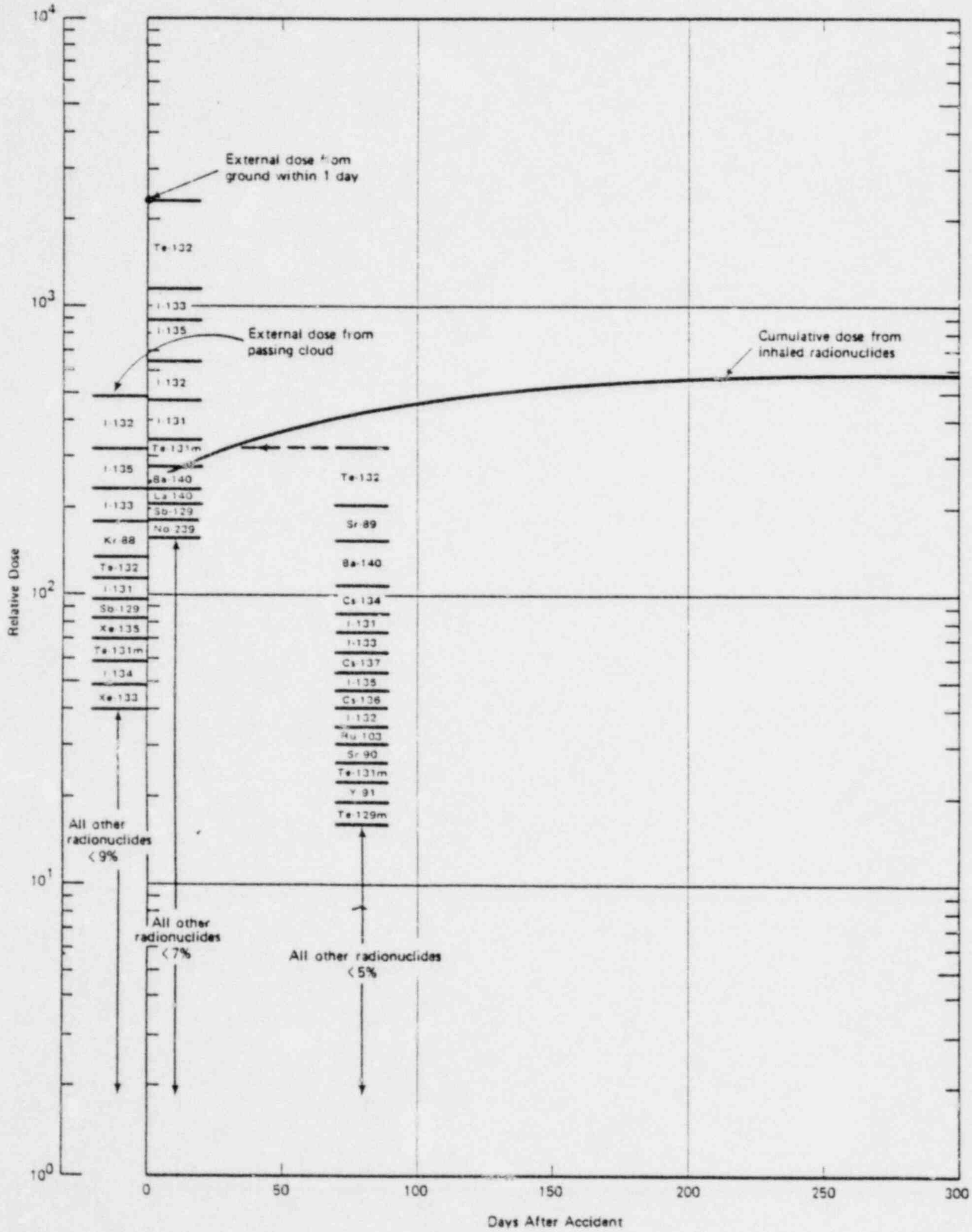


FIGURE VI 13-1 Relative doses to bone marrow at 0.5 miles from reactor.

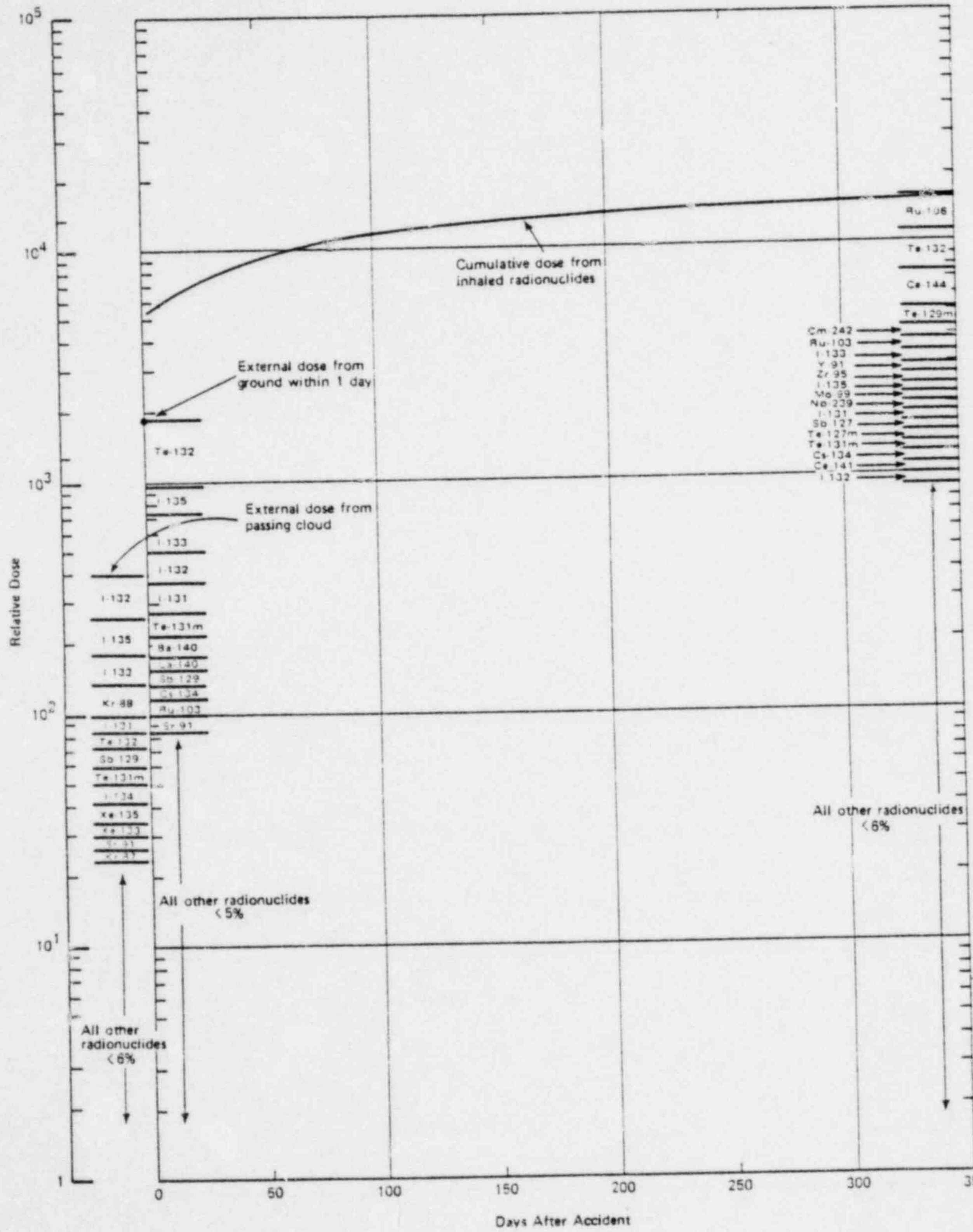


FIGURE VI 13-2 Relative doses to lung at 0.5 miles from reactor.

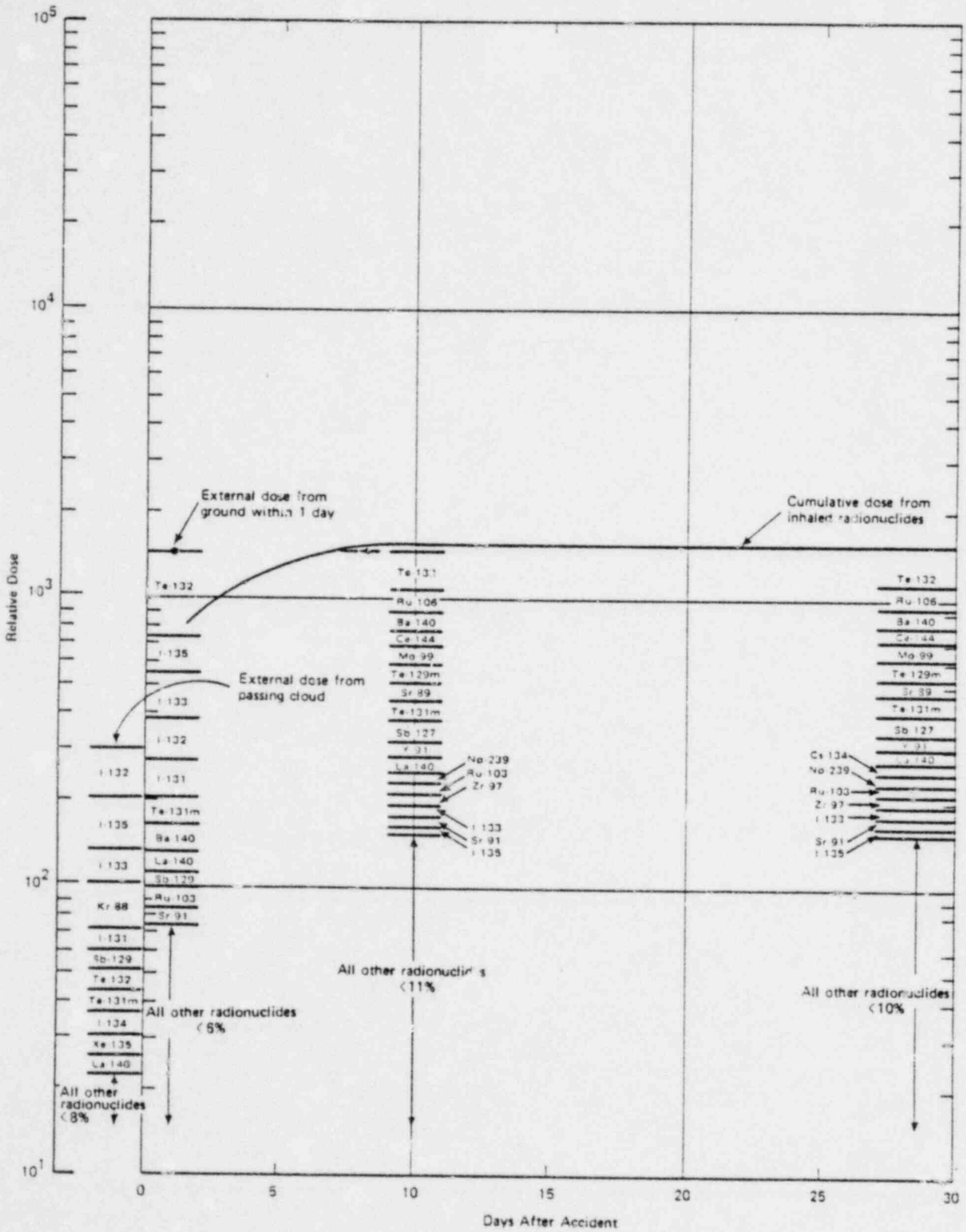


FIGURE VI 13-3 Relative doses to regenerative cells of lower large intestine at 0.5 miles from reactor.

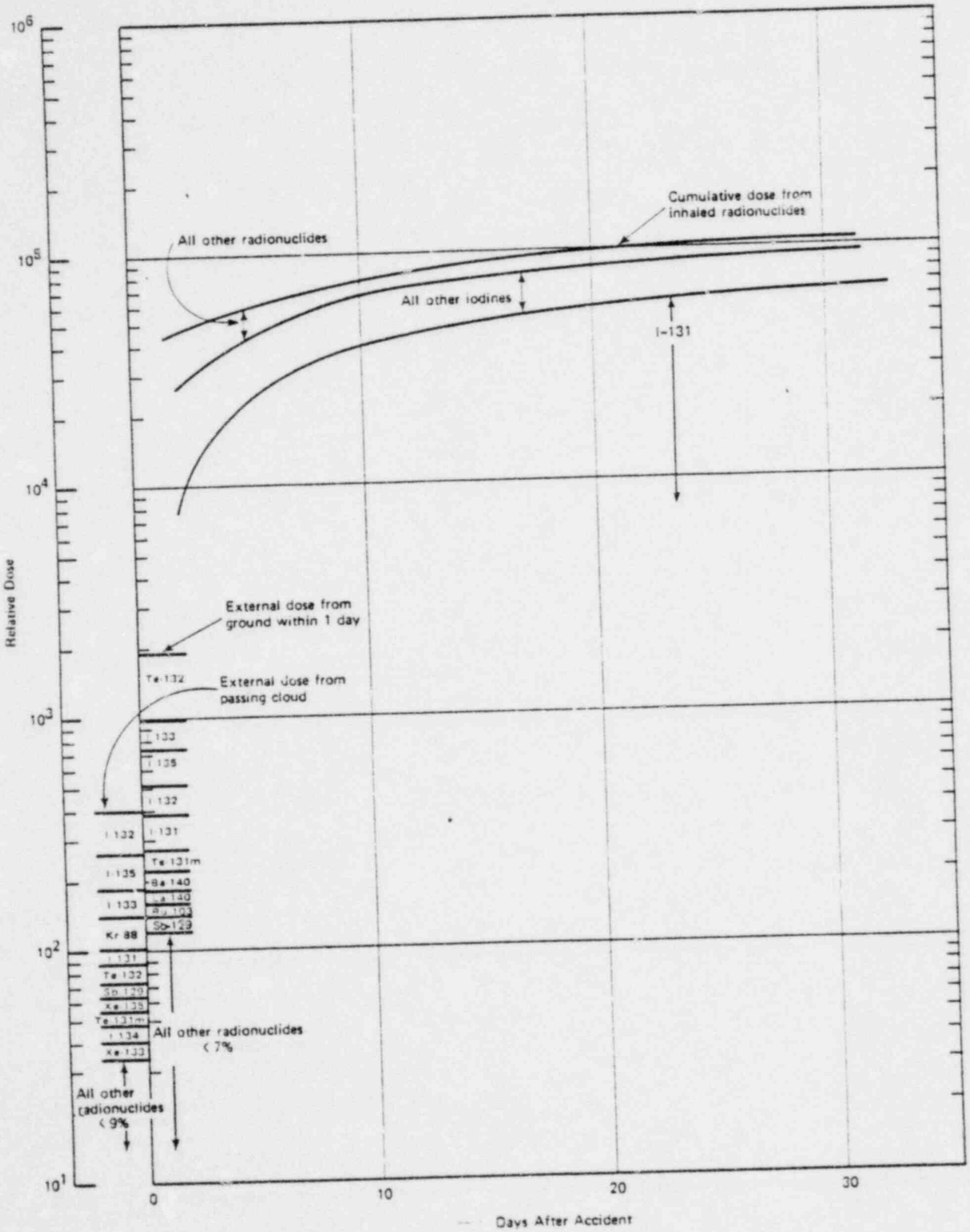


FIGURE VI 13-4 Relative doses to thyroid at 0.5 miles from reactor.

To establish the effect of weather, graphs have been drawn of the magnitude of the doses to the bone marrow, the lung, the gastrointestinal tract and the thyroid within the appropriate time periods as a function of distance from the reactor. Figs. VI 13-5 and VI 13-6 are such graphs for two hypothetical cases in which a large, cold, ground-level release is assumed and the weather is assumed to be time-invariant. These weather conditions are (1) stability category A with 0.5 m/sec (1.1 mph) wind speed, and (2) stability category F with 2.0 m/sec (4.5 mph). The earlier dose-time graphs may be scaled for different distances and weather types by using the relationships depicted in these graphs for these hypothetical cases. Out of all possible combinations of stability and wind speed, the above two weather types were selected to represent extremes with respect to doses within 20 miles but still having relatively high probabilities of occurrence. It should be noted in Figs. VI 13-5 and VI 13-6 that, for each weather type, the doses to the four organs as a function of distance are approximately parallel. This feature reflects the proportionality argument given above. By comparing the doses to the bone marrow, the lung and the gastrointestinal tract at a given distance with the corresponding dose-mortality criteria for these organs in Fig. VI 9-1, VI 9-3, and VI 9-4, respectively, one can compute the percentage of the population at that distance that will die within 60 or 365 days. Fig. VI 13-7 shows that, for these hypothetical weathers, early and continuing mortalities are limited to 10 miles from the reactor and that damage to the bone marrow is the dominant mechanism.[1]

Latent cancer fatalities and genetic effects may result from smaller doses and lower dose rates than those that cause early health effects, accumulated over time periods as long as 50 years or more after the accident. These long-term doses depend on the interdiction policies which are discussed in section 11.2.2. It is helpful to consider separately two population groups. The first group would be relatively close, e.g., 10 to 30 miles, to the reactor at the time of the hypothetical accident so that they inhaled a substantial quantity of radioactive material but insufficient to result in early death. The land on which this population lived would probably be sufficiently contaminated to require relocation of these people so that they would receive no long-term external dose. The inhaled radioactive material is largely retained in the body where it either decays radioactivity or is eliminated from the body throughout the remaining life-span. The long-term doses to the bone marrow, the lung, the mineral bone, the breast, and the testes from these internally deposited radionuclides are plotted in Figs. VI 13-8 through VI 13-12 for consecutive time periods from 1 to 50 years after a large, cold release. The dose magnitudes are calculated for a distance of 10 miles from the reactor by assuming time-invariant weather of stability category A and 0.5 m/sec. Only people born prior to the accident can receive this internal dose and, as explained in sections 9.3.2.3 and 9.4.2, the aging of this population should be taken into account in calculations of latent cancer fatalities and genetic effects. In order to account for aging, the dose received in each time period is used, so Figs. VI 13-8 _et seq_. are not plotted on a cumulative basis. The main radionuclides contributing to dose in each period are shown and will be discussed below.

The second population group would be located relatively far from the reactor (e.g., 30 to 100 miles) at the time of the hypothetical accident. Their doses both external from the passing cloud and internal from the inhaled radionuclides would be relatively small. However, the land on which this population lived would probably not be contaminated above the level requiring their relocation. As long as these people remained on this land, they would receive small external doses from the contaminated ground, and small internal doses from ingested foodstuffs and inhalation of resuspended radioactive material. The long-term doses to the bone marrow, the lung, the mineral bone, the breast, and the testes from each of these exposure modes (a 0.33 shielding factor is applied to the external ground dose) are shown in Figs. VI 13-13 through 13-17.[2] The dose magnitudes shown in these graphs are representative of 100 miles from the reactor in the event of a large, cold, ground-level release. It should be understood that these calculated doses are for individual who lives continuously at the same location and ingests locally produced foodstuffs exclusively, i.e., no produce, meat,

[1]When time-dependent meteorology is considered, there are infrequent weather sequences in which early fatalities can occur beyond 10 miles and the risk of death from lung damage competes with that from bone marrow damage. For example, several hours of brisk winds with stability category A followed by a near calm or rain can result in high ground dose rates at 15 or more miles from reactor. See section 13.3.1 and Fig. VI 13-23.

[2]The dose from a specified radionuclide includes any contribution from its daughters.

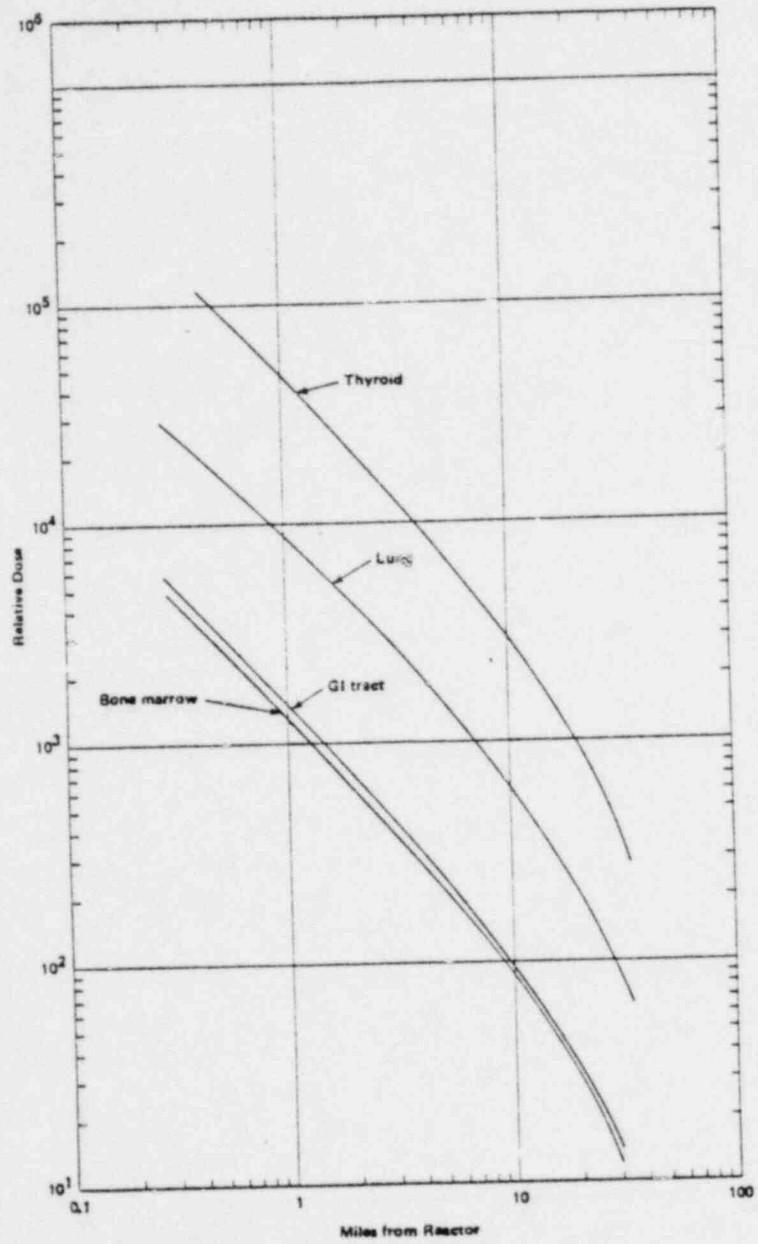


FIGURE VI 13-5 Total organ doses versus distance from reactor for hypothetical weather: stability A, wind speed of 0.5 m/sec. Thyroid dose = 1-day ground + external cloud dose + 30-day inhalation dose; Lung dose = 1-day ground + external cloud dose + 1-year inhalation dose; GI tract dose = 1-day ground + external cloud dose + 7-day inhalation dose (the GI tract dose is the dose to the regenerative cells of the lower large intestine); bone marrow dose = 1-day ground + external cloud dose + ½(7-day inhalation + 30-day inhalation dose)

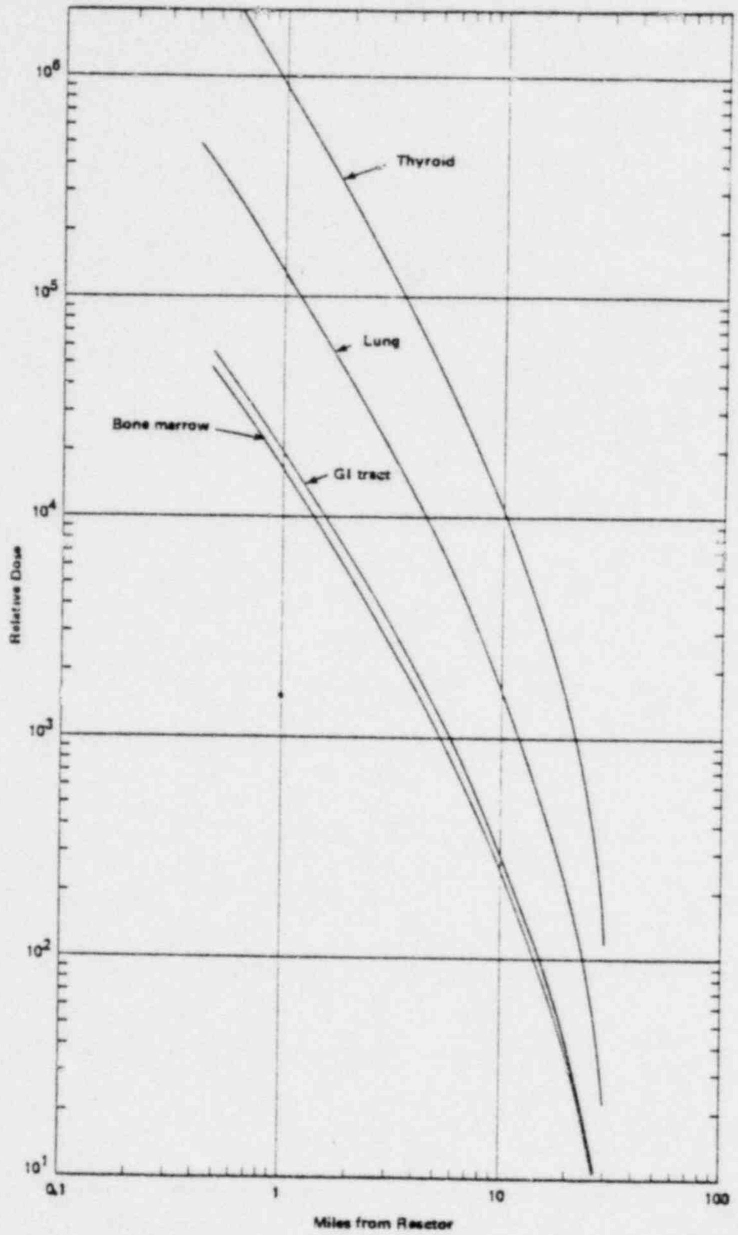


FIGURE VI 13-6 Total organ doses versus distance from reactor for hypothetical weather; stability F, wind speed = 2.0 m/sec. Thyroid dose = 1-day ground + external cloud dose + 30-day inhalation dose; Lung dose = 1-day ground + external cloud dose + 1-year inhalation dose; GI tract dose = 1-day ground + external cloud dose + 7-day inhalation dose (the GI tract dose is the dose to the regenerative cells of the lower large intestine); bone marrow dose = 1-day ground + external cloud dose + ½(7-day inhalation + 30-day inhalation dose)

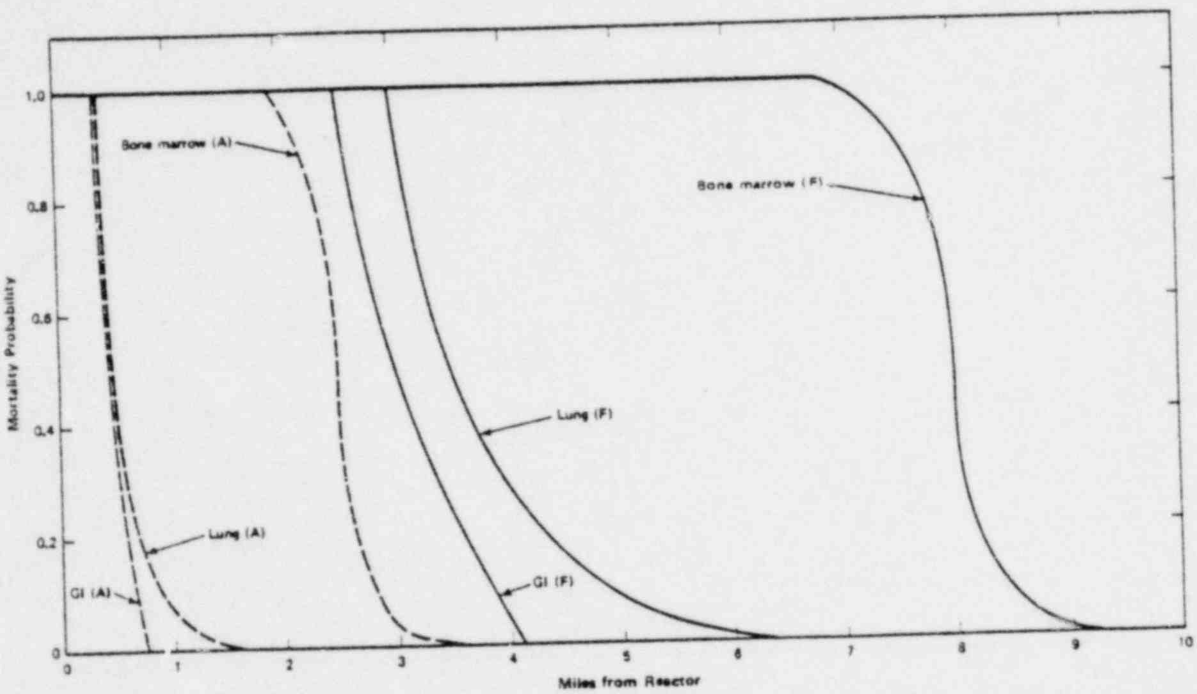


FIGURE VI 13-7 Mortality probability for an affected population versus distance from reactor for two hypothetical weathers: stability category A, wind speed = 0.5 m/sec; stability category F, wind speed = 2.0 m/sec.

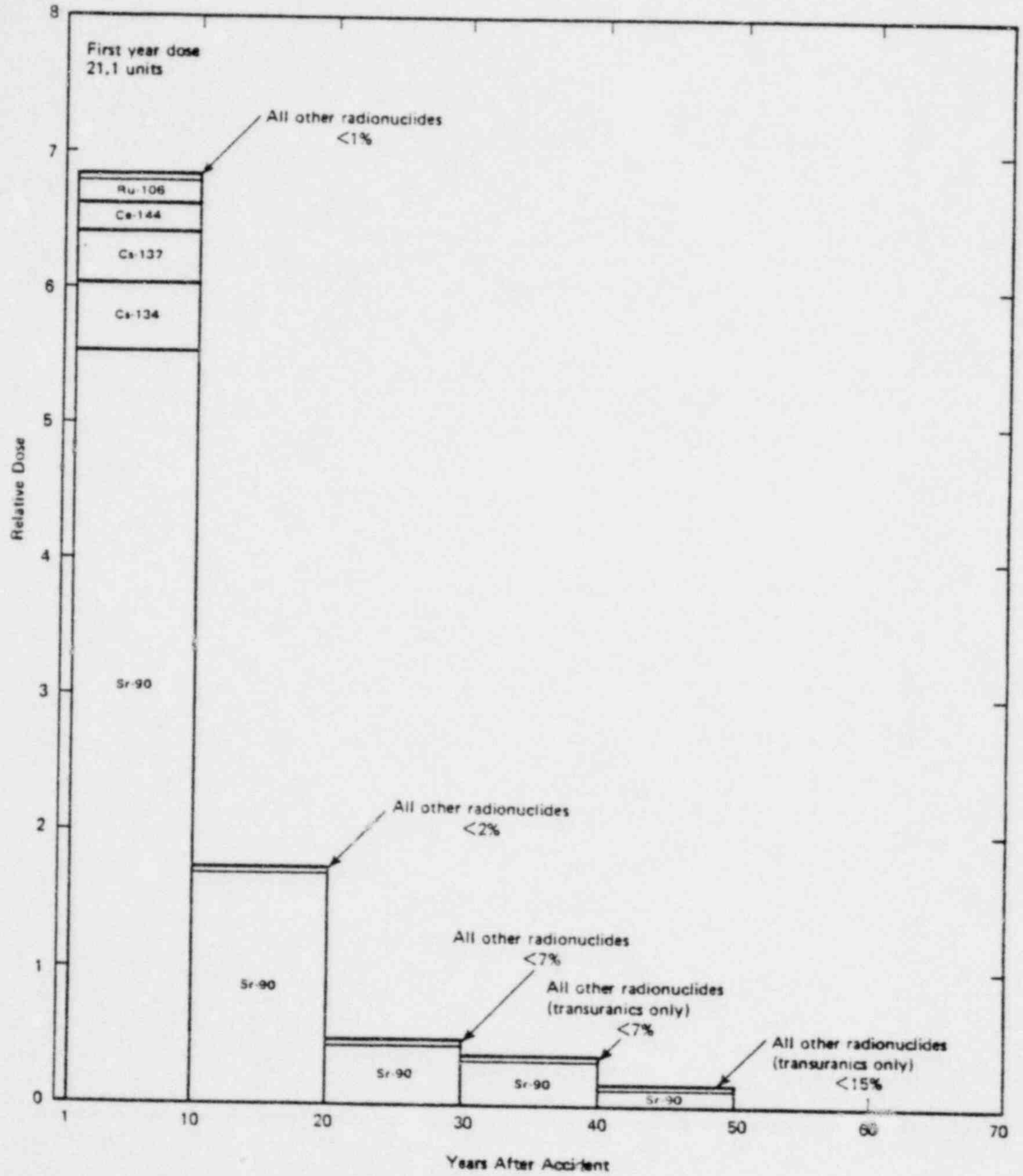


FIGURE VI 13-8 Relative incremental dose to bone marrow from inhaled radionuclides at 10 miles from reactor.

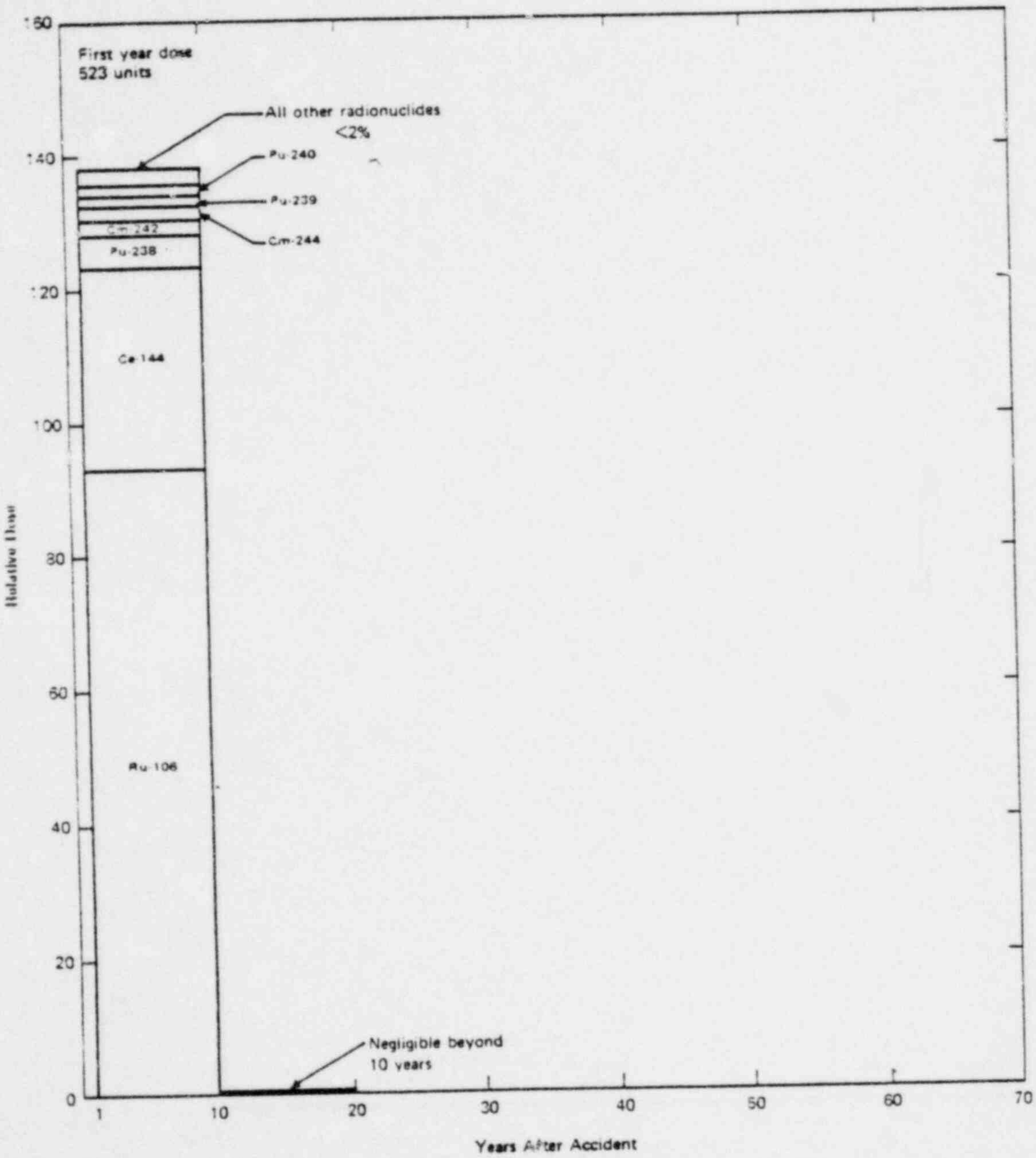


FIGURE VI 13-9 Relative incremental dose to lung from inhaled radionuclides at 10 miles from reactor.

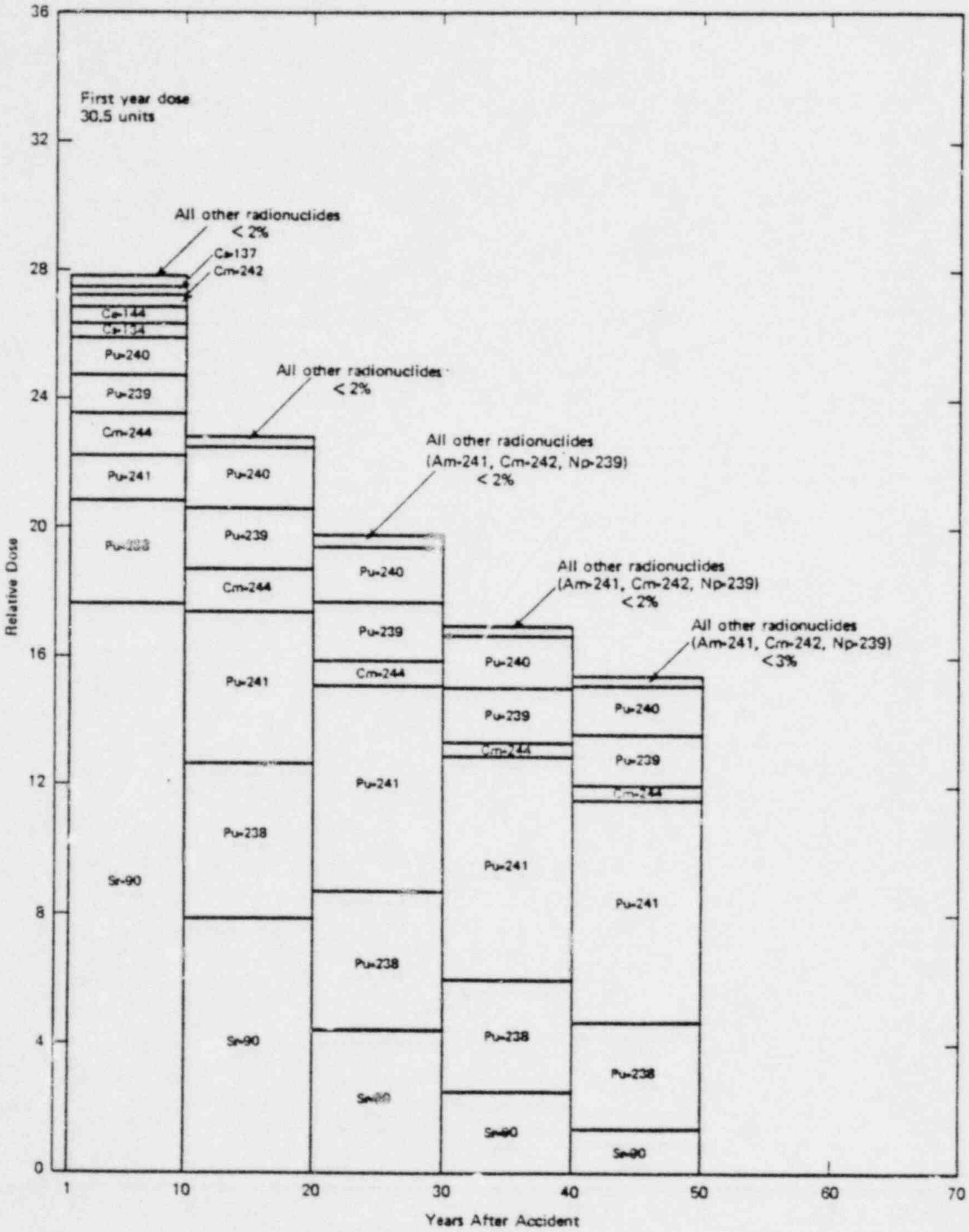


FIGURE VI 13-10 Relative incremental dose to mineral bone from inhaled radionuclides at 10 miles from reactor.

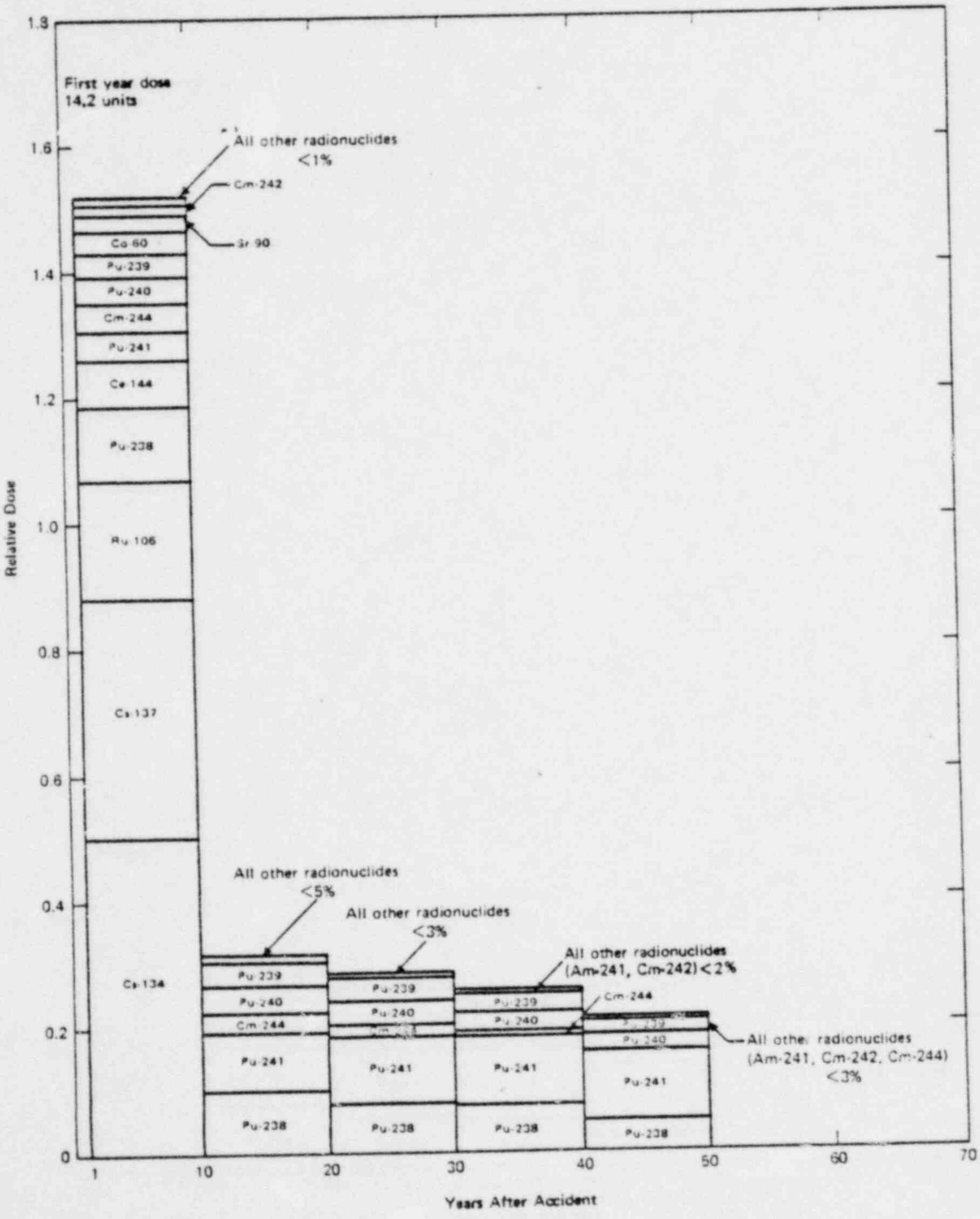


FIGURE VI 13-11 Relative incremental dose to breast from inhaled radionuclides at 10 miles from reactor.

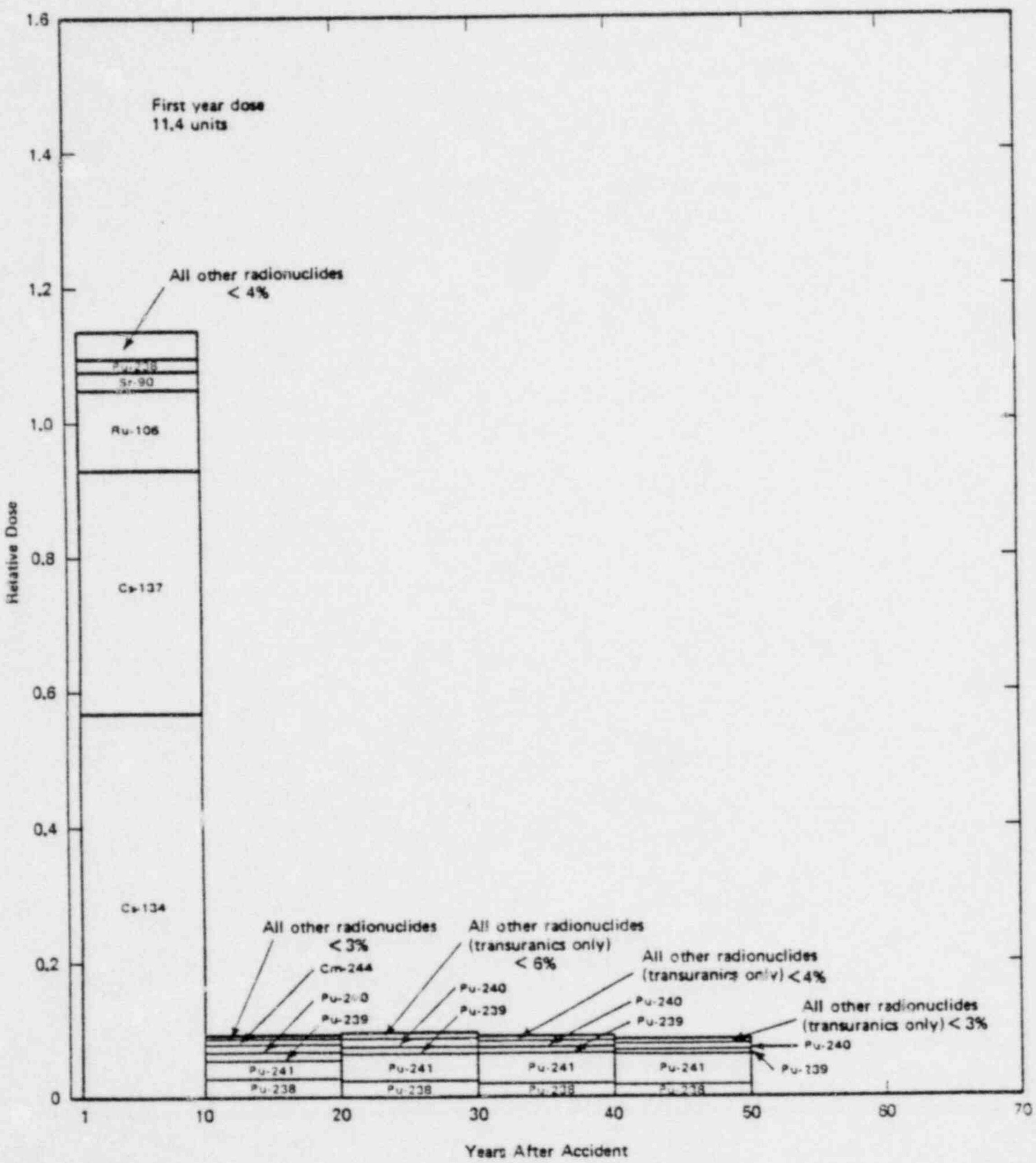


FIGURE VI 13-12 Relative incremental dose to testes from inhaled radionuclides at 10 miles from reactor.

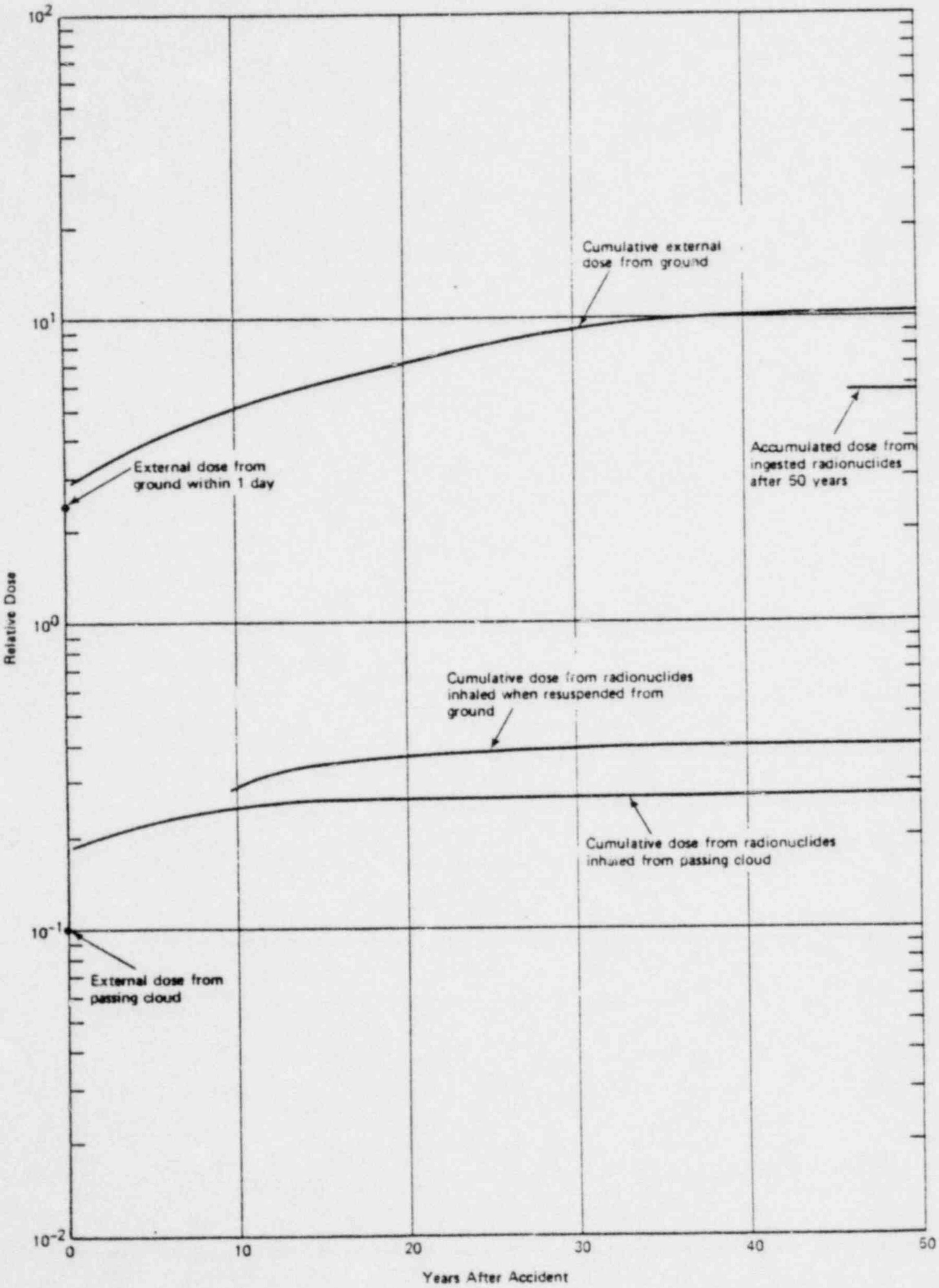


FIGURE VI 13-13 Relative doses to bone marrow at 100 miles from reactor.

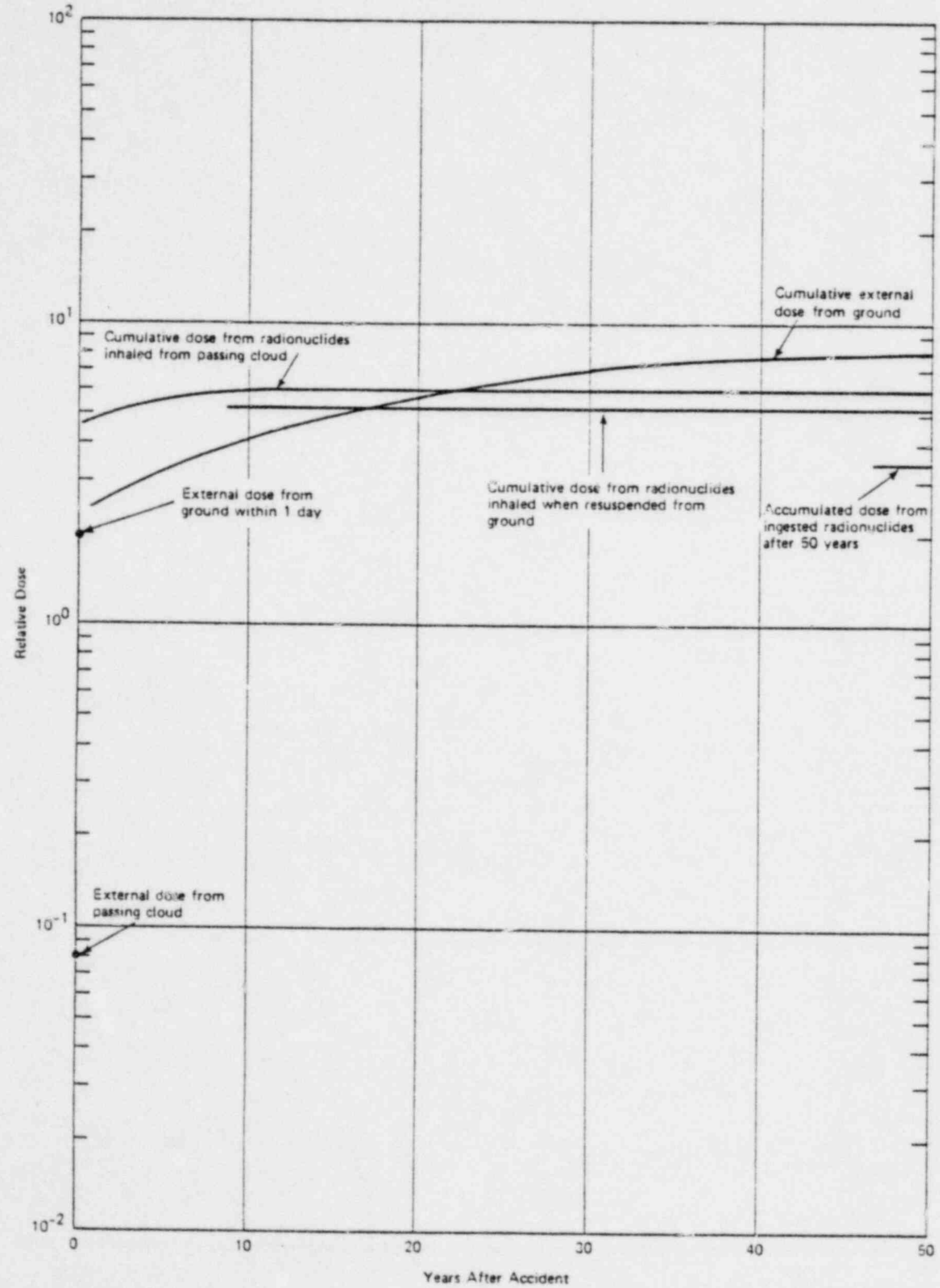


FIGURE VI 13-14 Relative doses to lung at 100 miles from reactor.

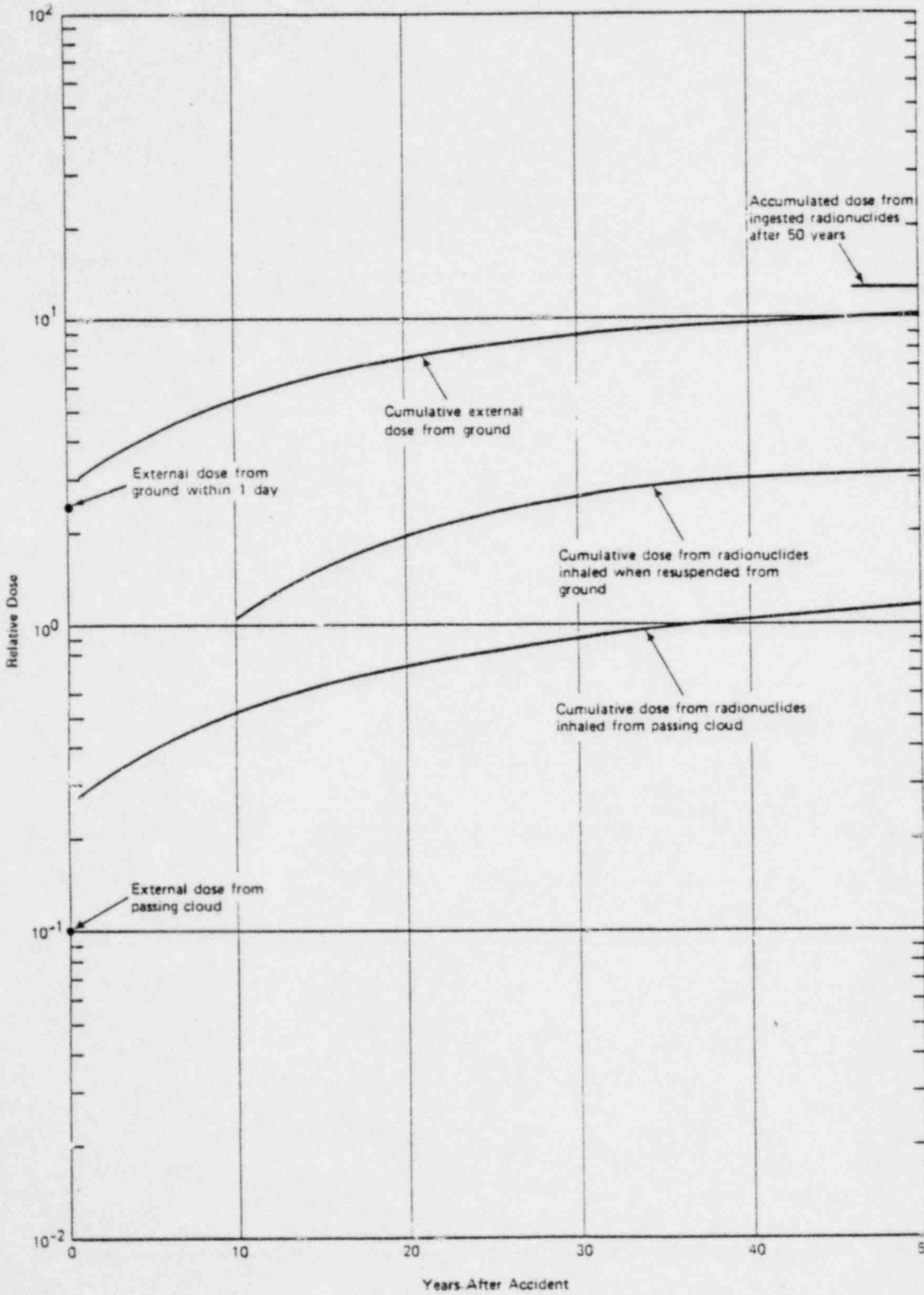


FIGURE VI 13-15 Relative doses to mineral bone at 100 miles from reactor.

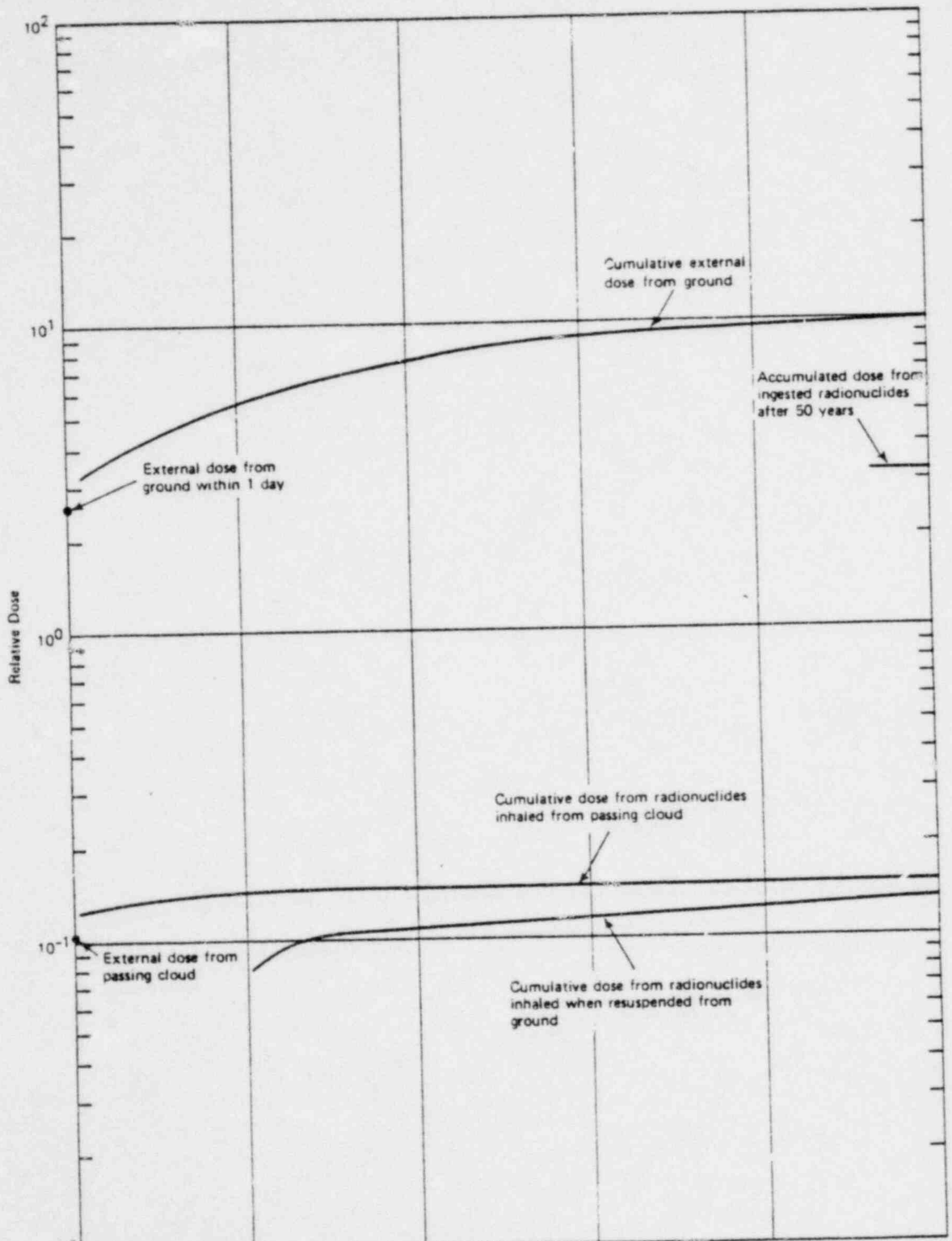


FIGURE VI 13-16 Relative doses to breast at 100 miles from reactor.

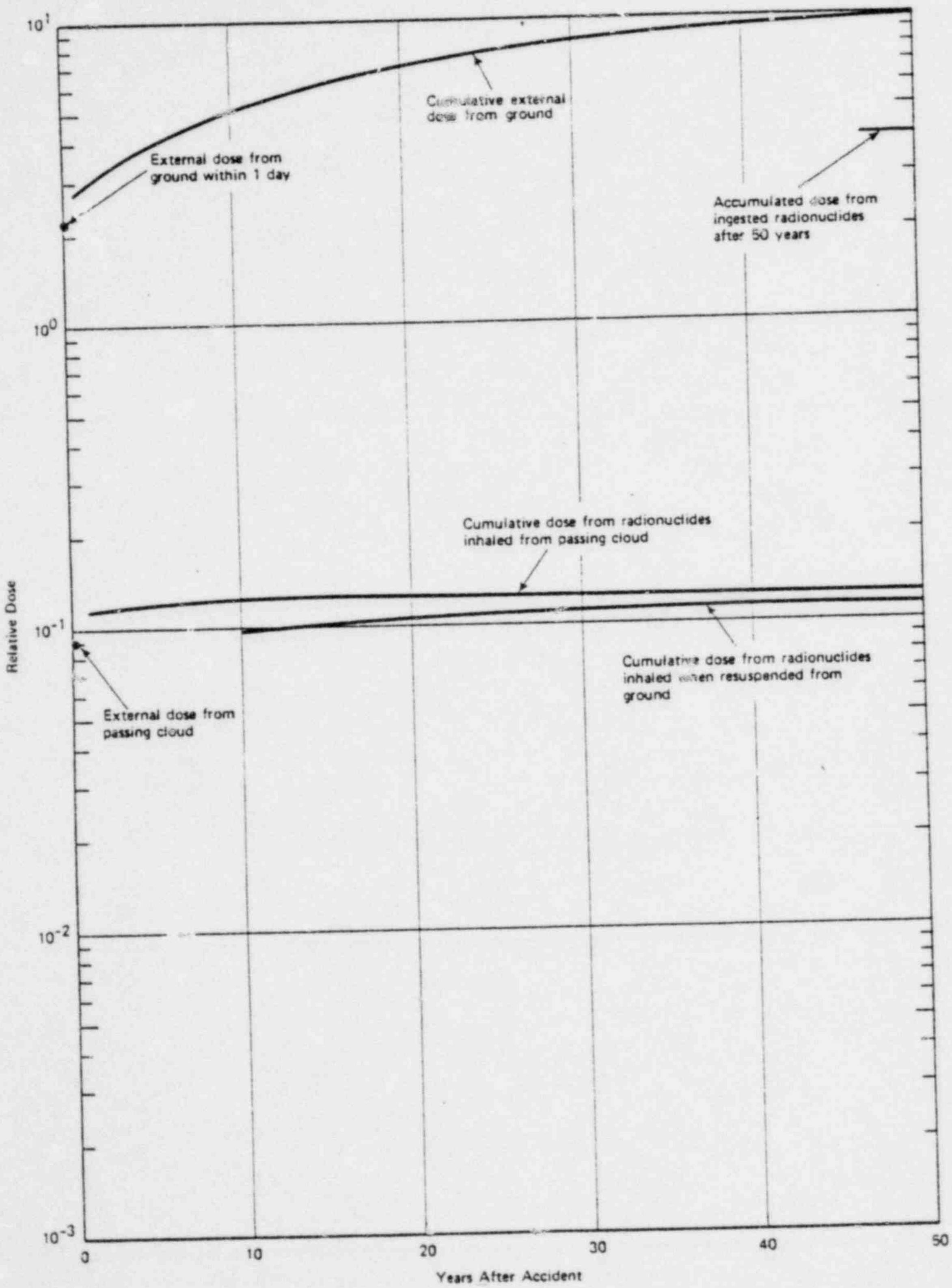


FIGURE VI 13-17 Relative doses to testes at 100 miles from reactor.

grains, or milk imported from other geographical locations. In today's mobile society in which foodstuffs are shipped thousands of miles, these assumptions are clearly conservative. As discussed in section 11.2.2, interdiction criteria are based on doses received to the whole body (bone-marrow) or gonads over a 30-year period. It is evident in Figs. VI 13-13 <u>et seq</u>. that external exposure from contaminated ground is the controlling exposure mode. Furthermore, at distances at which interdiction occurs, the doses received either external from the passing cloud or internal from inhaled radionuclides are small compared to that received from the contaminated ground over 30 years so that only the latter dose need be considered in establishing the interdicted area.

Each of the 54 radionuclides used in this study can be characterized by its contribution to the doses to various organs in various time periods. Table VI 13-1 shows such a breakdown. The doses considered are the doses from inhaled radionuclides to the bone marrow, lung, gastrointestinal tract, mineral bone, thyroid, "other tissues," and testes as well as those due to external exposure from the ground and from the passing cloud. Both early and late contributions to health effects are noted. A scale from zero to two is established; on which 2 indicates that the radionuclide contributed significantly to the specified dose and 1 indicates a small contribution. By summing these values for each radionuclide, a very crude ranking of the radionuclides is obtained. From this ranking, the radionuclides in the release that make little contribution can be identified.[1] They are listed in Table VI 13-2. From this table, it is seen that one-third of the released radionuclides used in this study could be neglected with small loss of accuracy, but with substantial reduction in the computation time of the consequence model.

TABLE VI 13-2 RELEASED RADIONUCLIDES CONTRIBUTING LITTLE TO HEALTH EFFECTS

Y-90	Kr-85m	Co-58	Rh-105	Te-129	Nd-147
Nb-95	Kr-87	Co-60	Ru-105	Ce-143	Am-241
Tc-99m	Rb-86	K-85	Te-127	Pr-143	

In the event of a reactor accident, the spectrum of doses received by the exposed population is very broad. As noted in section 9, the models for several health effects are influenced by the relative numbers of people receiving large or small doses. Figs. VI 13-18 and VI 13-19 give the frequency distribution of the number of people versus dose received to the bone marrow within 50 years and to the thyroid within 30 days respectively. The numbers of people are the mean values of 90 trials from one meteorological data set, assuming a large release, 100 people/mile^2 and an interdiction criterion of 25 rem in 30 years. The reader should note that the histograms are plotted with nonuniform increments on the abscissa. The use of equal increments would more readily illustrate the skewness of the distributions towards low doses. The population dose versus the 50-year bone marrow dose is also plotted in Fig. VI 13-18. From this histogram, the percentages of the total whole-body man-rem associated with individuals receiving in excess of 10, 30 and 50 rem are 75, 60 and 13% respectively. From similar calculations, the approximate percentages of latent cancer fatalities attributable to each exposure mode are stated in Table VI-13-3, both on a whole-body and organ-by-organ basis.[2] It is evident that lung cancer due to inhalation of radioactive material in the passing cloud is the dominant contribution to the total latent cancer fatalities. Furthermore, this domination underscores the importance of calculating latent cancer fatalities due to an accident on an organ-by-organ basis.

[1]A released radionuclide is important if it contributes significantly to a health effect and/or its radioactive daughters contribute significantly. For example, the released quantity of Am-241 is unimportant but that quantity which results from the decay of Pu-241 is important. The dose from the decay of Pu-241 is unimportant.

[2]The contribution of each exposure mode is estimated by setting its conversion factors to zero and subtracting corresponding latent fatalities from the total. This method is only approximate since the central estimate is based upon a nonlinear model.

TABLE VI 13-1 IMPORTANCE OF VARIOUS RADIONUCLIDES FOR HEALTH EFFECTS CALCULATIONS[(a)]

Released radio-nuclide	Contributions to Early and Continuing Health Effects							Contribution to Late Health Effects (0-50Y)						Σ
			Inhalation						Inhalation					
	Cloud Dose	Short-Term Ground Dose	Bone Marrow (30 days)	Lung (365 days)	GI (7 days)	Thyroid (30 days)	Testes (60 days)	Ground	Bone Marrow	Lung	Mineral Bone	Other	Testes	
Co-58														
Co-60														
Kr-85														
Kr-85m														
Kr-87														
Kr-88	2													2
Rb-86														
Sr-89			2		1		1		2		2	1	1	10
Sr-90			1						1		2			4
Sr-91		1			1									2
Y-90														
Y-91			1	1	1				1	1	1			6
Zr-95				1						1				2
Zr-97					1									1
Nb-95														
Mo-99				1	1					1				3
Tc-99m														
Ru-103		1	1	1	1			1	1	1		1		8
Ru-105														
Ru-106				2	2			1		2		1		8
Rh-105														
Te-127														
Te-127m				1						1				2
Te-129														
Te-129m			1	1	1				1	1	1			6
Te-131m	1	1	1	1	1				1	1				7
Te-132	1	2	2	2	2	1	2		2	2	2	2	2	22
Sb-127				1	1					1				3
Sb-129	1	1												2
I-131	1	2	1	1		2	1		1	1	1	1	1	13
I-132	2	2	1	1			1		1	1		1	1	11
I-133	2	2	1	1	1	1	1		1	1		1	1	13
I-134	1													1
I-135	2	2	1	1	1	1	1		1	1		1	1	13
Xe-133	1													1
Xe-135	1													1
Cs-134			2	1			2	2	2	1	2	2	2	16
Cs-136			1				1		1			1	1	5
Cs-137			1				1	2	1		1	2	2	10

TABLE VI 13-1 (Continued)

Released radionuclide	Contributions to Early and Continuing Health Effects							Contribution to Late Health Effects (0-50Y)						Σ
			Inhalation						Inhalation					
	Cloud Dose	Short-Term Ground Dose	Bone Marrow (30 days)	Lung (365 days)	GI (7 days)	Thyroid (30 days)	Testes (60 days)	Ground	Bone Marrow	Lung	Mineral Bone	Other	Testes	
Ba-140		1	2		2		1		2		1	1	1	11
La-140	1	1			1									3
Ce-141				1						1				2
Ce-143														
Ce-144				2	1					2				5
Pr-143														
Nd-147														
Np-239				1	1					1				3
Pu-238											1			1
Pu-239											1			1
Pu-240											1			1
Pu-241											1			1
Am-241														
Cm-242				1						1	1 (b)			3
Cm-244											1			1

(a) Key: 1 = small but important contribution to total dose; 2 = substantial contribution to total dose.

(b) Cm-242 contributes significantly within the first year to the mineral bone dose.

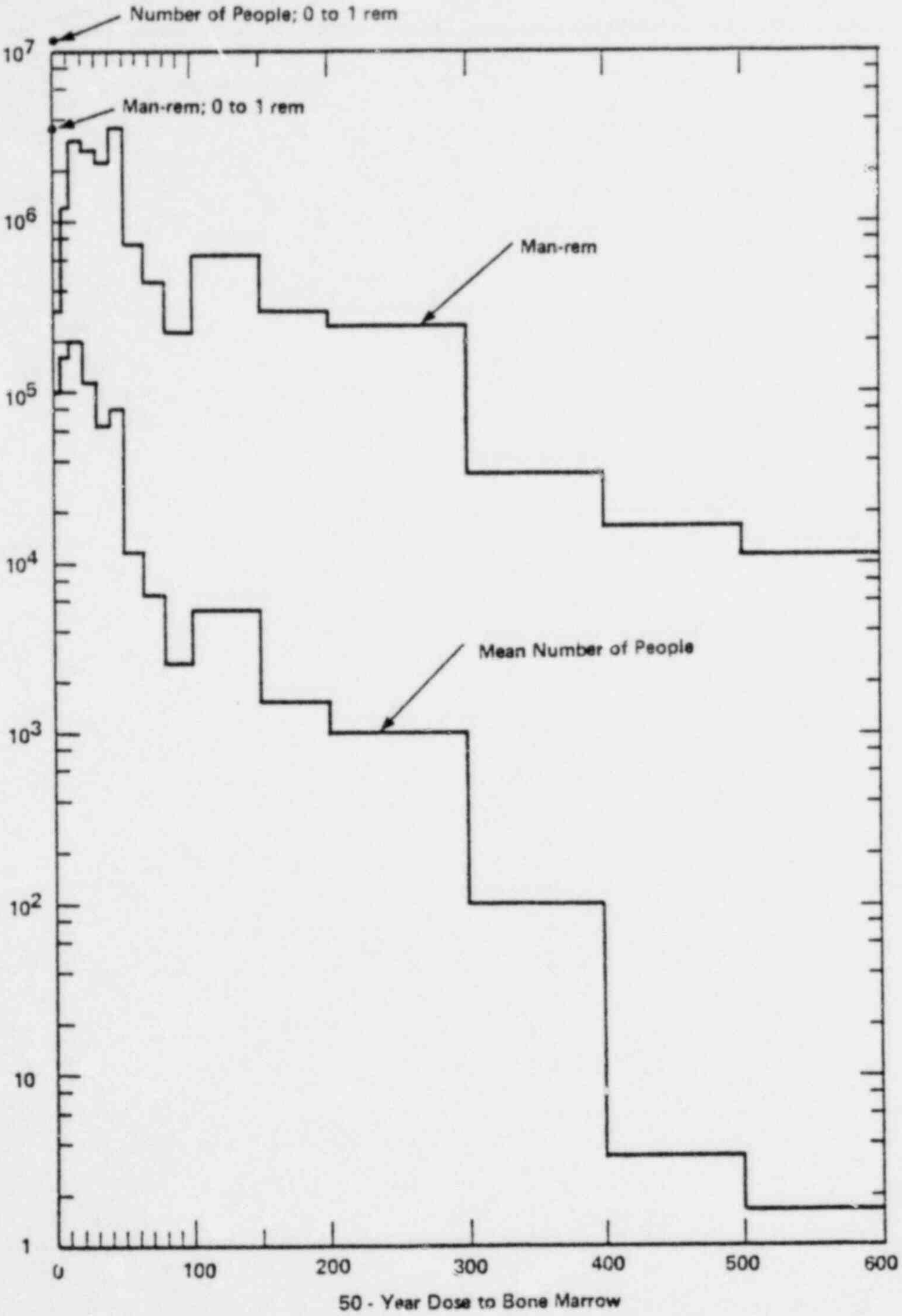


FIGURE VI 13-18 Frequency distribution of number of people and population dose versus bone marrow dose within 50 years (PWR-1B release, 100 people/mile^2)

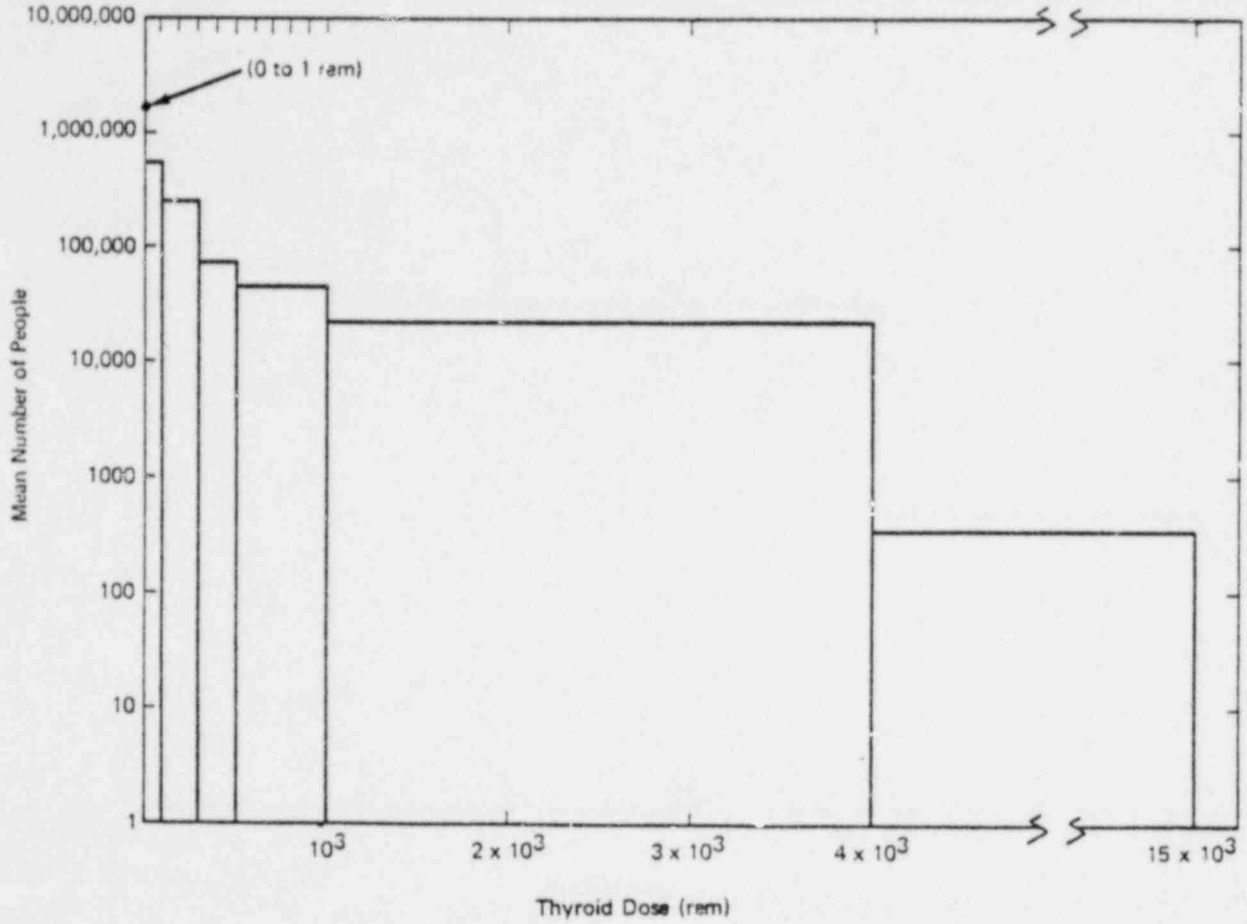


FIGURE VI 13-12 Frequency distribution of number of people versus thyroid dose within 30 days (PWR-1B release).

TABLE VI 13-3 CONTRIBUTION OF DIFFERENT EXPOSURE MODES TO LATENT CANCER FATALITIES

	Percentages							
	Leukemia	Lung	Breast	Bone	GI Tract	All Other	Total	Whole Body[(a)]
External cloud	0.2	0.5	0.5	0.1	0.1	0.3	1	3
Inhalation from cloud	0.5	59.0	10.0	0.2	1.0	0.2	71	15
External ground (<7 days)	4.0	8.0	8.0	1.0	1.0	3.0	25	47
External ground (>7 days)	2.0	2.0	6.0	1.0	1.0	2.0	13	30
Inhalation of resuspended contamination	0.1	3.0	0.1	0.1	0.1	0	3	2
Injestion of contaminated foods	0.2	0.2	0.5	0.1	0.1	0.2	1	4
Subtotals	7	66	16	2	3	6	100	100

[(a)] Whole body values are proportional to 50-year whole-body man-rem.

Section 9.3 discusses different calculation methods for the latent cancer fatalities; whole body versus organ-by-organ and upper bound versus central estimate. Table VI 13-4 shows the effective incidence by the four methods. When using the whole-body dose and BEIR (upper bound) values, the incidence is 121.6 per 10^6 man-rem as stated in Table VI 9-4. On an organ-by-organ basis, this incidence is increased to 190 due to the preferential dose to the lung. Introduction of the dose-effectiveness factors reduces both these incidences but has less effect on the organ-by-organ value than on the whole body value since lung cancers are the dominant contribution and the lung dose is usually greater than 25 rem. Mean values are given in Table VI 13-4. For the largest calculated accidents, values on an organ-by-organ basis are somewhat higher and the dose-effectiveness factors have less influence.

TABLE VI 13-4 EXPECTED CASES OF LATENT CANCER FATALITIES PER MILLION MAN-REM

Method	Upper Bound (BEIR)	Central Estimate
Whole body	122	48
Sum of individual organs	190	100

13.2 SAMPLING

The atmospheric dispersion of the radioactive material depends on the weather over a period of 10 to 30 hours. The magnitudes of specified consequences are determined by the interaction of this atmospheric dispersion with the distribution of population which varies with distance and direction from the reactor. Clearly, there is an almost infinite number of combinations of weather and population, each leading to an unique set of consequences. Such a problem is not amenable to closed-form solution. A common approach to such a problem is to sample the underlying distributions a finite number of times in such a way that the true distribution of consequences is closely approximated. This latter approach is incorporated into the consequence model. This section describes the sampling method and presents some analyses that establish its adequacy.

13.2.1 SAMPLING METHODS

Sampling methods are particularly suitable to computer techniques and there is a large literature on choosing a sampling method and determining its adequacy (Hammersley and Handscomb, 1964; Kahn, 1957; Kempthorne, 1952). The available meteorological data are hourly readings of stability, wind speed and direction and precipitation at a reactor site over a period of one or more years. Three sampling methods were considered for the consequence model. The most obvious method is a random sampling from these 8760 readings (one year's worth). That is, a starting hour, when the radioactive material is assumed to be released, is randomly selected and, by using this and the succeeding 20 or so hours of weather readings, the resultant atmospheric dispersion is calculated. By repeating this process for 100 or more random trials, a population (in a statistical sense) of radioactive plumes is generated which may be used in conjunction with the population (people) distributions to calculate a frequency distribution for each consequence.

NUREG 0020
VOL. 4 NO. 1
JANUARY

Nuclear Regulatory Commission

OPERATING UNITS STATUS REPORT

DATA AS OF 12-31-79

EXCERPTS

LICENSED OPERATING REACTOR

OYSTER CREEK

FACILITY DATA

Facility Description

1. Location (state/county) (nearest population center)	New Jersey/Ocean; 9 miles S of Toms River
2. Electric Reliability Council	MAAC
3. Type of Reactor	BWR
4. Power Level (MWT)	1930
5. Design Electrical Rating (MWE Net)	650
6. Date of Initial Criticality	May 3, 1969
7. Date of Commercial Operation	December 1969
8. Condenser Cooling Method	Once Through
9. Condenser Cooling Water Source	Barnegat Bay

Utility & Contractor Information

10. Lice	Jersey Central Power & Light Co.
11. Corporate Address	Madison Avenue At Punch Bowl Road Morristown, New Jersey 07960
12. Corporate Contact	I. Finfrock, Vice President Power Generation
13. Architect/Engineer	Burns & Roe
14. Nuclear Steam Supply System	GE
15. Constructor	J. A. Jones

Regulatory Information

16. IE Region responsible	I
17. IE Branch Chief	E. Brunner
18. IE Senior Inspector	E. McCabe
19. IE Principal Inspector	L. Briggs
20. Licensing Project Manager	S. J. Nowicki
21. Docket Number	50 219
22. License Number/Date of Issue	DPR 16, 4/9/69
23. Public Document Room	Ocean County Library 15 Hooper Avenue Toms River, New Jersey 08753

INSPECTION STATUS

ENFORCEMENT STATUS

NONE

INSPECTION STATUS

OTHER ITEMS OF INTEREST

SYSTEMS AND COMPONENT PROBLEMS:

None

FACILITY ITEMS (PLANS AND PROCEDURES):

* The plant was shutdown for a scheduled 10 week refueling outage on January 5.

MANAGERIAL ITEMS:

None

PLANT STATUS:

* The plant operated during December with an offgas rate of 168,000 microcuries per second and a stack release rate of 26,700 microcuries per second.

* LAST IE SITE INSPECTION DATE: 01/14/80

* INSPECTION REPORT NO: 80-01

SUMMARY

INSPECTION SUMMARY

* Nov. 30 (79-22): Routine, announced inspection by four region based inspectors (16 hours) of a licensee conducted emergency drill. Noncompliances: None

NRC P[illegible] RESTRICTIONS: NONE

REPORTS RECEIVED FROM LICENSEE

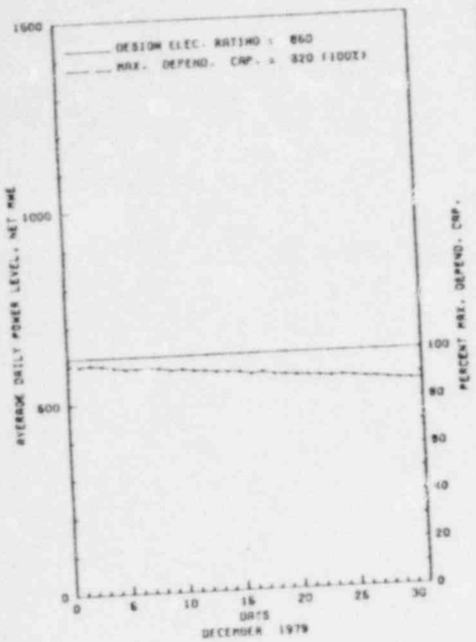
NUMBER	DATE OF EVENT	DATE OF REPORT	TYPE OF REPORT	SUBJECT
79-037/03L	11/03/79	11/30/79	30 Day LER	Failure of core spray booster pump to start during routine surveillance due to control power fuse
79-038/03L	11-05/79	11/30/79	30 Day LER	Failure of D.G. No. 1 to start due to position switch adjustment
79-039/03L	11/05/79	12/03/79	30 Day LER	APRM Channel 1 (1 of 6) rod block setpoint found 1 percent above T.S. limit
79-040/03L	11/02/79	11/30/79	30 Day LER	Failure to perform methyl iodine removal efficiency of SBGTS charcoal filters. Tests completed satisfactorily
79-041/03L	11/02/79	12/03/79	30 Day LER	Radioactive releases (low level) from new radwaste building not accurately monitored
79-042/03L	11/06/79	12/06/79	30 Day LER	Inadvertent lifting of one electromatic relief valve due to setpoint drift of new pressure switch

REVIEWED BY OMPA LOEB: Jack J. Riggs DATE: 2-11-80

REVIEWED BY NRR DOR: S. J. Nowicki DATE: 2/12/80

OYSTER CREEK

AVERAGE DAILY POWER LEVEL (MWe)



OPERATING STATUS

ITEM 21 CALCULATED BY USING A WEIGHTED AVERAGE

1. Docket Number: 50-219
2. Utility Contact: C. F. McClain (201) 455-8748
3. Licensed Thermal Power (MWt): 1930
4. Nameplate Rating (Gross MWe): 687.5 x 0.8 = 550.
5. Design Electrical Rating (Net MWe): 650
6. Maximum Dependable Capacity (Gross MWe): 650
7. Maximum Dependable Capacity (Net MWe): 620
8. If Changes Occur in Capacity Ratings Above Since Last Report, Give Reasons: NONE
9. Power Level To Which Restricted, If Any (Net MWe): NONE
10. Reasons For Restrictions, If Any: NONE

	MONTH	YEAR	CUMULATIVE
11. Hours in Reporting Period	744.0	8,760.0	87,839.0
12. Hours Reactor Was Critical	744.0	7,470.2	68,425.3
13. Reactor Reserve Shutdown Hours	0	0	468.2
14. Hours Generator On-Line	744.0	7,324.2	67,193.2
15. Unit Reserve Shutdown Hours	0	0	0
16. Gross Thermal Energy (MWH)	1,279,373	12,852,161	113,879,128
17. Gross Electrical Energy (MWH)	440,000	5,292,310	38,882,275
18. Net Electrical Energy (MWH)	423,099	5,363,223	37,181,073
19. Unit Service Factor	100.0	83.9	76.6
20. Unit Availability Factor	100.0	83.9	76.6
*21. Unit Capacity Factor (MDC Net)	91.9	85.0	68.6
22. Unit Capacity Factor (DER Net)	87.5	20.1	65.6
23. Unit Forced Outage Rate	0	15.1	8.3

24. Shutdowns Scheduled Over Next 6 Months (Type, Date, and Duration of Each): REFUELING 0180
25. If Shut Down At End of Report Period, Estimated Date of Startup: N/A

UNIT SHUTDOWNS/REDUCTIONS

No.	Date	Type[1]	Duration (Hours)	Reason[2]	Method of Shutting Down Reactor[3]	Licensee Event Report No.	System Code[4]	Component Code[5]	Cause & Corrective Action to Prevent Recurrence
	NONE								

SUMMARY

OPERATION WAS ROUTINE IN AN END OF CYCLE COASTDOWN THROUGHOUT THE REPORT PERIOD, WITH NO FURTHER REDUCTIONS OR OUTAGES REPORTED

LEGEND

[1] Type:
F Forced
S Scheduled

[2] Reason:
A Equipment Failure
B Maintenance or Test
C Refueling
D Regulatory Restriction
E Operator Training & License Examination
F Administrative
G Operational Error
H Other

[3] Method:
1 Manual
2 Manual Scram
3 Automatic Scram
4 Continuations
5 Load Reduction
9 Other

[4] Exhibit F
Instructions for Preparation of Data Entry Sheets for Licensee Event Report (LER) File (NUREG 0161)

[5] Exhibit H
Same source

SALEM 1

NRC POWER RESTRICTIONS: NONE

FACILITY DATA

Facility Description

1.	Location (state/county) (nearest population center)	New Jersey/Salem 20 miles S of Wilmington, Del.
2.	Electric Reliability Council	NPCC
3.	Type of Reactor	PWR
4.	Power Level (MWT)	3338
5.	Design Electrical Rating (MWE Net)	1090
6.	Date of Initial Criticality	December 11, 1976
7.	Date of Commercial Operation	June 30, 1977
8.	Condenser Cooling Method	Once Through
9.	Condenser Cooling Water Source	Delaware River

Utility & Contractor Information

10.	Licensee	Public Service Electric & Gas Co.
11.	Corporate Address	80 Park Place Newark, New Jersey 07101
12.	Corporate Contact	F. P. Librizzi General Manager - Electric Prod.
13.	Architect/Engineer	PSE&G
14.	Nuclear Steam Supply System	Westinghouse
15.	Constructor	UE&C

Regulatory Information

16.	IE Region responsible	I
17.	IE Branch Chief	E. Brunner
18.	IE Senior Inspector	R. R. Keimig
19.	IE Resident Inspector	L. J. Norrholm (FTS 341 3000)
20.	Licensing Project Manager	W. Ross
21.	Docket Number	50-272
22.	License Number/Date of Issue	DPR 70, 8/13/76
23.	Public Document Room	Salem Free Public Library 112 West Broadway Salem, New Jersey 08079

INSPECTION STATUS

ENFORCEMENT STATUS

THE 16.5 DEGREE F MAXIMUM T ACROSS THE CONDENSER WAS EXCEEDED DURING NORMAL OPERATION WITH ALL CIRCULATING WATER PUMPS OPERATING ON SEVERAL OCCASIONS INCLUDING 1/4, 5, 21 & 25; 2/5-6 & 3/4/79. THE 27.5 DEGREE F INSTANTANEOUS MAXIMUM T ACROSS THE CONDENSER WAS EXCEEDED ON 1/18 & 25/79. SECTION 2.1.1 OF APP B. ETS FOR SALEM GENERATING STATION UNIT 1
(7929 INFRACTION)

RECORDS OF PLANT THERMAL MONITORING REQUIRED BY SECTION 2.1 OF THE ETS WERE NOT MADE & RETAINED FOR THE PERIOD FROM 0900 THRU 2400 HRS ON 1/15/79. SECTION 5.7.1 OF APP B. ETS.
(7929 DEFICIENCY)

ON SEVERAL OCCASIONS, INCLUDING THOSE INSTANCES INDICATED IN ITEM A OF THIS APP, THE EXCEEDING OF THE CONDENSER T LIMITING CONDITION FOR OPERATION INCLUDING THOSE OF 1/4, 5, 21 & 25; 2/5-6 & 3/4/79 WERE NOT REPORT AS REQUIRED. SECTION 5.6.2 OF APP B. ETS.
(7929 DEFICIENCY)

*

I N S P E C T I O N   S T A T U S

OTHER ITEMS OF INTEREST

SYSTEMS AND COMPONENT PROBLEMS:

* None

FACILITY ITEMS (PLANS AND PROCEDURES):

* The licensee is completing seismic reanalysis per IEB 79-07 and making support modifications as necessary.

MANAGERIAL ITEMS:

None

PLANT STATUS:

* Unit resumed operation at the end of December.

* LAST IE SITE INSPECTION DATE: 01/22/80

* INSPECTION REPORT NO: 79-33

SUMMARY

INSPECTION SUMMARY

* Oct 7 - Nov 13 (79-28): Routine inspections of plant operations including: tours of the facility; log and record reviews; review of licensee events; followup on IE Bulletins and Immediate Action Letters; and followup on previous inspection items. The inspections involved 75 onsite hours by the resident NRC inspector. One item of noncompliance and one deviation were identified (failure to follow procedures relative to valve status; failure to complete seismic support modifications prior to Mode 4 operation).

* Oct 31 - Nov 1-2 (79-30): Routine unannounced inspection of inservice inspection data package and licensee action on previous inspection findings. The inspection involved 24 hours onsite by one NRC region-based inspector. No noncompliances were identified.

REPORTS RECEIVED FROM LICENSEE

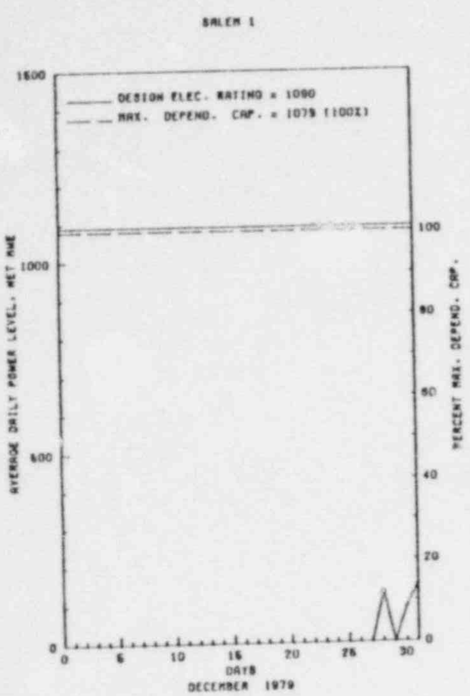
NUMBER	DATE OF EVENT	DATE OF REPORT	TYPE OF REPORT	SUBJECT
	NONE			

REVIEWED BY OMPA LOEB: T.C. Cintula DATE: 2•11•80

REVIEWED BY NRR DOR: W J Ross DATE: 2/13/80

SALEM 1

AVERAGE DAILY POWER LEVEL(MWe)



OPERATING STATUS

1. Docket Number: 50-272
2. Utility Contact: L. K. Miller (609) 365-7000
3. Licensed Thermal Power (MWt): 3338
4. Nameplate Rating (Gross MWe): 1300 x 0.9 = 1170
5. Design Electrical Rating (Net MWe): 1090
6. Maximum Dependable Capacity (Gross MWe): 1124
7. Maximum Dependable Capacity (Net MWe): 1079
8. If Changes Occur in Capacity Ratings Above Since Last Report, Give Reasons:
   NONE
9. Power Level To Which Restricted, If Any (Net MWe): NONE
10. Reasons for Restrictions, If Any:
   NONE

	MONTH	YEAR	CUMULATIVE
11. Hours In Reporting Period	744.0	8,760.0	21,361.0
12. Hours Reactor Was Critical	256.9	2,421.6	10,308.1
13. Reactor Reserve Shutdown Hours	.0	22.7	22.7
14. Hours Generator On-Line	71.8	2,233.1	9,311.1
15. Unit Reserve Shutdown Hours	.0	.0	.0
16. Gross Thermal Energy (MWH)	67,070	6,351,361	27,536,296
17. Gross Electrical Energy (MWH)	12,926	2,195,670	9,167,388
18. Net Electrical Energy (MWH)	-2,261	2,052,613	8,629,398
19. Unit Service Factor	9.7	25.5	43.6
20. Unit Availability Factor	9.7	25.5	43.1
21. Unit Capacity Factor (MDC Net)	.0	21.6	36.5
22. Unit Capacity Factor (DER Net)	.0	21.5	36.1
23. Unit Forced Outage Rate	90.3	61.5	35.8

24. Shutdowns Scheduled Over Next 6 Months (Type, Date, and Duration of Each):
   NONE
25. If Shut Down At End of Report Period, Estimated Date of Startup: N/A

UNIT SHUTDOWNS/REDUCTIONS

No.	Date	Type[1]	Duration (Hours)	Reason[2]	Method of Shutting Down Reactor[3]	Licensee Event Report No.	System Code[4]	Component Code[5]	Cause & Corrective Action to Prevent Recurrence
79-349	12/01/79	F	.0	B	5		SH	ZZZZZZ	SAFETY ENVIRONMENTAL REQUIREMENTS
79-350	12/01/79	F	18[illegible].5	B	9		SH	ZZZZZZ	NRC TECH. SPECS./REG. GUIDES.
79-352	12/05/79	F	537.8	B	9		SH	ZZZZZZ	NRC REQUIRED MOD/ADD. TO PLANT
79-354	12/27/79	F	.6	B	5		SH	ZZZZZZ	NRC TECH. SPECS./REG. GUIDES
79-356	12/27/79	F	.5	B	9		SH	ZZZZZZ	SWITCHGEAR.
79-358	12/27/79	F	.8	B	5		SH	ZZZZZZ	NRC TECH. SPECS./REG. GUIDES.
79-360	12/29/79	F	18.6	B	9		SH	ZZZZZZ	REQUIRED INSPECTION OR TEST.
79-362	12/30/79	F	.8	B	5		SH	ZZZZZZ	NRC TECH. SPECS./REG. GUIDES.
79-364	12/30/79	F	6.8	B	9		SH	ZZZZZZ	REQUIRED INSPECTION OR TEST.
79-365	12/30/79	S	.4	B	5		SH	ZZZZZZ	NRC TECH. SPECS./REG. GUIDES.
79-366	12/31/79	F	7.6	B	3		CC	PUMPXX	STEAM GENERATOR HIGH HIGH LEVEL.

SUMMARY

THE UNIT REMAINED SHUTDOWN FOR MOST OF THE REPORT PERIOD AS A COMBINATION OF LAST PERIOD'S MAINTENANCE OUTAGE. LOAD INCREASES OCCURRED ON 12/28/79 FOR FLUX MAPPING, AND ON 12/31/79 IN PREPARATION FOR POWER OPERATION.

LEGEND

[1] Type
F Forced
S Scheduled

[2] Reason
A Equipment Failure
B Maintenance or Test
C Refueling
D Regulatory Restriction
E Operator Training & License Examination
F Administrative
G Operational Error
H Other

[3] Method
1 Manual
2 Manual Scram
3 Automatic Scram
4 Continuation
5 Load Reduction
9 Other

[4] Exhibit F
Instructions for Preparation of Data Entry Sheets for Licensee Event Report (LER) File (NUREG-0161)

[5] Exhibit H
Same source

NUREG-0480

COAL AND NUCLEAR: A COMPARISON OF THE COST OF GENERATING BASELOAD ELECTRICITY BY REGION

J. O. Roberts
S. M. Davis
D. A. Nash

EXCERPT

Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission

Available from
National Technical Information Service
Springfield, Virginia 22161
Price: Printed Copy $6.50; Microfiche $3.00

The price of this document for requesters outside of the North American Continent can be obtained from the National Technical Information Service.

COAL VS. NUCLEAR

A COMPARISON OF THE COST OF GENERATING BASELOAD ELECTRICITY BY REGION

INTRODUCTION

This report compares the economics of a 2400 MWe nuclear and coal electric generating station in 10 regions of the U.S. Delivered coal costs are the primary cause of regional generating cost variations; therefore, the regions were based on the Department of Energy's (DOE) regions for delivered coal costs. The economics are based on the station beginning operation about 1990 for an investor-owned utility.

The report's primary objective is to develop a generic comparison for NEPA purposes of the economics of the principal energy sources (i.e., nuclear and coal) for the generation of baseload electricity in the U.S. throughout the rest of this century. The report is intended to assist in accumulating and establishing current and future capital costs, fuel costs, operation and maintenance costs, and the resulting total generation costs for baseload coal and nuclear generating stations. The report's secondary objective is to establish methodology, ground rules, criteria and rationale for a generic comparison of the economics of the two principal energy sources currently available for the generation of electricity. The authors recognize that other assumptions and input data may be viewed by some to be more appropriate. For example, the present worth calculations in this report are based on 30 years operating life, 5% inflation rate during operation and 10% discount rate where as other agencies, state public utility commissions, the utility industry, etc., may select a shorter time period and different inflation and discount rates; the assumptions and input data for coal and nuclear fuel costs may be viewed differently by industry or other government agencies in or among different regions of the country; this study used a fixed charge rate suitable for an investor owned utility which a publicly owned utility would consider too high; the purpose for making economic calculations or comparisons may require different methods and approaches than were taken by the staff in this report. Therefore, a deliberate effort has been made to clearly identify assumptions and their rationale, reference sources of data, describe calculational methods and present intermediate results in such a way that a reader may use the data in other methods of analysis or change the input data and assumptions, and recalculate the cost on other bases.

While the analysis has been done on a regional basis to reflect differences in the economics of coal and nuclear from one part of the country to another, it is a generic study and the results are not necessarily applicable to individual cases. For the assumptions used in this report, the accuracy of the results should be on the order of ± 10%. However, because of site specific conditions, the difference in the cost of generation for a particular site could be as high as ± 30% of the cost shown. Since the comparison is between coal and nuclear and the costs for both types of generating units were developed on the same basis, the error in comparing the two alternatives should not be significant i.e., about ± 10%. Unless, of course, site conditions affect one differently than the other. For example, air quality standards at one site may affect the cost of coal generating units differently than nuclear, or seismic conditions at one site may affect the cost of nuclear generating cost differently than coal. Costs are shown to two decimal places for calculational reasons, thus the accuracy implied should not be attached to these numbers.

The generation costs are presented for a 2400 MWe coal and nuclear station. The nuclear station consists of two 1200 MWe units, and the coal station consists of three 800 MWe units. The capital cost of coal generating units includes the cost of sulfur removal equipment. The generating units were assumed to begin operation in 1990. The principal ground rules, assumptions and criteria are discussed in the following section.

SUMMARY

A summary of the unit generation cost (Mills/kWh) for the initial year of operation (1990) is presented in Tables 1 and 2 for coal and nuclear stations in 10 regions of the [illegible] The costs in Table 1 include taxes in the fixed cost and in the carrying charges for the nuclear fuel, while in Table 2 the taxes have been excluded.* Because of long-term fuel cost changes, Tables 1 and 2 cannot be relied upon solely for regional coal versus nuclear cost comparisons. Tables 3 and 4 present a summary of the present value cost of 30 years operation (1990-2020). The costs in Table 3 include taxes and the costs in Table 4 do not.

The footnotes for the four tables set forth the major economic parameters. The regions are defined in Figure 3.

A pictorial comparison of nuclear and coal generating costs by region is presented in Figure 1 for the 1990 unit costs shown in Table 1 and Figure 2 for the present value cost shown in Table 3.

*One point of view is that taxes are a transfer payment not directly related to the cost of generating electricity and thus should not be included in a cost benefit analysis under the National Environmental Policy Act which evaluates the resources expended in power generation.

TABLE 1

SUMMARY - GENERATION COST (WITH TAXES) FOR INITIAL YEAR OPERATION (1990), MILLS/KWH[1]

REGION	NUCLEAR						COAL					
			FUEL[3]		TOTAL				FUEL[4]		TOTAL	
	FIXED COST[2]	O&M	RECYCLE	NO RECYCLE	RECYCLE	NO RECYCLE	FIXED COST	O&M	DOE	DOE ADJUSTED	DOE	DOE ADJUSTED
New England	44.43	3.03	12.49	14.76	59.95	62.22	35.22	6.23	24.70	32.33	66.15	73.78
New York/ New Jersey	45.79	3.03	12.49	14.76	61.31	63.58	37.53	6.23	22.49	29.96	66.25	73.72
Middle Atlantic	39.65	3.03	12.49	14.76	55.17	57.44	31.26	6.23	20.44	[illegible]7.59	57.93	65.08
South Atlantic	40.04	3.03	12.49	14.76	55.56	57.83	32.42	6.23	22.66	30.15	61.31	68.86
Midwest	44.13	3.03	12.49	14.76	59.65	61.92	35.94	6.23	19.42	26.55	61.59	68.72
Southwest	39.13	3.03	12.49	14.76	54.65	56.92	31.73	6.23	23.00	26.08	60.96	64.04
Central	43.42	3.03	12.49	14.76	58.94	61.21	34.79	6.23	17.89	24.83	58.91	65.85
North Central	41.66	3.03	12.49	14.76	57.18	59.45	33.48	6.23	14.48	19.91	54.19	59.62
West	44.52	3.03	12.49	14.76	60.04	62.31	36.81	6.23	20.10	22.09	63.14	65.13
Northwest	43.99	3.03	12.49	14.76	59.51	61.78	35.45	6.23	22.83	25.22	64.51	66.90

FOOTNOTES TO TABLE 1

1/ Based on two 1200 MWe nuclear units and three 800 MWe coal units, 17% fixed charge rate, 5% per year escalation to 1990 and 65% capacity factor.

2/ The annual fixed charges for nuclear include 0.23 mills/kWh for prompt removal/dismantling in 2020. For alternate decommissioning methods (mothballing or entombing with delayed removal) the cost would be approximately .08 mills/kWh.

3/ The 1977 costs for fuel cycle components were escalated at 5% per year to 1990 to account for general inflation. The U_3O_8 cost takes into account the depletion of high grade uranium resources. Fuel costs include carrying charges calculated at 14%.

4/ The delivered coal costs are based on DOE's forecast contained in the Annual Report to Congress, April 1978. The unadjusted DOE figures were escalated at 5% per year to 1990 to account for general inflation. The adjusted DOE figures for all regions, except the southwest and north central regions, include a 30% increase over the next three years in the FOB mine prices projected to result from the mine labor contract of Spring, 1978, plus 2% per year real escalation due to depletion of high grade ores in addition to the 5% for general inflation. [There is no correction included in coal costs to account for real escalation in mine labor contracts (i.e., increased or decreased mine labor productivity), real escalation due to upgrading the rail transportation systems or pending potential legislation on policy initiatives.] It is our belief that the 2% real increase does not take full account of these highly probable upward pressures on cost.

The carrying charges of less than 0.1 mill/kWh on a coal pile for 60-90 days operation have been ignored.

FIGURE 1

SUMMARY — GENERATION COST FOR INITIAL YEAR OPERATION (1990)

MILLS/Kwh

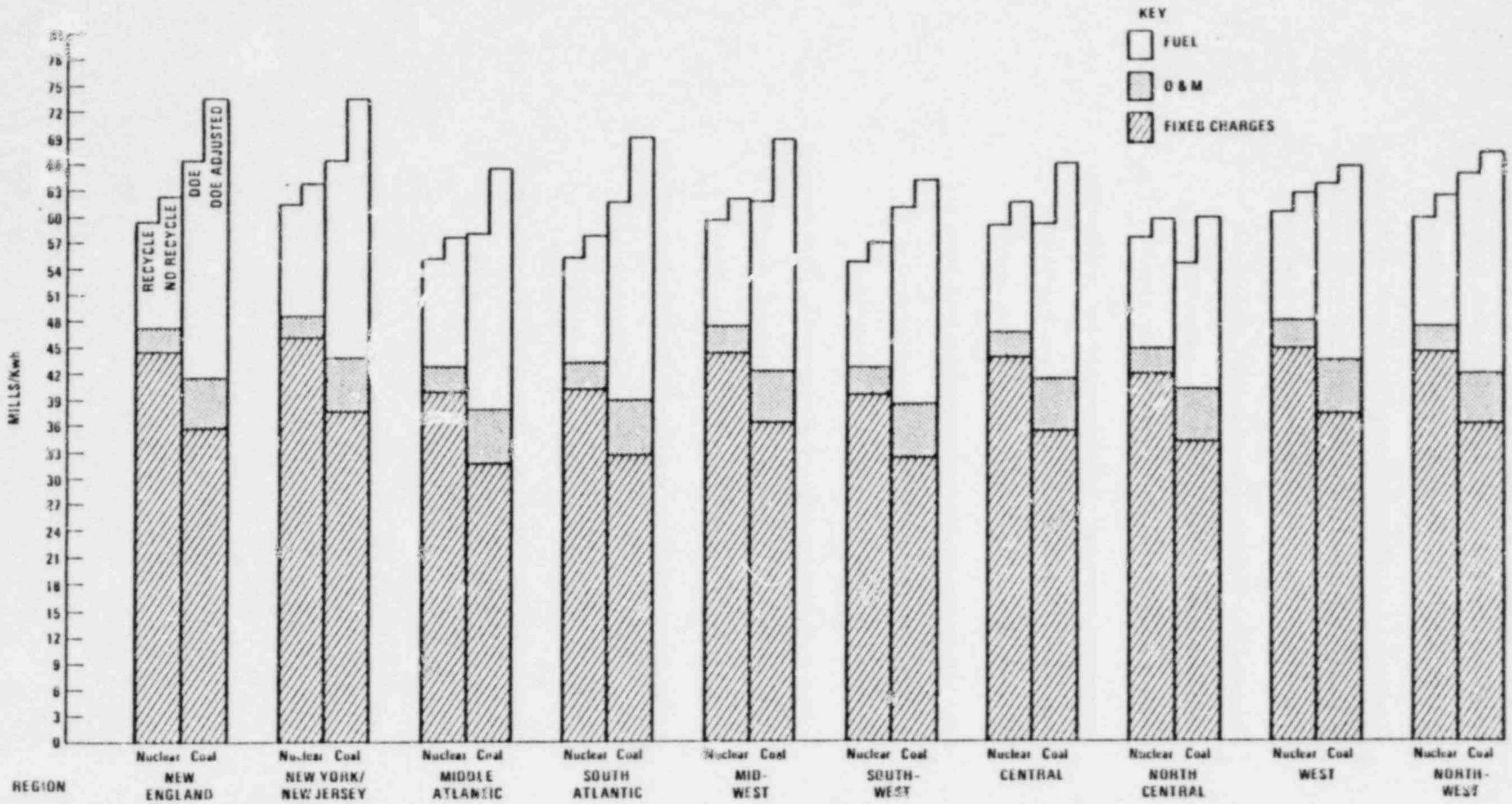


TABLE 2

SUMMARY - GENERATION COST (WITHOUT TAXES) FOR

INITIAL YEAR OPERATION (1990), MILLS/KWH[1]

REGION	NUCLEAR						COAL					
			FUEL[3]		TOTAL				FUEL[4]		TOTAL	
	FIXED COST[2]	O&M	RECYCLE	NO RECYCLE	RECYCLE	NO RECYCLE	FIXED COST	O&M	DOE	DOE ADJUSTED	DOE	DOE ADJUSTED
New England	28.75	3.03	11.13	13.39	42.91	45.17	22.79	6.23	24.70	32.33	53.72	61.35
New York/ New Jersey	29.63	3.03	11.13	13.39	43.79	46.05	24.28	6.23	22.49	29.96	53.00	60.47
Middle Atlantic	25.66	3.03	11.13	13.39	39.82	42.08	20.23	6.23	20.34	27.59	46.90	54.05
South Atlantic	25.91	3.03	11.13	13.39	40.07	42.33	20.98	6.23	22.66	30.15	49.87	57.36
Midwest	28.55	3.03	11.13	13.39	42.71	44.97	23.26	6.23	19.42	26.55	48.91	56.04
Southwest	25.32	3.03	11.13	13.39	39.48	41.74	20.53	6.23	23.00	26.08	49.76	52.84
Central	28.10	3.03	11.13	13.39	42.26	44.52	22.51	6.23	17.89	24.83	46.63	53.57
North Central	26.96	3.03	11.13	13.39	41.12	43.38	21.66	6.23	14.48	19.91	42.37	47.80
West	28.81	3.03	11.13	13.39	42.97	45.23	23.82	6.23	20.10	22.09	50.15	52.14
Northwest	28.46	3.03	11.13	13.39	42.62	44.88	22.94	6.23	22.83	25.22	52.00	54.39

FOOTNOTES TO TABLE 2

1/ Based on two 1200 MWe nuclear units and three 800 MWe coal units, 11% fixed charge rate, 5% per year escalation to 1990 and 65% capacity factor.

2/ See footnote 2, Table 1.

3/ Fuel costs include carrying charges calculated at 10% (cost of money, excluding taxes).

4/ See footnote 4, Table 1.

TABLE 3

SUMMARY - PRESENT VALUE COST (WITH TAXES) OF

30 YEARS OPERATION (1990-2020) (MILLION DOLLARS)[1]

REGION	NUCLEAR						COAL					
			FUEL[2]		TOTAL				FUEL[3]		TOTAL	
	FIXED COST	O&M	RECYCLE	NO RECYCLE	RECYCLE	NO RECYCLE	FIXED COST	O&M	DOE	DOE ADJUSTED	DOE	DOE ADJUSTED
New England	5724	660	2949	4213	9333	10597	4537	1347	5324	9000	11208	14884
New York/ New Jersey	5899	660	2949	4213	9508	10772	4835	1347	4850	8328	11032	14510
Middle Atlantic	5108	660	2949	4213	8717	9981	4027	1347	4408	7677	9782	13051
South Atlantic	5158	660	2949	4213	8767	10031	4176	1347	4898	8389	10421	13912
Midwest	5685	660	2949	4213	9294	10558	4630	1347	4187	7391	10164	13368
Southwest	5041	660	2949	4213	8650	9911	4088	1347	4961	7249	10396	12684
Central	5594	660	2949	4213	9203	10467	4482	1347	3855	6903	9684	12732
North Central	5367	660	2949	4213	8976	10240	4313	1347	3128	5538	8788	11398
West	5735	660	2949	4213	9344	10608	4742	1347	4345	6149	10434	12238
Northwest	5667	660	2949	4213	9276	10540	4567	1347	4929	7025	10843	12939

FOOTNOTES TO TABLE 3

1/ Based on two 1200 MWe nuclear units and three 800 MWe coal units, 5% per year escalation for general inflation and 10% discount rate, 17% fixed charge rate on capital investments and 65% capacity factor.

2/ For the no recycle case, U_3O_8 costs were escalated at 4% per year to account for high grade uranium resource depletion in addition to the 5% per year for general inflation. The carrying charges on fuel, calculated at 14%, were escalated at 2% per year to reflect real escalation of U_3O_8 costs along with 5% for general inflation. For the recycle case, U_3O_8 costs, recovered U-235 credit, and recovered Pu credit were escalated at 2% per year for resource depletion in addition to the 5% for general inflation. Carrying charges on fuel were escalated at 1% per year in addition to the 5% for general inflation.

3/ The unadjusted DOE 1990 coal costs in Table 1 were escalated at 5% per year over the 30-year life of the plant to account for general inflation and discounted at 10% to obtain 1990 present values. The "DOE adjusted" figures are based on the adjusted costs in Table 1, which incorporated cost increases due to the 1978 mine labor contract, escalated at 2% per year to account for resource depletion and upgrading of the transportation system in addition to 5% per year for general inflation. There is no correction included for real escalation in mine labor contracts (i.e., increased or decreased mine labor productivity), nor for real escalation due to pending or potential legislation on policy initiatives.

FIGURE 2

SUMMARY — PRESENT VALUE COST OF 30 YEARS OPERATION (1990-2020)

(Millions of Dollars)

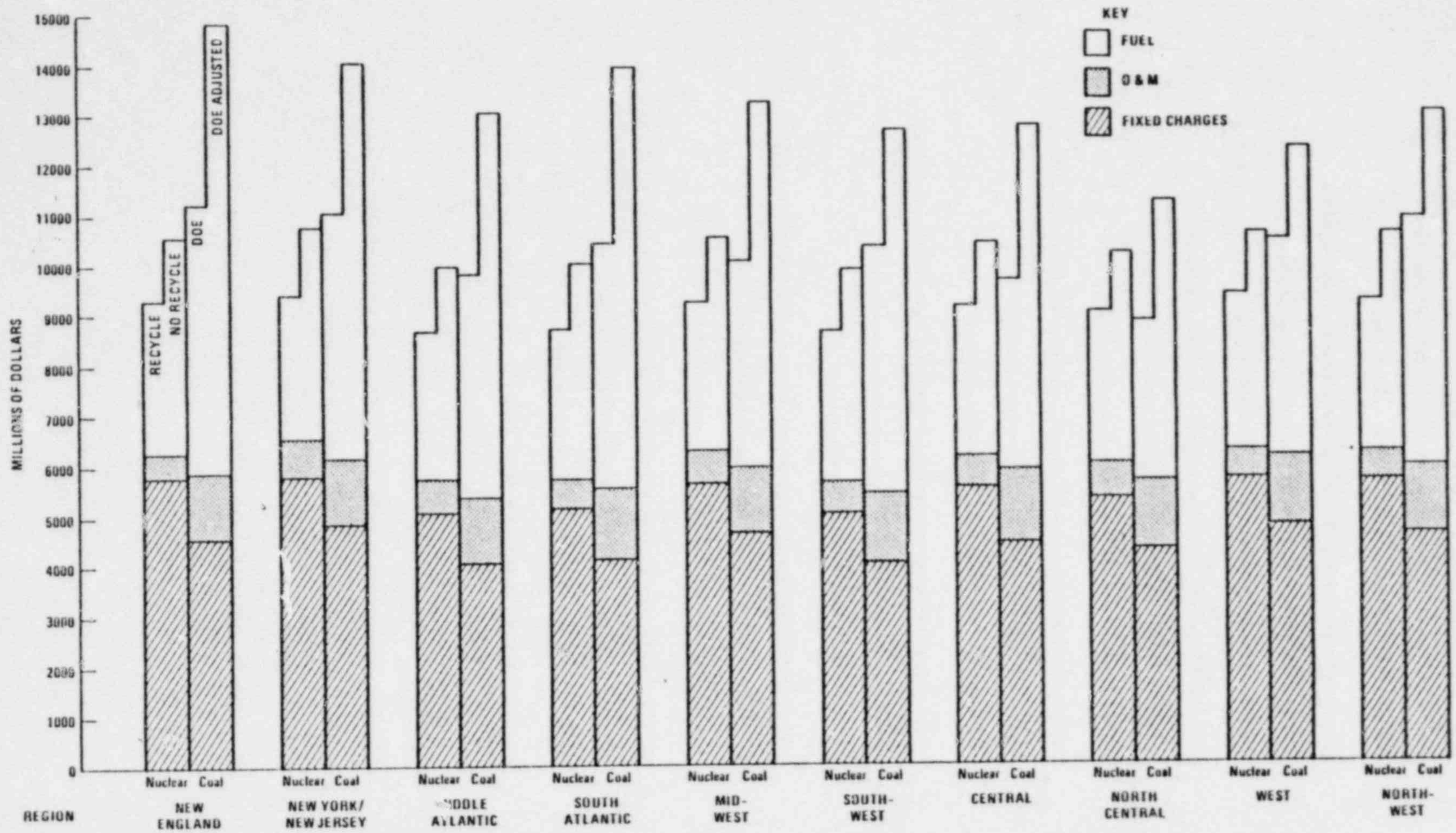


TABLE 4

SUMMARY - PRESENT VALUE COST (WITHOUT TAXES) OF

30 YEARS OPERATION (1990-2020) (MILLION DOLLARS)[1]

REGION	NUCLEAR						COAL					
			FUEL[2]		TOTAL				FUEL[3]		TOTAL	
	FIXED COST	O&M	RECYCLE	NO RECYCLE	RECYCLE	NO RECYCLE	FIXED COST	O&M	DOE	DOE ADJUSTED	DOE	DOE ADJUSTED
New England	3704	660	2614	3832	6978	8196	2936	1347	5324	9000	9607	13283
New York/ New Jersey	3817	660	2614	3832	7091	8309	3129	1347	4850	8328	9326	12804
Middle Atlantic	3305	660	2614	3832	6579	7797	2606	1347	4408	7677	8361	11630
South Atlantic	3338	660	2614	3832	6612	7830	2702	1347	4898	8389	8947	12438
Midwest	3679	660	2614	3832	6953	8171	2996	1347	4187	7391	8530	11734
Southwest	3262	660	2614	3832	6536	7754	2645	1347	4961	7249	8953	11241
Central	3620	660	2614	3832	6894	8112	2900	1347	3855	6903	8102	11150
North Central	3473	660	2614	3832	6747	7965	2791	1347	3128	5538	7266	9676
West	3711	660	2614	3832	6985	8203	3068	1347	4345	6149	8760	10564
Northwest	3667	660	2614	3832	6941	8159	2955	1347	4929	7025	9231	11327

FOOTNOTES TO TABLE 4

1/ Based on two 1200 MWe nuclear units and three 800 MWe coal units, 5% per year for general inflation, 10% discount rate, 11% fixed charge rate (which excludes taxes) on capital investment, and 65% capacity factor.

2/ See footnote 2, Table 3, for escalation rates applied to fuel cycle components. However, the carrying charges included in these figures were calculated at 10% (cost of money, excluding taxes).

3/ See footnote 3, Table 3.

FIGURE 3
REGIONS USED FOR COST COMPARISONS

	REGION*	STATES	CITIES**
I	NEW ENGLAND	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont	(4)Boston
II	NEW YORK/ NEW JERSEY	New Jersey, New York	(15)New York City
III	MIDDLE ATLANTIC	Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia	(2)Baltimore (16)Philadelphia (17)Pittsburgh
IV	SOUTH ATLANTIC	Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee	(1)Atlanta (3)Birmingham
V	MIDWEST	Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin	(5)Chicago (6)Cincinnati (7)Cleveland (10)Detroit (13)Minneapolis
VI	SOUTHWEST	Arkansas, Louisiana, New Mexico, Oklahoma, Texas	(8)Dallas (14)New Orleans
VII	CENTRAL	Iowa, Kansas, Missouri, Nebraska	(11)Kansas City (18)St. Louis
VIII	NORTH CENTRAL	Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming	(9)Denver
IX	WEST	Arizona, California, Hawaii, Nevada	(12) Los Angeles (19) San Francisco
X	NORTH WEST	Alaska, Idaho, Oregon, Washington	(20)Seattle

*Regions defined by DOE in the EIA Annual Report to Congress, Vol. II, 1977. (Analysis does not include Alaska and Hawaii.)

**Labor and materials cost data for these cities were used to estimate regional capital costs.

The study results indicate that nuclear generating units are more economical than coal in most regions of the country. In those regions where coal resources are located, coal plants may be more economical or the difference is marginal. It should be noted that the difference between coal and nuclear generating costs (for initial year of operation, Table 1) in all regions is less than about 20% and site-specific conditions could alter the economic choice in all regions. Furthermore, other conditions such as diversity of fuel resources, licensing considerations, environmental impacts, etc., may have a greater impact on the selection of the preferred power plant than economics. Note that excluding taxes favors the nuclear option.

STUDY SCOPE AND BACKGROUND

General Approach - This study, using currently available technology, analyzes the cost of producing electricity from coal and nuclear power stations. The analysis has been made on a regional basis to reflect differences in various parts of the country. Regional differences such as the delivered cost of coal, coal characteristics, and construction cost for labor and materials are taken into account; thus, the study is more specific than studies based on national averages. The regional cost estimates do not take into account site-specific requirements. Thus, the study is less detailed than studies made by utilities analyzing specific projects.

Regional variations are reflected in two major cost components: the capital costs of coal and nuclear generating units, and the delivered cost of coal. Estimates of the operation and maintenance cost and the nuclear fuel cycle cost do not vary with region. A computer program called CONCEPT (Refs. 1 and 2) was used to develop capital cost estimates for nuclear and coal-fired generating units for 20 major cities in the United States (Figure 3). The program uses data on wage rates fr· 16 construction crafts and unit costs for 7 site-related materials, as reported by a trade publication over the past 15 years (Ref. 3) and average cost index data for factory equipment, as reported by the U.S. Department of Labor. These data are used to determine historical trends in the cost of site labor and materials, providing a basis for projecting future costs.

The cost of coal delivered to 10 demand areas was obtained from DOE's Annual Report to Congress. The delivered cost of coal to the electric utilities by region is summarized in Table 5. The 10 regions are defined in Figure 3. The DOE's forecast of coal costs was based on 1977 costs of capital, labor, benefit payments, and power and supplies, plus various charges for coal preparation, local severance taxes, black lung insurance, reclamation charges, and royalties. Each of these cost final

NUREG-0512

environmental statement

related to construction of

GREENE COUNTY NUCLEAR POWER PLANT

POWER AUTHORITY OF THE STATE OF NEW YORK

JANUARY 1979

Docket No. 50-549

EXCERPTS

U. S. Nuclear Regulatory Commission • Office of Nuclear Reactor Regulation

Available from
National Technical Information Service
Springfield, Virginia 22161
Price: Printed Copy $21.50; Microfiche $3.00

The price of this document for requesters outside of the North American Continent can be obtained from the National Technical Information Service.

7. ENVIRONMENTAL IMPACT OF POSTULATED ACCIDENTS

7.1 POSTULATED ACCIDENTS INVOLVING RADIOACTIVE MATERIALS

A high degree of protection against the occurrence of postulated accidents in the Greene County Nuclear Power Plant is provided through correct design, manufacture, and operation, and the quality assurance program used to establish the necessary high integrity of the reactor system, as will be considered in the Commission's Safety Evaluation. Deviations that may occur are handled by protective systems to place and hold the plant in a safe condition. Notwithstanding this, the conservative postulate is made that serious accidents might occur, even though they may be extremely unlikely; and engineered safety features are installed to mitigate the consequences of those postulated events that are judged credible.

The probability of the occurrence of accidents and the spectrum of their consequences to be considered from an environmental effects standpoint have been analyzed using best estimates of probabilities and realistic fission product release and transport assumptions. For site evaluation in the Commission's safety review, extremely conservative assumptions are used to compare calculated doses resulting from a hypothetical release of fission products from the fuel with the 10 CFR Part 100 siting guidelines. Realistically computed doses that would be received by the population and environment from postulated accidents would be significantly less than those to be presented in the Safety Evaluation.

he Commission issued guidance to applicants on September 1, 1971, requiring the consideration of a spectrum of accidents with assumptions as realistic as the state of knowledge permits. The applicant's response was contained in the Environmental Report.

The applicant's report has been evaluated, using the standard accident assumptions and guidance issued as a proposed amendment to Appendix D of 10 CFR Part 50 by the Commission on December , 1971. Nine classes of postulated accidents and occurrences ranging in severity from trivial to very serious were identified by the Commission. In general, accidents in the high-potential-consequence end of the spectrum have a low occurrence rate, and those on the low-potential-consequence end have a higher occurrence rate. The examples selected by the applicants for these cases are shown in Table 7.1. The examples selected are reasonably homogeneous in terms of probability within each class.

Commission estimates of the dose that might be received by an assumed individual standing at the site boundary in the downwind direction, using the assumptions in the proposed Annex to Appendix D, are presented in Table 7.2. Estimates of the integrated exposure that might be delivered to the population within 50 miles of the site are also presented in Table 7.2. The man-rem estimate was based on the projected population within 50 miles of the site for the year 2020.

To rigorously establish a realistic annual risk, the calculated doses in Table 7.2 would have to be multiplied by estimated probabilities. The events in classes 1 and 2 represent occurrences that are anticipated during plant operation; and their consequences, which are very small, are considered within the framework of routine effluents from the plant. Except for a limited amount of fuel failures and some steam generator leakage, the events in classes 3 through 5 are not anticipated during plant operation; but events of this type could occur sometime during the 40-year plant lifetime. Accidents in classes 6 and 7 and small accidents in class 8 are of similar or lower , obability than accidents in classes 3 through 5, but are still possible. The probability of occurrence of large class 8 accidents is very small. Therefore, when the consequences indicated in Table 7.2 are weighted by probabilities, the environmental risk is very low.

The postulated occurrences in class 9 involve sequences of successive failures more severe than those required to be considered in the design bases of protection systems and engineered

Table 7.1. Classification of postulated accidents and occurrences

Class	NRC description	Applicant's examples
1	Trivial incidents	Included in the evaluation of routine releases
2	Small releases outside containment	Included in the evaluation of routine releases
3	Radioactive waste system failure	Releases from the boron recovery tank, process gas system, and high-level waste drain tank
4	Fission products to primary system (BWR)	Not applicable
5	Fission products to primary and secondary systems (PWR)	Steam generator tube leaks or tube rupture
6	Refueling accident	Fuel assembly drop; heavy object drop onto fuel in core
7	Spent-fuel handling accident	Fuel assembly drop in the fuel pool; heavy object drop onto fuel storage rack; fuel cask drop
8	Accident initiation events considered in design-basis evaluation in the Safety Analysis Report (SAR)	Pipe breaks; rod ejection accident; steam line breaks
9	Hypothetical sequence of failures more severe than class 8	Not considered

safety features. Their consequences could be severe. However, the probability of their occurrence is judged so small that their environmental risk is extremely low. Defense in depth (multiple physical barriers); quality assurance for design, manufacture, and operation; continued surveillance and testing; and conservative design are all applied to provide and maintain a high degree of assurance that potential accidents in this class are, and will remain, sufficiently small in probability that the environmental risk is extremely low.

The NRC has performed a study to assess these risks more quantitatively. The initial results of these efforts were made available for comment in draft form on August 20, 1974,[1] and released in final form on October 30, 1975.[2] This study, called the Reactor Safety Study, was an effort to develop realistic data on the probabilities and consequences of accidents in water-cooled power reactors in order to improve the quantification of available knowledge related to nuclear reactor accident probabilities. The Commission organized a group of about 50 specialists under the direction of Professor Norman Rasmussen of MIT to conduct the study. The scope of the study has been discussed with the EPA and described in correspondence with the EPA, which has been placed in the NRC Public Document Room (letter, Doub to Dominick, dated June 5, 1973).

In July 1977, the NRC organized the independent Risk Assessment Review Group to (1) clarify the achievements and limitations of the Reactor Safety Study (RSS), (2) assess the peer comments thereon and the responses to the comments, (3) study the current state of such risk assessment methodology, and (4) recommend to the Commission how and whether such methodology can be used in the regulatory and licensing process. The results of this study were issued September 1978.[3] This report, called the Lewis Report, contains several findings and recommendations concerning the RSS. Some of the more significant findings are summarized below.

1. A number of sources of both conservatism and nonconservatism in the probability calculations in RSS were found, which were very difficult to balance. The Review Group was unable to determine whether the overall probability of a core-melt given in the RSS was high or low, but they did conclude that the error bands were understated.

2. The methodology, which was an important advance over earlier methodologies that had been applied to reactor risk, was sound.

Table 7.2. Summary of radiological consequences of postulated accidents[a]

Class	Event	Estimated fraction of 10 CRF 20 limit at site boundary[b]	Estimated dose to population in 50-mile radius (man-rems)
1.0	Trivial incidents	c	c
2.0	Small releases outside containment	c	c
3.0	Radioactive system failures		
3.1	Equipment leakage or malfunction	0.052	6.2
3.2	Release of waste gas storage tank contents	0.20	25
3.3	Release of liquid waste storage contents	0.006	0.68
4.0	Fission products to primary system (BWR)	N. A.	N. A.
5.0	Fission products to primary and secondary systems (PWR)		
5.1	Fuel cladding defects and steam generator leaks	c	c
5.2	Off-design transients that induce fuel failure above those expected, and steam generator leak	0.001	0.14
5.3	Steam generator tube rupture	0.068	8.2
6.0	Refueling accidents		
6.1	Fuel bundle drop	0.011	1.3
6.2	Heavy object drop onto fuel in core	0.19	22
7.0	Spent-fuel handling accident		
7.1	Fuel assembly drop in fuel storage pool	0.007	0.82
7.2	Heavy object drop onto fuel rack	0.027	3.3
7.3	Fuel cask drop	0.17	20
8.0	Accident initiation events considered in design-basis evaluation in the SAR		
8.1	Loss-of-coolant accidents		
	Small break	0.11	25
	Large break	0.10	34
8.1(a)	Break in instrument line from primary system that penetrates the containment	N. A.	N. A.
8.2(a)	Rod ejection accident (PWR)	0.010	3.4
8.2(b)	Rod drop accident (BWR)	N. A.	N. A.
8.3(a)	Steam line breaks (PWR's outside containment)		
	Small break	<0.001	<0.1
	Large break	<0.001	<0.1
8.3(b)	Steam line break (BWR)	N. A.	N. A.

[a]The doses calculated as consequences of the postulated accidents are based on airborne transport of radioactive materials, resulting in both a direct and an inhalation dose. Our evaluation of the accident doses assumes that the applicant's environmental monitoring program and appropriate additional monitoring (which could be initiated subsequent to a liquid release incident detected by in-plant monitoring) would detect the presence of radioactivity in the environment in a timely manner such that remedial action could be taken, if necessary, to limit exposure from other potential pathways to man.

[b]Represents the calculated fraction of a whole-body dose of 500 millirems, or the equivalent dose to an organ.

[c]These radionuclide releases are considered in developing the gaseous and liquid source term presented in Sect. 3 and are included in doses in Sect. 5.

3. It is very difficult to follow the detailed thread of calculations through the RSS. In particular, the Executive Summary is a poor description of the contents of the report, should not be used as such, and has lent itself to misuse in the discussion of reactor risk.

On January 19, 1979, the Commission issued a statement of policy concerning the RSS and the Review Group Report. The Commission accepted the findings of the Review Group.

Table 7.2 indicates that the realistically estimated radiological consequences of the postulated accidents would result in exposures of an assumed individual at the site boundary that are less than those that would result from a year's exposure to the maximum permissible concentrations (MPC) of 10 CFR Part 20. The table also shows the estimated integrated exposure of the population within 50 miles of the plant from each postulated accident. Any of these integrated exposures would be much smaller than that from naturally occurring radioactivity. When considered with the probability of occurrence, the annual potential radiation exposure of the population from all the postulated accidents is an even smaller fraction of the exposure from natural background radiation and, in fact, is well within naturally occurring variations in the natural background. It is concluded from the results of the realistic analysis that the environmental risks due to postulated radiological accidents are exceedingly small and need not be considered further.

7.2 TRANSPORTATION ACCIDENTS

The transportation of cold fuel to the plant, of irradiated fuel from the reactor to a fuel reprocessing plant, and of solid radioactive waste from the reactor to burial grounds is within the scope of the AEC report entitled *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants*, dated December 1972. The environmental risks of accidents in transportation are summarized in Table 7.3.

Table 7.3. Environmental risks of accidents in transport of fuel and waste to and from a typical light-water-cooled nuclear power reactor[a]

	Environmental risk
Radiological effects	Small[b]
Common (nonradiological) causes	1 fatal injury in 100 reactor-years; 1 nonfatal injury in 10 reactor-years; $475 property damage per reactor-year

[a]Data supporting this table are given in the Commission's *Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants*, WASH-1238, December 1972 and Suppl. 1 (NUREG-75/038), April 1975.

[b]Although, the environmental risk of radiological effects stemming from transportation accidents is currently incapable of being numerically quantified, the risk remains small regardless of whether it is being applied to a single-reactor or a multireactor site.

REFERENCES FOR SECTION 7

1. *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants, Draft*, WASH-1400, August 1974.

2. *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commerical Nuclear Power Plants*, WASH-1400 (NUREG 75/014), October 1975.

3. *Risk Assessment Review Group Report*, NUREG/CR-0400, September 1978.

potential energy sources nor the more efficient conversion processes are likely to be in use sufficient to reduce the growth rate of electric energy required from central power stations during the next decade.

9.1.3 Comparison of nuclear and coal-fired power plants

9.1.3.1 Health effects

In addition to the environmental costs attributable to coal and nuclear fuels (Table 9.1), the differing health effects from using coal and nuclear fuels have been considered in the environmental assessment of each alternative. In making these assessments, the entire fuel cycle rather than just the power-generation phase was considered to compare the total impacts of each cycle. For coal, the cycle consists of mining, processing, fuel transportation, power generations, and waste disposal. The nuclear fuel cycle includes mining, milling, uranium enrichment, fuel preparation, fuel transportation, power generation, irradiated fuel transportation and reprocessing, and waste disposal.

Table 9.1. Comparative environmental costs for an 1800-MWe coal plant and the Greene County Nuclear Power Plant at full output

Impact	Coal	Nuclear
Land use, ha		
Station proper and associated ponds; fuel and waste storage areas	≈1,600	470
Release to air[a]		
Dust, tonnes/day	20	None
Sulfur dioxide, tonnes/day	230	None
Nitrogen oxides, tonnes/day	132	None
Radioactivity, Ci/year	Small	21,000
Releases to surface water		
Chemicals dissolved in blowdown, tonnes/day	[b]	
Radioactivity, Ci/year	None	160
Water consumed, m^3/min	≈55	106
Fuel		
Consumed, tonnes/day	≈20,000	1.2[c]
Ash, tonnes/day	≈2,000	
Social	Moderate	Moderate
Aesthetic	Both require large industrial-type structures and cooling towers. Coal yard, ash pit, tall stack required.	

[a]Coal-fired plant emissions estimated on the basis that the plant just meets applicable EPA standards.
[b]Information not available.
[c]Of U_3O_8.

In preparing this assessment it has been recognized that there are great uncertainties due to the lack of an adequate data base in certain areas of each fuel-cycle alternative. The overall uncertainty in the nuclear fuel cycle is probably about an order of magnitude (increased or decreased by a factor of 10) over 100 years and about two or more orders of magnitude over 1000 years. The uncertainty associated with the coal fuel cycle tends to be much larger because of the inability to estimate total health impacts from all the pollutants released to the environment from that cycle. However, if one assumes most of the public impact over a period of several decades is because of inhalation of sulfur compounds and associated pollutants, there is as much as a two-order-of-magnitude uncertainty in the assessment of the coal fuel cycle. The much greater uncertainty associated with the coal fuel cycle results from the relatively sparse and equivocal data regarding cause-effect relationships for most of the principal pollutants in the coal fuel cycle, the effect of Federal laws on the future performance of coal-fired power plants, mine safety, and culm-bank stabilization, and the long-term impacts of coal ash and flue gas desulfurization sludges.

Health effects, as the term is used here, is intended to mean excess mortality, morbidity (disease and illness), and injury among occupational workers and the general public. ("Excess" is used here to mean effects occurring at a higher-than-normal rate. In the case of death it is used synonymously with premature mortality.) The most recent and detailed assessments of health effects of the coal fuel cycle have been prepared by the Brookhaven and Argonne National Laboratories.[105-110] The most complete and recent assessment of the radiological health effects of the uranium fuel cycle for normal operations was prepared for the "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors" (GESMO I).[111]

However, in accordance with 10 CFR Part 51.20(e), the current impact of the uranium fuel cycle (excluding reactors and mines) is defined by the 14 March 1977 revision of Table S-3, 10 CFR Part 51. [Consistent with the Commission's announced intention to reexamine the rule periodically to accommodate new information (39 FR 14188, 22 April 1974, and 42 FR 13803, 14 March 1977), staff studies are under way to determine what areas, in addition to waste management and reprocessing, may require updating in Table S-3 (Notice of Proposed Rulemaking, Docket No. RM 50-3, Environmental Effects of the Uranium Fuel Cycle, 41 FR 45849, 18 October 1976).] Using the Table S-3 effluents and the models developed for GESMO I, it was possible to estimate the impact of the uranium fuel cycle on the general public for routine operations. These values are shown in Tables 9.2-9.7 and some critical assumptions related to estimates are shown in Appendix G.

Because Table S-3 excludes radon releases from uranium mines, the health effects of such releases on the general public are not included in Tables 9.2-9.7. The effects of such releases would result in some small increases in the total risks of mortality and morbidity as discussed further under "Other Considerations."

Table 9.2. Summary of current energy source excess mortality per year per 0.8 GWy(e)

Fuel cycle	Occupational		General public		Total
	Accident	Disease	Accident	Disease	
Nuclear (U.S. population)					
All nuclear	0.22[a]	0.14[b]	0.05[c]	0.18–1.3[b]	0.59–1.7 (1.0)[d]
With 100% of electricity used in the fuel cycle produced by coal power	0.24–0.25[a,e]	0.14–0.46[b,e]	0.10[c,g]	0.77–6.3[h]	1.2–6.8 (2.9)
Coal (regional population)	0.35–0.65[e]	0–7[f]	1.2[g]	13–110[h]	15–120 (42)
Ratio of coal to nuclear (range): (geometric means)	42 (all nuclear) 14 (with coal power)[i]				

[a]Primarily fatal nonradiological accidents, such as falls or explosions.

[b]Primarily fatal radiogenic cancers and leukemias from normal operations at mines, mills, power plants, and reprocessing plants.

[c]Primarily fatal transportation accidents (Table S-4, 10 CFR Part 51) and serious nuclear accidents.

[d]Values in parentheses are the geometric means of the ranges ($\sqrt{ab}$).

[e]Primarily fatal mining accidents, such as cave-ins, fires, and explosions.

[f]Primarily coal workers pneumoconiosis (CWP) and related respiratory diseases leading to respiratory failure.

[g]Primarily members of the general public killed at rail crossings by coal trains.

[h]Primarily respiratory failure among the sick and elderly from combustion products from power plants, but includes deaths from waste-coal-bank fires.

[i]With 100% of all electricity consumed by the nuclear fuel cycle produced by coal power; amounts to 45 MWe per 0.8 GWy(e).

Table 9.3. Excess mortality per 0.8 GWy(e) — nuclear[a]

Fuel-cycle component	Occupational		General public		Total
	Accident[b]	Disease[c,d,e]	Accident[e,f]	Disease[g]	
Resource recovery (mining, drilling, etc.)	0.2	0.038	≈0	0.085	
Processing[h]	0.005[i]	0.042	j	0.026–1.18	
Power generation	0.01	0.061	0.04	0.016–0.20	
Fuel storage	j	≈0	j	≈0	
Transportation	≈0	≈0	0.01	≈0	
Reprocessing	j	0.003	j	0.054–0.062	
Waste management	j	≈0	j	0.001	
Total	0.22	0.14	0.05	0.18–1.3	0.59–1.7

[a] Breakdown of Table 9.2.

[b] L. D. Hamilton, Ed., *The Health and Environmental Effects of Electricity Generation — A Preliminary Report*, Brookhaven National Laboratory (July 1974).

[c] U.S. Nuclear Regulatory Commission, *Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors*, NUREG-0002 (August 1976).

[d] 10 CFR Part 51, Table S-3.

[e] 10 CFR Part 51, Table S-4.

[f] U.S. Nuclear Regulatory Commission, *Reactor Safety Study*, WASH-1400 (NUREG-75-014) (October 1975).

[g] Long-term effects from Rn-222 releases from mills and tailings piles account for all but 0.001 health effects.

[h] Includes milling, uranium hexafluoride production, uranium enrichment, and fuel fabrication.

[i] Corrected for factor of 10 error based on referenced value (report WASH-1250).

[j] The effects associated with these activities are not known at this time. Although such effects are generally believed to be small, they would increase the total in the column.

Table 9.4. Excess mortality per 0.8 GWy(e) — coal[a]

Fuel-cycle component	Occupational		General public		Total
	Accident	Disease	Accident	Disease	
Resource recovery (mining, drilling, etc.)	0.3–0.6	0–7	b	b	
Processing	0.04	b	b	10	
Power generation	0.01	b	b	3–100	
Fuel storage	b	b	b	b	
Transportation	b	b	1.2	b	
Waste management	b	b	b	b	
Total	0.35–0.65	0–7	1.2	13–110	15–120

[a] Breakdown of Table 9.2. See also L. D. Hamilton, Ed., *The Health and Environmental Effects of Electricity Generation—A Preliminary Report*, Brookhaven National Laboratory (July 1974).

[b] The effects associated with these activities are not known at this time. Although such effects are generally believed to be small, they would increase the total in the column.

Table 9.5. Summary of current energy source excess morbidity and injury per 0.8-GWy(e) power plant

Fuel cycle	Occupational		General public		Total
	Morbidity	Injury	Morbidity	Injury	
Nuclear (U.S. population)					
All nuclear	0.84[a]	12[b]	1.0–3.1[c]	0.1[d]	14–16 (15)[e]
With 100% of electricity used by the fuel cycle produced by coal power	1.7–4.1[f]	13–14[b]	1.5–7.6[g]	0.55[h]	17–24 (21)
Coal (regional population)[i]	20–70[f]	17–34[j]	10–100[g]	10[h]	57–210 (109)
Ratio of coal to nuclear (range): (geometric means)	7.3 (all nuclear) 5.2 (with coal power)[k]				

[a]Primarily nonfatal cancers and thyroid nodules.

[b]Primarily nonfatal injuries associated with accidents in uranium mines, such as rock falls or explosions.

[c]Primarily nonfatal cancers, thyroid nodules, genetically related diseases, and nonfatal illnesses (such as radiation thyroiditis, prodromal vomiting, and temporary sterility) following high radiation doses.

[d]Transportation-related injuries from Table S-4, 10 CFR Part 51.

[e]Values in parentheses are the geometric means of the ranges ($\sqrt{ab}$).

[f]Primarily nonfatal diseases associated with coal mining such as CWP, bronchitis, and emphysema.

[g]Primarily respiratory diseases among adults and children caused by sulfur emissions from coal-fired power plants and waste-coal-bank fires.

[h]Primarily nonfatal injuries among members of the general public from collisions with coal trains at railroad crossings.

[i]Coal effects are based on a regional population of 3.8 million people within 80 km of the coal plant.

[j]Primarily injuries to coal miners from cave-ins, fires, and explosions.

[k]With 100% of all electricity consumed by the nuclear fuel cycle produced by coal power; amounts to 45 MWe per 0.8 GWy(e).

Although Table S-3 no longer includes release estimates for Rn-222 from uranium and milling operations,* the staff has reevaluated the question and prepared new estimates which were used in this assessment. These new estimates indicate that Rn-222 releases account for most of the potential premature mortality from the uranium fuel cycle.

In addition, Table S-3 does not generically address releases for light-water-cooled power reactors. The estimated total body population dose commitments for both occupational workers and the general public were taken from GESMO I (uranium recycle only option). In addition, the occupational dose commitments to workers in uranium mines, mills, uranium hexafluoride plants, uranium fuel plants, and uranium enrichment plants were taken from GESMO I, because they are not considered in Table S-3. However, these dose commitments are comparable to those that would result from the radiological releases described in NUREG-0216, which provides background support for Table S-3.

The dose commitments to the public and occupational workers in the March 1977 Table S-3 were used for estimating health effects from the reprocessing and waste-management aspects of the uranium fuel cycle. The risk estimators used to estimate health effects from radiation dose commitments were taken from GESMO I and WASH-1400.[112]

The impact of accidents in fuel-cycle facilities[113] and reactors[112] generally does not markedly increase the impact of normal operations for the uranium fuel cycle, but has been included in this assessment for completeness. No comparable analysis of health effects resulting from accidents in coal-fired plants is available at this time.

*Effective Apr. 14, 1978 [*Fed. Regist.* 43(15613) (Apr. 11, 1978)], the NRC directed the staff to delete the 74.5-Ci Rn-222 source term from Table S-3 (10 CFR Part 51), and consider such health effects as might result from radon releases from mining and milling one RRY of uranium on a case-by-case basis.

Table 9.6. Morbidity and injury per 0.8 GWy(e) – nuclear[a]

Fuel-cycle component	Occupational		General public		Total
	Morbidity	Injury[b]	Morbidity	Injury[c]	
Resource recovery (mining and drilling)	*d*	10	*e*	≈0	
Processing[f]	*d*	0.6	*e*	≈0	
Power generation	*d*	1.3	*e*	≈0	
Fuel storage	*d*	*g*	*e*	≈0	
Transportation	*d*	<1	*e*	0.1	
Reprocessing	*d*	*g*	*e*	*g*	
Waste management	*d*	*g*	*e*	≈0	
Total	0.84	12	1.0–3.1	0.1	14–16

[a]Breakdown of Table 9.5.

[b]L. D. Hamilton, Ed., *The Health and Environmental Effects of Electricity Generation—A Preliminary Report*, Brookhaven National Laboratory (July 1974).

[c]Table S-4, 10 CFR Part 51.

[d]Nonfatal cancers ≤ fatal cancers (excluding thyroid) or ≈0.14. Nonfatal thyroid cancers and benign nodules ≈3 × fatal cancers or ≈0.42. Genetic defects ≈2 × fatal cancers or ≈0.28.

[e]Reactor accidents: 10 × fatalities or ≈0.40 nonfatal cases.

Normal operations: Nonfatal cancers ≤ fatal cancers or ≈0.18–1.3.
Nonfatal thyroid cancers and nodules ≈3 × fatal cancers (from total body doses) or ≈0.26–0.84.
Genetic effects ≈2 × fatal cancers (from total body doses) or ≈0.17–0.56.

[f]Includes milling, uranium hexafluoride production, uranium enrichment, and fuel fabrication.

[g]The effects associated with these activities are not known at this time. Although such effects are generally believed to be small, they would increase the total in the column.

Table 9.7. Morbidity per 0.8 GWy(e) – coal[a]

Fuel-cycle component	Occupational		General public		Total
	Morbidity	Injury	Morbidity	Injury	
Resource recovery (mining and drilling)	20–70	13–30	*b*	*b*	
Processing	*b*	3	*b*	*b*	
Power generation	*b*	1.2	10–100	*b*	
Fuel storage	*b*	*b*	*b*	*b*	
Transportation	*b*	*b*	*b*	10	
Waste management	*b*	*b*	*b*	*b*	
Total	20–70	17–34	10–100	10	57–210

[a]Breakdown of Table 9.5. See also L. D. Hamilton, Ed., *The Health and Environmental Effects of Electricity Generation—A Preliminary Report*, Brookhaven National Laboratory (July 19[illegible]).

[b]The effects associated with these activities are not known at this time. Although such effects are generally believed to be small, they would increase the total in the column.

Estimates of death, disease and injury from nonradiological causes for the uranium fuel cycle are from the Brookhaven evaluations,[105-107] with the exception of transportation-accident-related deaths, which were taken from Table S-4, 10 CFR Part 51. The results of these assessments are shown in Tables 9.2-9.7. It should be noted that there are two lines under the nuclear fuel cycle: the first assumes all of the electricity used within the uranium fuel cycle is generated by nuclear power (i.e., all-nuclear economy); the second line assumes, as shown in Table S-3 (10 CFR Part 51), that 100% of the electricity used within the nuclear fuel cycle comes from coal power. This is equivalent to a 45-MWe coal-fired plant, or 4.5% of the power produced.

The uranium fuel cycle

Currently the NRC estimates that the excess deaths per 0.8 gigawatt-year electric [GWy(e)] will be about 0.47 for an all-nuclear economy. This is probably somewhat high due to the conservatism required in evaluations of generic plants and sites. (Conservatism is used here to mean that assumptions regarding atmospheric dispersion, deposition of particulates, bioaccumulation, etc., generally result in estimates of impact that are typically "upper bound" estimates. In most cases, the estimates would be lower for real plants.) However, it is not greatly different from estimates by others such as Comar and Sagan[114] (0.11 to 1.0), Hamilton[105] (0.7 to 1.6), and Rose et al.[115] (0.50). The uncertainty in the estimate is about an order of magnitude for times up to about 100 years, and probably two or more orders of magnitude for estimates as far into the future as 1000 years. If, as shown in Table S-3, 100% of the electrical power used by the uranium fuel cycle comes from coal-fired power plants, the NRC estimates there would be about 1.1 to 5.4 excess deaths per 0.8 GWy(e). Of this total, about 0.62 to 4.9 excess deaths per 0.8 GWy(e) would be attributable to coal power (Table 9.6). The uncertainty in the estimate is about one order of magnitude.

The total number of injuries and diseases that might occur among workers and the entire U.S. population as a result of normal operations and accidents in the uranium fuel cycle was estimated to be about 14 per 0.8 GWy(e) for an all-nuclear economy. Injuries among uranium miners from accidents account for 10 of the 14 cases (Table 9.5). If 100% of the electrical power used by the uranium fuel cycle comes from coal-fired power plants, the NRC estimates there would be about 17 to 24 injuries and diseases per 0.8 GWy(e). Of this total, about 3 to 10 excess events per 0.8 GWy(e) would be attributable to coal power (Table 9.6). The uncertainty in the estimate is also about one order of magnitude.

Although anticipated somatic (nongenetic) effects associated with normal releases of radioactive effluents from the nuclear fuel cycle are limited to potential cancers and leukemias, for the higher doses associated with serious nuclear accidents there is some small risk of various nonfatal somatic effects (Table 9.5, footnote *c*). At this time only light-water-cooled power reactors have been thoroughly evaluated.[112] However, it should be noted that power reactors probably account for most of the potential health effects associated with nuclear accidents in the uranium fuel cycle.

This results from the fact that power reactors represent 80% of all fuel-cycle facilities expected to be operating for the balance of this century[111] and account for the majority of occupationally exposed individuals. In addition, although the probability of serious accidents is extremely small, if one were to occur, the health effects would be larger than for any other type of fuel-cycle facility. Serious nuclear accidents in power reactors might also contribute about 0.04 excess deaths per 0.8 GWy(e), whereas transportation-related accidents are estimated to contribute about 0.01 excess deaths per 0.8 GWy(e) (Table 9.2, footnote *c*).

Early and latent nonfatal somatic effects that might be expected after high radiation doses include a variety of effects (Table 9.5, footnote *c*). It is possible that nonfatal somatic effects could be an order of magnitude greater than excess deaths resulting from accidents;[112] thus, the total number per 0.8 GWy(e) would be about 0.4. This accounts for about one-third of the morbidity shown for the general public and an all-nuclear economy in Table 9.5. The number of nonfatal thyroid cancers (5-10% mortality rate) and benign thyroid nodules would be about 0.6 per 0.8 GWy(e) from routine releases to the public and occupational exposures (primarily external irradiation), whereas other nonfatal cancers would be less than or equal in number to fatal cancers [about 0.2 per 0.8 GWy(e)] (Table 9.5, footnote *c*).

It is believed that genetically related diseases (e.g., cystic fibrosis, hemophilia, certain anemias, and congenital abnormalities such as mental retardation, short-limbed dwarfism, and extra digits), and abnormalities in the descendants of workers and the general public from both normal operations and accidents would be perhaps twice the number of excess deaths due to cancer from total body irradiation;[110,116] this could add another 0.3 health effects per 0.8 GWy(e) among workers and 0.2 health effects per 0.8 GWy(e) among the general public (Tables 9.5 and 9.6, footnote *c*).

In assessing the impact of coal power used in the uranium fuel cycle, Table S-3 (10 CFR Part 51) was the basis for the assumption that 100% of the electricity used in the uranium fuel cycle, primarily for uranium enrichment and reactor operation, came from coal-fired plants. Adding 4.5% of the health effects per 0.8 GWy(e) from the coal fuel cycle significantly increases the health effects power 0.8 GWy(e) from the uranium fuel cycle, as shown on the second lines of Tables 9.2 and 9.7.

The coal fuel cycle

Current estimates of mortality and morbidity resulting from the coal fuel cycle are quite uncertain; this is the principal reason for the wide range of values reported in the literature. These uncertainties result from the limited number of epidemiological studies and differences in interpretation of the results of such studies. There is additional uncertainty regarding the effects of new Federal laws on coal-cycle facilities in the next decade. Current estimates of excess deaths for the entire coal cycle range from 15 to 120 per 0.8 GWy(e), whereas disease and injury estimates range from 57 to 210 per 0.8 GWy(e).

In the case of occupational effects, there is considerable uncertainty because of anticipated reductions in health effects resulting from the implementation of the Federal Coal Mine Health and Safety Act of 1969 (PL 91-173). The provisions of this act should result in significant improvement of the underground work environment, particularly regarding coal dust. Coal dust is both a cause of underground explosions and fires and a cause of coal workers pneumoconiosis (CWP), commonly called black lung disease, and subsequent progressive massive fibrosis (PMF).[105-109] In addition, more coal in the years ahead is expected to be produced by strip mining, which results in lower mortality rates.[105] As a result, the frequencies of both types of events are anticipated to decline in the years ahead, on a per GWy(e) basis. On the other hand, statistics show new coal miners experience higher mortality and injury rates than experienced miners.[109] As a result of expected increases in coal production, an influx of inexperienced miners will tend to increase the mortality and injury rates for miners as a group.

For the general public, there is also considerable uncertainty in the estimation of health effects. (In the case of coal-plant effluents, consideration of health effects was limited to the population within 80 km of such plants). For example, although there are estimates of health effects related to burning culm banks (waste banks from coal screening), recent efforts by mine operators have greatly reduced such fires, and future processing activities are expected to avoid fires as a result of new methods of stabilizing the banks to prevent slides.[117] Current estimates of excess deaths in the public from sulfates from such fires range from one to ten per 0.8 GWy(e) (Table 9.2, footnote *g*). Power generation is estimated to result in 3 to 100 excess deaths per 0.8 GWy(e) (Table 9.2, footnote *g*), whereas excess morbidity ranges from about 10-100 per 0.8 GWy(e) (Table 9.5, footnote *e*).

The uncertainties are even greater in the power-generation phase of the coal cycle, where estimates of health effects range over several orders of magnitude.[114] This is largely due to the lack of a reliable data base for predicting health effects from the various pollutants emitted from coal plants, and the effect of the EPA New Source Performance Standards for coal plants regarding particulate and sulfur emissions in future years on a long-term basis. There is some uncertainty as to whether these standards can be met in large coal-fired power plants over the life of the plant. The major pollutants emitted include:

1. Particulates: Contain large amounts of toxic trace metals in respirable particle size[118] such as arsenic, antimony, cadmium, lead, selenium, manganese, and thallium;[109] significant quantities of beryllium, chromium, nickel, titanium, zinc, molybdenum, and cobalt;[119] and traces of Ra-226 and -228 and Th-228 and -232.[120]
2. Hydrocarbons: Include very potent carcinogens (cancer-causing substances) such as benzo(a)pyrene.
3. Sulfur oxides.
4. Nitrogen oxides.
5. Other gases: Include ozone, carbon monoxide, carbon dioxide, mercury vapor, and Rn-222.

Regarding the preceding list of pollutants, there are no well-established epidemiologic cause-effect relationships that can be used to estimate total health effects accurately, either from acute exposures during air-pollution episodes or from chronic long-term exposures.

Although definitive cause-effect relationships are lacking, tentative cause-effect relationships for sulfur emissions have been used by numerous groups to estimate health effects from sulfur emissions from coal plants; they are described by the National Academy of Sciences in a recent report to the U.S. Senate.[121] The most widely quoted studies are those by Lave and Seskin,[122] Winkelstein et al.,[123] and an unpublished study by EPA that was used in the NAS/NRC study for the U.S. Senate.[121]

In general, the effects range from excess deaths from cardiovascular failure and increases in asthma attacks during severe air pollution to excess respiratory disease from long-term chronic exposures. Most of the acute deaths are among the elderly and the severely ill, whereas morbidity from long-term exposure also includes children. Although widely accepted cause-effect relationships were not derived from studies of acute air-pollution episodes in London in 1952;[124] Donora, Pennsylvania, 1948;[125] and New York,[126] these studies definitely support the conclusions regarding excess death and disease associated with emissions from combustion of coal.

There are no estimates of possible long-term carcinogenic effects by sulfur oxides or associated pollutants. In addition, the recently completed (1976) large-scale EPA Community Health and Environmental Surveillance System (CHESS) study failed to provide any new or definitive cause-effect relationships for any of the pollutants from coal-fired plants that could be used to provide better estimates of health effects than are currently available.[127] The $22 million CHESS study attempted to correlate air-pollution data collected from six U.S. cities with a variety of health problems.

Assuming that new coal-fired plants in the 1980s can meet EPA New Source Performance Standards (which could require 90% sulfur removal for high-sulfur coal and about 99% particulate removal) and other Federal laws regarding mine safety and culm-bank stabilization, the number of deaths should be reduced. Thus, current estimates of 15 to 120 per 0.8 GWy(e), due largely to sulfates from combustion of coal, may be reduced by about half.

Recently, Argonne National Laboratory developed a predictive model for deaths from emission of benzo(a)pyrene, which indicates about 1 to 4 deaths per 0.8 GWy(e) depending on use of conventional combustion or fluidized-bed combustion.[110] Such effects, although greater than the expected deaths from the entire uranium fuel cycle (all-nuclear economy), do not significantly change the total impact of the coal fuel cycle and were not included in the effects listed in Table 9.2.

Probably the most reliable estimates of deaths associated with the coal fuel cycle are those associated with transportation accidents. Because a 1000-MWe coal-fired plant consumes about 2.7 million tonnes (three million tons) of coal per year, there are literally thousands of carloads of coal being transported by rail from mines to plants. It has been estimated that about one out of every ten trains in the U.S. is a coal train going to a coal-fired power plant.[128] These trains are estimated to travel an average distance of about 480 km (300 miles) from the mine to the plants.[117] As a result, there are about 1.2 deaths per 0.8 GWy(e) among workers and the general public. Further, because most of these deaths occur at railroad crossings, the numbers can be expected to increase as more automobiles are operated and driven greater distances, and as rail-transportation distances increase when hauling low-sulfur western coals to eastern markets.

Sickness among coal miners and the general public accounts for most of the nonfatal occurrences in the coal fuel cycle, with most of the remainder due to injuries among coal miners. As a result of implementation of Federal laws, it is probable that future rates among underground miners will be substantially reduced. It is not unreasonable to assume that current estimates of about 57 to 210 cases of sickness and injury among workers and the general public could be reduced in the years ahead, inasmuch as occupational sickness and injury currently account for about half of the total nonfatal health effects.

The overall uncertainty in the estimates of health effects for the coal fuel cycle in this assessment is probably about one to two orders of magnitude. Although the breakdown estimates generally fall within the range of estimates in the literature, such estimates represent only the impacts occurring over a period of a few decades (e.g., while a power plant is operating) and do not include potential long-term health effects resulting from Rn-222 and toxic heavy metals which may be released to the biosphere from coal ash and flue gas desulfurization sludge waste pits. Such releases, which may occur over centuries or millenia, could substantially increase the estimated health impacts presented in this assessment. Therefore, these potential long-term impacts substantially increase the uncertainty in the health impacts just discussed.

Other considerations

Although the Reactor Safety Study[112] has helped provide a perspective of the risk of mortality or morbidity from potential power-reactor accidents (the current experience for serious accidents is zero),* there is the additional problem associated with individual perception of risk. Thus although the study concluded that "All non-nuclear accidents examined in this study, including fires, explosions, toxic chemical releases, dam failures, airplane crashes, earthquakes, hurricanes and tornadoes, are much more likely to occur and can have consequences comparable to or larger than, those of nuclear accidents," there will continue to be uncertainty associated with such evaluations. Furthermore, there may be a problem of public acceptance of potential accidents, because the consequences can be severe. In fact, it appears that some people[129] more readily accept, for example, having 55,000 people actually killed each year in violent highway accidents, one or two at a time, than they do the unlikely occurrence of perhaps several thousand possible deaths from a single catastrophic accident during their lifetime.

As noted in footnote 5 to the March 1977 revision of Table S-3 (10 CFR Part 51), the GESMO I Rn-222 release increases from 74.5 Ci to about 4800 Ci when releases from mines are included. This would result in a small increase in the total number of excess deaths shown in Table 9.2, although the mortality per 0.8 GWy(e) for the general public would increase by about 30%.

With regard to the coal fuel cycle, it is a well-established fact that the use of coal results in numerous other costs to society that have not yet been adequately quantified. These include

1. The short- and long-term impacts of sulfur and nitrogen oxides on biota and materials. Acid rain, for example, is known to be severely damaging to terrestrial and aquatic habitats. Argonne National Laboratory provides a detailed discussion of these and other effects of sulfur and nitrogen oxide emissions.[109] However, as more coal plants come on line, these effects can be expected to expand to surrounding areas.
2. Damage to materials, such as paints, building surfaces, statuary, and metals, caused by emissions of sulfur oxides, ozone, and nitrogen oxides. A 1976 review of such effects indicates that the costs could range into billions of dollars per year in the U.S. alone.[130]

---

*In July 1977, the NRC organized the independent Risk Assessment Review Group to: (1) clarify the achievements and limitations of the Reactor Safety Study (RSS); (2) assess the peer comments thereon, and the responses to those comments; (3) study the present state of such risk assessment methodology; and (4) recommend to the Commission how and whether such methodology can be used in the regulatory and licensing process. The results of this study were issued in September 1978 (U.S. Nuclear Regulatory Commission, *Risk Assessment Review Group Report*, NUREG/CR-0400, September 1978). While praising the RSS's general methodology and recognizing its contribution to assessing the risks of nuclear power, the Review Group found that they were unable to determine whether the absolute probabilities of accident sequences in report WASH-1400 are high or low. They did conclude that the error bounds on those estimates are, in general, greatly understated. On January 19, 1979, the Commission issued a statement of policy concerning the RSS and Review Group Report. The Commission accepted the findings of the Review Group and concluded that the RSS's numerical estimates of the overall risks of reactor accidents should not be regarded as reliable.

The importance of this uncertainty can be better perceived by considering the effects of an increase in the risks of reactor accidents on the estimated overall mortality rate associated with the nuclear fuel cycle. Assuming the reactor accident risk to be 100 times that estimated in the RSS (which would roughly correspond to a value based solely on statistical analysis of the observation of no core melts in about 500 reactor years of commercial LWR operation), the upper bound of the range of mortality per reference reactor year presented in this document from the nuclear fuel cycle could increase from 1.7 to 3.7. On the other hand, if the risk of such accidents were lower than estimated in the RSS, the lower bound of the range of mortality would not change appreciably.

3. Contamination of soil and vegetation to toxic levels by such mechanisms as deposition and bioaccumulation of trace elements present in gaseous emissions.

4. Destruction of entire ecosystems in streams and rivers by acid mine drainage, and the potential for public-health effects from downstream use of such water for domestic or agricultural purposes.

5. In addition to the occurrence of excess mortalities, injuries, and morbidities, the costs to society in terms of medical costs, lost productivity, and other social losses, represent a significant consideration that has not been completely evaluated at this time. Two recent studies, which concern these extremely complex issues,[131,132] conclude that social costs from one coal-fired plant may currently be about $50 million per year, not considering the rest of the costs for the coal fuel cycle.

6. The possibility of the so-called "greenhouse effect," a phenomenon expected to occur sometime early in the next century as a result of the present and future anticipated production rates of carbon dioxide from the combustion of fossil fuels.[133] Because each 1000-MWe coal plant produces about 6.8 to 9.5 million tonnes (7.5 to 10.5 million tons) of carbon dioxide per year,[105] it is believed these emissions from hundreds of fossil-fueled power plants may result in greater releases of carbon dioxide than the atmosphere and oceans can cycle. As a result, the carbon dioxide concentrations would be expected to increase in the atmosphere. Because carbon dioxide strongly absorbs infrared, it is postulated that the mean atmospheric temperature will rise several degrees. This may cause all or part of the polar ice caps to melt, resulting in inundation of many inhabited areas of the world. At the same time, drought would be expected to prevail in many of the agricultural areas of the temperate zones, resulting in huge crop losses. It is possible that the particulates emitted by fossil plants will counteract some of the greenhouse effect by reducing the amount of sunlight reaching the surface of the earth.

   However, another effect from carbon dioxide released by coal combustion occurs because coal has essentially no carbon-14. In effect, the stable carbon dilutes the carbon-14 in the biosphere, resulting in a reduction in the radiological impact of both naturally occurring and man-made carbon-14.

7. An additional consideration that has not been evaluated for the coal cycle--the radiological impact of mining and burning coal. Of interest is the release of radon-222 from the decay of radium-226 in coal. Not only is the radon released during mining and combustion, but it will continue to emanate from flyash for millions of years after the coal has been burned. Although Pohl[134] has shown that this is not a problem with most eastern coal (generally of high sulfur content but with 1-3 ppm uranium content), the average uranium and radium content of some reserves of low-sulfur western coal is as much as 50 times higher than that of most eastern coal.[135,136] Combustion of the coal and disposal of the remaining ash leads to about the same health effects from radon-222 emissions as do uranium-mill-tailings piles. These releases would account for less than one excess death per 0.8 GWy(e) due to fuel-cycle activities during the rest of this century. As a result, such releases do not significantly affect the conclusions reached with regard to a comparison of the two alternative fuel cycles. In addition, some believe[137] that if the physical and biological properties of the radium released from conventional coal-powered plants (burning coal with 1-2 ppm U-238 and Th-232) are considered, such plants discharge relatively greater quantities of radioactive materials into the atmosphere than do nuclear plants of comparable size. The Environmental Protection Agency has estimated radiation doses from coal and nuclear plants of early designs and reached similar conclusions.[121]

<u>Summary and conclusions</u>

For the reasons discussed above, it is extremely difficult to provide precise quantitative values for excess mortality and morbidity, particularly for the coal fuel cycle. Nevertheless, a number of estimates of mortality and morbidity have been prepared based on present-day knowledge of health effects, and present-day plant design and anticipated emission rates, occupational experience and other data. These are summarized in Tables 9.2 and 9.5 (see footnote *k*, Table 9.5), with some important assumptions inherent in the calculations of health effects listed in Appendix E.

Although future technological improvements in both fuel cycles may result in significant reductions in health effects, based on current estimates for present-day technology, it must be concluded that the nuclear fuel cycle is considerably less harmful to man than the coal fuel cycle.[105-109,114,115,131,132,137-140] As shown in Tables 9.2-9.7, the coal fuel-cycle alternative may be more harmful to man by factors of 7 to 42 depending on the effect being considered, for an all-nuclear economy, or factors of 6 to 14 with the assumption that all of the electricity used by the uranium fuel cycle comes from coal-powered plants.

Although there are large uncertainties in the estimates of most of the potential health effects of the coal cycle, it should be noted that the impact of transportation of coal is based on firm statistics; this impact alone is greater than the conservative estimates of health effects for the entire uranium fuel cycle (all-nuclear economy) and can reasonably be expected to worsen as more coal is shipped over greater distances. In the case where coal-generated electricity is used in the nuclear fuel cycle, primarily for uranium enrichment and auxiliary reactor systems, the impact of the coal power accounts for essentially all of the impact of the uranium fuel cycle.

However, lest the results of this be misunderstood, it should be emphasized that the increased risk of health effects for either fuel cycle represents a very small incremental risk to the average public individual. For example, Comar and Sagan[114] have shown that such increases in risk of health effects represent minute increases in the normal expectation of mortality from other causes.

A more comprehensive assessment of these two alternatives and others is anticipated in 1979 from the National Research Council Committee on Nuclear and Alternative Energy Systems. This study may assist substantially in reducing much of the uncertainty in the analysis presented.

9.1.3.2 Economics of power generation

The applicant[141] has recently submitted revised cost estimates for the construction and operation of the Greene County Nuclear Power Plant and a coal-fired alternative, as shown in Table 9.8. Fuel oil is not considered a viable option for new base-load power stations. This current analysis of power generation costs confirms the applicant's earlier analysis in the Environmental Report and supports the decision to select the nuclear power alternative on the basis of a lifetime levelized generating cost about 72% of that for a coal-fired station.

Table 9.8. Generating costs for the Greene County Nuclear Power Plant and a coal-fired alternative developed by the Power Authority of the State of New York (PASNY) for 1986 commercial operation

	Nuclear	Coal
Plant capital cost, millions of dollars	1721.3	1253.4
Transmission capital cost, millions of dollars	46.2	46.2[a]
Total capital cost, millions of dollars	1767.5	1299.6
Fixed charge rate, %	9.52	9.37
Levelized capital cost,[b] mills/kWhr	23.38	16.92
Levelized O & M cost, mills/kWhr	9.24	6.70
Levelized fuel cost, mills/kWhr	14.27	41.71
Levelized generating cost, mills/kWhr	46.89	65.33

[a] Assumed equivalent to nuclear plant for same site.
[b] Lifetime annual plant factor of 68.5%.

The staff has performed an independent analysis of the comparative generating costs of a nuclear station and a coal-fired alternative station using eastern, high-sulfur coal. The details of the staff's analysis are presented in Appendix I and are summarized here. The staff used the CONCEPT computer code[142] to prepare the capital-cost estimates. Values for escalation and site labor requirements were derived from data stored in the model subroutines and the interest rate, 7%/year, used by the applicant was adopted.

The staff used the OMCST computer code[143] to prepare the operation and maintenance costs. The basic nuclear fuel costs were prepared using the NUCOST computer code[144] and basic assumptions for nuclear-fuel-cycle components as described in Appendix I. The staff assumed a 5% escalation rate from average 1976 fuel-cycle costs, except that the cost of U_3O_8 is further escalated to account for higher cost of recovery of poorer grades of ore. The basic cost of coal was calculated using a 5% escalation rate applied to the estimated average 1978 cost of about $30.50/ton for coal delivered from West Virginia to eastern New York (Appendix I). A discount rate of 7% was used to convert future (30 years) fuel and operating and maintenance costs to January 1987 present-worth values.

Table 9.9 summarizes the comparative economics of the two types of power plants (as extracted from Appendix I) operating at a plant capacity factor ranging from 50 to 70% using the base-line capital and fuel costs. It can be seen that the generating costs for the nuclear-fueled power station are about 26% lower than those for the coal-fired alternative at 50% capacity factor. The relative economic advantage for nuclear power increases to about 29% at a 70% plant capacity factor.

Table 9.9. Staff's generic comparison of generation costs for nuclear and coal-fired plants in the mid-Hudson region for operation in January 1987

	Nuclear			Coal		
	Plant factors (%)					
	50	60	70	50	60	70
Capital cost[a] (millions of dollars)	1465	1465	1465	1347	1347	1347
Levelized capital cost,[b] mills/kWhr	26.34	21.95	18.81	24.01	20.01	17.15
Levelized O&M costs, mills/kWhr	6.85	5.74	4.95	13.34	11.91	9.53
Levelized fuel cost, mills/kWhr	17.0	16.7	16.5	30.24	30.24	30.24
Levelized generating cost, mills/kWhr	50.18	44.4	40.25	67.95	62.16	56.92

[a] Excluding transmission line costs.

[b] Fixed charge rates: 9.52% for nuclear, 9.37% for coal.

In the evaluation of fuel substitution (Sect. 8.5), the staff also used a 10% discount rate for future operating costs (O&M and fuel). In the present comparison of nuclear and coal-fired generating costs, use of the higher discount rate effects a slight reduction (1-2 mills/kWhr) in total generating costs of both the nuclear and coal-fired alternatives. However, the relative comparison is virtually unchanged.

The relative comparison of generation costs at nuclear and high-sulfur coal-fired plants in the staff's analysis is reasonably consistent with other recently reported generation cost studies.[145-148] The relatively favorable status of nuclear power exhibited in the staff's results reconfirm the acceptability of the applicant's fuel choice.

The staff evaluated the sensitivity of this economic comparison to factors such as capital cost and fuel cost (Appendix I). In the case of sensitivity to fuel-cost variations, the coal-fired plants are not competitive with the nuclear plants, unless the escalation in the cost of coal is 5 to 10% per year (absolute) less than that for nuclear fuel cost (assuming base-line capital costs). With respect to capital costs, the nuclear plant costs would have to increase by about 65% to make the coal-fired plant competitive (assuming base-line fuel costs). Neither of these variations is considered likely. Combination of these two factors and O&M costs in favor of the coal-fired alternative might occur (although statistically less probable) that could lower the economic advantage for the nuclear option. However, the staff does not believe that the coal-fired option could achieve an economic advantage over nuclear power in the state of New York with the present trends of capital and fuel costs.

The staff also reviewed the costs of decommissioning (Appendix I). Based on the procedure of mothballing, followed ultimately by dismantling the radioactive portions of the facility, the staff found that the annualized nuclear generation costs would increase by about $3.9 million, or 0.62 mill/kWhr. This factor does not significantly detract from the economic advantage of the nuclear power plant over the coal-fired alternative.

The staff also looked at the potential generation cost of power plants using fuel oil. The fuel oil costs for power generation are significantly higher than those for the coal-fired alternative considered above (Appendix I). Therefore, consideration of oil for new base-load power plants is economically not justified.

In summary, the staff has concluded that the lower probable lifetime generating costs (present worth) in the late 1980s and the lesser health effects to the general population of the nuclear plant favor the nuclear-fueled plant over the coal-fired alternative. The staff is aware of some uncertainty associated with future construction costs and fuel costs. However, it is generally expected that variation in these costs from the staff's basic assumptions will be slight and will be in the same direction for both plant types. Thus, change in the nuclear-vs-coal cost comparison is expected to be slight. Only in the case of extremely favorable bias for the coal-fired plant and adverse bias for the nuclear plant does the staff find an economically competitive position for coal-fired plants in the mid-Hudson river region.

9.2 SITES

9.2.1 Introduction

An amendment of the New York State Legislature directing the Power Authority of the State of New York to supply power for the Metropolitan Transportation Authority (MTA) was approved on May 24, 1972 (Chaps. 385 and 489, Laws of New York, 1972). Stone and Webster was selected as a consultant firm and was instructed to investigate sites for both fossil- and nuclear-fueled plants. The subsequent report,[149] issued on April 23, 1973, included the following: (1) an evaluation of a multitude of factors involved in selecting a generic siting region to supply the designated load; (2) a conclusion that the most economically and environmentally preferred region is along, or near, the Hudson River, downstream of Albany, with nuclear units located only upstream of Westchester County; and (3) an evaluation of specific sites within the preferred region and recommendation of more favorable nuclear- and fossil-fueled plant sites.

The staff earlier found (see DES) that the methodology was adequate and consistent with regulatory requirements at the time of the applicant's analysis (1973).

However, recent regulatory decisions have given guidance to the staff relating to the examination of the alternative sites, particularly with respect to the natural and human environmental criteria. Therefore, the staff has recently undertaken a reevaluation of alternative sites.

The following discussion summarizes the substance of the applicant's alternative site evaluation and provides the staff assessment of the methodology and results.

9.2.2 Candidate regions

The applicant subdivided the state of New York into regions (resource areas) primarily related to the sources of cooling water for waste heat dissipation. The following is a summary of the applicant's regional considerations and the staff's assessment.

Upstate New York

This region includes the area generally north and west of Albany. The primary sources of condenser cooling water are Lakes Ontario and Erie.

The shoreline and coastal strip along these lakes are prime industrial development areas based on the following factors: (1) plentiful supply of water; (2) water-borne transportation; (3) nearby rail and highway network; and (4) extensive undeveloped, lightly inhabitated zones along the shoreline. The New York utilities already utilize this siting area and are constructing, or have proposed, about 7000 MWe of additional generating capacity by 1995. Table 9.10 provides a list of existing and currently projected major power plants (>500 MWe) along the shorelines.[150] As noted, three of the sites have construction permits or operating licenses for nuclear power units and have ample space and water availability for expansion of the facilities. Therefore, the staff finds that any of these three sites are an environmentally acceptable alternative for the proposed power station. Using topographic and highway maps, the staff has examined the general environmental and social characteristics of the other four sites and

Safety Evaluation Report

NUREG-0517

U. S. Nuclear Regulatory Commission

related to operation of

Salem Nuclear Generating Station, Unit 2

Office of Nuclear Reactor Regulation

Docket No. 50-311

December 1978

Public Service Electric and Gas Company, et al.

EXCERPT

Supplement No. 3

20.0 FINANCIAL QUALIFICATIONS

20.1 Introduction

In Section 20.0 of the Safety Evaluation Report we concluded that the applicants possess or can obtain the necessary funds to meet the requirements of 10 CFR 50.33(f) to operate the Salem Nuclear Generating Station, Units 1 and 2 and if necessary permanently shut down the facility and maintain it in a safe shutdown condition.

The Commission's regulations relating to the determination of an applicant's financial qualifications for a facility operating license appear in Section 50.33(f) and Appendix C to 10 CFR Part 50. Subsequent to the issuance of the Safety Evalution Report, Public Service Electric and Gas Company, Philadelphia Electric Company, Atlantic City Electric Company, and Delmarva Power and Light Company submitted financial information at our request regarding estimated operating and decommissioning costs for Unit 2, along with additional material covering the applicants' financial status. The following analysis summarizes our review of this submittal and addresses each applicant's financial qualifications to operate, and, if necessary, permanently shut down and safely maintain the subject facility.

20.2 Estimated Operating and Shutdown Costs

For the purpose of estimating the facility's operating costs, the applicants assumed that 1980 would be the first full year of commercial operation. Estimates of the total annual cost of operating Unit 2 for each of the first five years are presented in Table 20.1. The unit costs (mills per kilowatt hour) are based on a net electrical capacity of 1131 megawatts electrical and an average plant capacity factor of 65 percent.

TABLE 20.1
OPERATING COST ESTIMATE

	Plant Capacity Factor	Operating Cost Estimate (thousands)	Mills per kilowatt hour
1980	55 percent	$215,705	39.64
1981	65 percent	$226,181	35.79
1982	68 percent	$243,991	36.62
1983	68 percent	$261.993	39.46
1984	68 percent	$280,548	42.29
5-year average	65 percent	$245,624	38.76

The estimates of operating costs cover operating and maintenance expenses (including fuel expense), depreciation, taxes, and a return on investment. The applicants currently estimate the cost of decommissioning at $6,066,800 with annual maintenance and surveillance costs of $210,200 in 1978 dollars. This estimate is based on a mothballing type of decommissioning. This estimate is conservative when compared with the cost estimates set forth in the Atomic Industrial Forum's Study, dated November 1976, entitled, "An Engineering Evaluation of Nuclear Power Reactor Decommissioning Alternatives." For the mothballing alternative, with respect to a pressurized water reactor, the Atomic Industrial Forum estimated an initial cost of $2.3 million (in 1975 dollars) plus $167,000 per year for maintenance and surveillance costs if a 24-hour manned security force is required and $88,000 per year if it is not. In a study commissioned by us, Battelle Northwest Laboratories concluded that the cost estimates developed by the Atomic Industrial Forum appeared to be realistic.

20.3 Source of Funds

The applicants expect to cover all operating costs, including those related to decommissioning, through revenues generated from their system-wide sales of electricity and in proportion to their ownership interests: 42.59 percent for Public Service Electric and Gas Company, 42.59 percent for Philadelphia Electric Company, 7.41 percent for Atlantic City Electric Company, and 7.41 percent for Delmarva Power and Light Company. All four applicants are investor-owned utilities providing electric and/or gas service to residential, commercial, and industrial customers in either Delaware, Maryland, New Jersey, Pennsylvania and Virginia. For the twelve months ended December 31, 1977, the unit prices per kilowatt-hour from system-wide sales of electric power for Public Service Electric and Gas Company, Philadelphia Electric Company, Atlantic City Electric Company, and Delmarva Power and Light Company were 5.11 cents, 4.47 cents, 4.61 cents and 4.17 cents, respectively. These prices are in excess of the projected operating costs presented above and in addition, do not reflect possible rate increases during the first five years of Unit 2's commercial operation. Furthermore, the applicants have consistently demonstrated the ability to achieve revenues sufficient to cover all operating costs and interest charges. Table 20.2 presents financial data on revenues and net income for each applicant during the five years ended 1977.

In addition, based upon the applicants' 1977 internal cash flows of over $295.8 million and the rather modest costs associated with decommissioning when compared to the total operating costs presented above, we have reasonable assurance that the applicants can meet the costs of decommissioning Unit 2 when and if incurred.

TABLE 20.2

REVENUES/NET INCOME (MILLIONS)

Public Service Electric and Gas Company

1973	1974	1975	1976	1977
$1,076.0/$150.0	$1,455.9/$153.8	$1,630.5/$158.6	$1,869.5/$204.0	$2.032.8/$214.2

Philadelphia Electric Company

1973	1974	1975	1976	1977
$766.7/$122.9	$1,011.7/$129.1	$1,134.8/$143.9	$1,224.1/$164.6	$1.394.8/$173.4

Atlantic City Electric Company

1973	1974	1975	1976	1977
$132.9/$22.9	$176.6/$27.0	$199.1/$28.3	$212.0/$30.8	$235.0/$27.4

Delmarva Power and Light Company

1973	1974	1975	1976	1977
$157.8/$30.7	$228.5/$32.7	$239.4/$31.5	$242.3/$36.4	$291.6/$39.3

20.4 Conclusion

In accordance with the regulations cited above, an applicant must demonstrate that it has reasonable assurance of obtaining the necessary funds to cover the estimated costs of the activities contemplated under the license. Based upon the preceding analysis, we conclude that the applicants have satisfied this reasonable assurance standard and are, therefore, financially qualified to operate and, if necessary, shut down and safely maintain Unit 2. Our conclusion is based upon the applicants' demonstrated ability to achieve revenues sufficient to cover all operating costs and interest charges, and the favorable comparison between its current unit price for electricity and the projected unit operating costs of this facility.

NUREG/CR-1060

Activities, Effects and Impacts of the Coal Fuel Cycle for a 1,000-MWe Electric Power Generating Plant

Final Report

Manuscript Completed: January 1980
Date Published: February 1980

Prepared by
R. C. Christman, J. Haslbeck, B. Sedlik, W. Murray, W. Wilson

Teknekron Research, Inc.
1483 Chain Bridge Road
McLean, VA 22101

Prepared for
Division of Site Safety and Environmental Analysis
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN No. B6500

EXCERPT

NOTICE

Available from

GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

and

National Technical Information Service
Springfield, Virginia 22161

1.4 CONCLUSIONS AND RECOMMENDATIONS

The results of the study are presented in tabular form in Section 2 which follows. A few major conclusions regarding these data are provided below:

- Mining accidents and coal shipment accidents account for a significant number of deaths and injuries. The numbers provided in Table A do not require further refinement and would vary only as a function of the assumptions made concerning the generic plant (underground vs. surface mined coal, distance from mine to plant, etc.).

- Excess deaths caused by sulfur oxides and particulate matter are estimated to be 0 to 20 per year for a plant located in an urban area. This wide range indicates the uncertainty in the air pollution health effects area. Although further search of the current literature would not improve the data, ongoing clinical and epidemiological studies may supply better data in the next few years.

- A number of materials (sulfates, trace metals, organic compounds) emitted from coal-fired power plants are suspected of having significant long-term health implications for humans. Although quantitative impact data are not available, Table A indicates the types of chronic health impacts associated with each material.

- Although coal-fired power plants have some serious water pollution potential, in general, the types of problems that exist are controllable and are not of major concern, when compared to other industrial, agricultural, and municipal sources. Water pollution problems associated with the steam cycle and the cooling tower are similar for coal and nuclear power plants.

- Land use associated with the coal fuel cycle is substantial. Both coal mining and flue gas desulfurization waste disposal entail more land disturbance than their counterparts in the uranium fuel cycle.

- Impacts from four potentially hazardous effects of the coal fuel cycle were not investigated in detail during the present study. These are the "greenhouse" effect, acid rain, long-range transport of sulfates, and chronic health effects of trace metals, carcinogens, etc. Current studies by the Federal Government and other organizations may reveal that these impacts are more severe than all the other impacts discussed in this report combined.

The following recommendations are suggested as a result of this study:

- The results of this effort related to the coal fuel cycle and ongoing work to revise and improve Table S-3 regarding the uranium fuel cycle need to be integrated to increase the compatibility and comparability of the two sets of data.

- Since quantitative data are not available concerning the impacts of the "greenhouse" effect, acid rain, long-range transport of sulfates, and chronic health effects of coal combustion, it is recommended that NRC keep itself informed of the progress of other organizations' studies aimed at obtaining these data. Since the formal literature often lags considerably behind actual scientific progress, a simple literature search would not be adequate. Periodic research status documents would provide both the results available and the future directions of the research efforts. Such documents should be developed through person-to-person contact between NRC's representatives and the individuals who are conducting these long-term studies.

- Many of the impacts discussed in this report are highly site- and case-specific. Certain of these correlate very well with readily available data concerning specific future power plants (population data, coal characteristics, pollution control efficiency, coal transportation routes, etc.). These items are amenable to a computerized system of estimating impacts for a specific power plant site being examined in an environmental impact statement effort.

2. TABLE A AND SUPPLEMENTARY TABLES

This section contains tables presenting the effects and impacts data collected during this project. A number of different tables are included to accommodate a variety of information. The tables include:

- Table A - Describes environmental and health impacts for the processes in the coal fuel cycle. The table is geared to a northeastern power plant burning Appalachian coal. A subsection of the table, entitled Table A [Power Generation], utilizes a different format to accommodate the variety of available information concerning air pollution from the power plant alone.
- Tables A-1 and A-2 - Point out a few of the major differences in impact (as compared to Table A) that can be attributed to regional differences (western and midwestern).
- Table B - Addresses socioeconomic impacts for each of the three regions under consideration.
- Table C - Essentially reformats and condenses Table A to present quantified environmental impacts grouped by media (land, air, water).

Table A

IMPACTS OF THE COAL FUEL CYCLE
FOR A 1,000-MWe POWER PLANT

ACTIVITY	EFFECT	IMPACT
Exploration	Land disturbed[(1)]	Minor.
	Water contamination[(1)]	Minor.
	Dust emissions[(1)]	Minor.
Mining* (underground)	Land disturbed 288 acres/year (116.5 hectares/year)[(2)]	Loss of terrestrial and aquatic habitat. Land disturbed value is based on 1,750 tons/acre-foot for an average seam thickness of 4 feet (1.2 meters) with a recovery factor of 57% for underground mining. The required supply for a 1,000-MWe power plant is 2,296,178 tons/year (2,082,633 metric tons/year).
	Degradation of water quality[(3)]	Regulated and controlled.
	Loss of fresh water supplies[(4)]	Minor in eastern and midwestern regions.
	Subsidence[(5)]	Varies by site from no impact to severe, long-term impacts difficult to predict.
	Mine accidents[(6)]	0.62 fatalities per year, 38.97 disabling injuries per year; underground accident rates are 0.54 fatalities per million tons mined and 36 disabling injuries per million man hours. Production in deep mines was 8.25 tons/man-day in 1978.
Mining* (surface)	Land disturbed 121.5 acres/year (49.2 hectares/year)[(7)]	Loss of terrestrial and aquatic habitat. Land disturbed is calculated from the required production (2,296,178 tons/year) with a conversion factor of 1,750 tons/acre-foot with an average seam thickness of 6 feet (1.8 meters) and a recovery factor of 90%. Surface mining accounts for 50% of coal mining in the Northern Appalachian Region.
	Degradation of water quality[(3)]	Regulated and controlled.

* The generic power plant is assumed to receive 50% of its coal supply from underground mines and 50% from strip mines.

Table A (cont.)

ACTIVITY	EFFECT	IMPACT
Mining (surface) (continued)	Loss of fresh water supplies[4]	Minor.
	Fugitive dust[8]	Minor. Wet climates in East and Midwest tend to mitigate this impact.
	Mine accidents[9]	0.1 fatalities per year and 3.67 disabling injuries per year. Mine accidents are described as .09 fatalities/million tons mined by surface methods and 10 disabling injuries/million man-hours. Productivity in surface mines was 25 tons/man-day in 1978.
Coal Cleaning	Land use[10]	Minor loss of habitat or other economic use. Area for cleaning plant is small as compared with other fuel cycle activities.
	Solid waste, 521,860 tons per year (473,327 metric tons per year)[11]	Land removed from other uses, unless waste is returned to the mine.
	Degradation of water quality[12]	Minor. Regulated and controlled.
	Particulate emissions from dryer, 20,000 to 32,500 tons per year (18,000 to 29,500 metric tons per year)[13]	Controlled to 70% to 90% of uncontrolled levels, may present local health problem.
	Noise[14]	Strong indication of worker hearing loss.
Coal Transportation	Various	Impacts are strong functions of transportation mode (rail, barge, truck, pipeline).
	Railroad grade crossing accidents[15]	1.8 fatalities/year and 20.2 injuries/year, based on 0.79 deaths and 8.8 injuries per million tons of coal transported by rail.
Coal Storage	Land use, 2 to 3 acres (.81 to 1.2 hectares)[16]	Loss of land for other economic uses. Based on 88-day supply, 40-foot (12.2 meters) high storage pile.
	Dust emissions, 3.5 to 5.25 tons/year (3.2 to 4.8 metric tons/year)[17]	Can produce severe problem on very windy, dry day, but usually confined to power plant property.

2. TABLE A AND SUPPLEMENTARY TABLES

This section contains tables presenting the effects and impacts data collected during this project. A number of different tables are included to accommodate a variety of information. The tables include:

- Table A - Describes environmental and health impacts for the processes in the coal fuel cycle. The table is geared to a northeastern power plant burning Appalachian coal. A subsection of the table, entitled Table A [Power Generation], utilizes a different format to accommodate the variety of available information concerning air pollution from the power plant alone.
- Tables A-1 and A-2 - Point out a few of the major differences in impact (as compared to Table A) that can be attributed to regional differences (western and midwestern).
- Table B - Addresses socioeconomic impacts for each of the three regions under consideration.
- Table C - Essentially reformats and condenses Table A to present quantified environmental impacts grouped by media (land, air, water).

Table A

IMPACTS OF THE COAL FUEL CYCLE
FOR A 1,000-MWe POWER PLANT

ACTIVITY	EFFECT	IMPACT
Exploration	Land disturbed(1)	Minor.
	Water contamination(1)	Minor.
	Dust emissions(1)	Minor.
Mining* (underground)	Land disturbed 288 acres/year (116.5 hectares/year)(2)	Loss of terrestrial and aquatic habitat. Land disturbed value is based on 1,750 tons/acre-foot for an average seam thickness of 4 feet (1.2 meters) with a recovery factor of 57% for underground mining. The required supply for a 1,000-MWe power plant is 2,296,178 tons/year (2,082,633 metric tons/year).
	Degradation of water quality(3)	Regulated and controlled.
	Loss of fresh water supplies(4)	Minor in eastern and midwestern regions.
	Subsidence(5)	Varies by site from no impact to severe, long-term impacts difficult to predict.
	Mine accidents(6)	0.62 fatalities per year, 38.97 disabling injuries per year; underground accident rates are 0.54 fatalities per million tons mined and 36 disabling injuries per million man hours. Production in deep mines was 8.25 tons/man-day in 1978.
Mining* (surface)	Land disturbed 121.5 acres/year (49.2 hectares/year)(7)	Loss of terrestrial and aquatic habitat. Land disturbed is calculated from the required production (2,296,178 tons/year) with a conversion factor of 1,750 tons/acre-foot with an average seam thickness of 6 feet (1.8 meters) and a recovery factor of 90%. Surface mining accounts for 50% of coal mining in the Northern Appalachian Region.
	Degradation of water quality(3)	Regulated and controlled.

* The generic power plant is assumed to receive 50% of its coal supply from underground mines and 50% from strip mines.

Table A (cont.)

ACTIVITY	EFFECT	IMPACT
Mining (surface) (continued)	Loss of fresh water supplies(4)	Minor.
	Fugitive dust(8)	Minor. Wet climates in East and Midwest tend to mitigate this impact.
	Mine accidents(9)	0.1 fatalities per year and 3.67 disabling injuries per year. Mine accidents are described as .09 fatalities/million tons mined by surface methods and 10 disabling injuries/million man-hours. Productivity in surface mines was 25 tons/man-day in 1978.
Coal Cleaning	Land use(10)	Minor loss of habitat or other economic use. Area for cleaning plant is small as compared with other fuel cycle activities.
	Solid waste, 521,860 tons per year (473,327 metric tons per year)(11)	Land removed from other uses, unless waste is returned to the mine.
	Degradation of water quality(12)	Minor. Regulated and controlled.
	Particulate emissions from dryer, 20,000 to 32,500 tons per year (18,000 to 29,500 metric tons per year)(13)	Controlled to 70% to 90% of uncontrolled levels, may present local health problem.
	Noise(14)	Strong indication of worker hearing loss.
Coal Transportation	Various	Impacts are strong functions of transportation mode (rail, barge, truck, pipeline).
	Railroad grade crossing accidents(15)	1.8 fatalities/year and 20.2 injuries/year, based on 0.79 deaths and 8.8 injuries per million tons of coal transported by rail.
Coal Storage	Land use, 2 to 3 acres (.81 to 1.2 hectares)(16)	Loss of land for other economic uses. Based on 88-day supply, 40-foot (12.2 meters) high storage pile.
	Dust emissions, 3.5 to 5.25 tons/year (3.2 to 4.8 metric tons/year)(17)	Can produce severe problem on very windy, dry day, but usually confined to power plant property.

Table A (cont.)

ACTIVITY	EFFECT	IMPACT
Coal Storage (continued)	Degradation of water quality	Minor.
Solid Waste Disposal[18]	Fugitive dust[19]	Minor local impact during dry, windy weather for installations where inadequate buffer between landfill and property line is available.
	Possible ground-water contamination[20,21]	Controlled. Use of sludge stabilization and a properly designed and operated final disposal site will probably be required as a result of the Resource Conservation and Recovery Act. These measures, along with the natural pollutant attenuation provided by soil should prevent any significant degradation of ground water quality, and thus, any measurable impact.
	Possible surface water contamination[22,23]	Minor. Contamination of surface water will be limited to accidental releases and will in many instances be accompanied by dilution with high rainfall (overflow of impoundments or landfill catch basins). The impact will be minor since pollutant concentration will be low enough that receiving streams will provide adequate dilution to prevent widespread, substantial environmental or health impact.
	Land use, 400 to 700 acres (162 to 283 hectares) for life of the plant[24,25]	Disruption of wildlife habitat, temporary removal of land from other economic uses. In most instances, the amount of land disrupted at any one time will be less than the full life-of-the-plant area. Teknekron estimates 52 to 92 acres (21 to 37 hectares) of disrupted land to be typical for a landfill operation. The full 400 to 700 acres (162 to 283 hectares) would be available for a variety of uses when the plant operation is complete. Long-term impact of possible toxic constituents on certain land uses is uncertain, thus some uses may be excluded permanently.
	Possible radiological hazard[26]	<<0.02 excess deaths per year. Gotchy provides the only quantitative estimate of impact found in the literature surveyed (0.02 excess deaths per 0.8 GWe-year). Work by others indicates that this (Gotchy's) estimate is probably very high.

NOTE: The effects and impacts of air pollution from power generation have been broken down in greater detail than in the above portion of Table A in order to accommodate the considerable amount of literature on this subject. The continuation of Table A, designated Table A [Power Generation], is in a different format to provide more detailed information.

Notes and References for Table A

(1) Effects and impacts from exploration activities are generally minor when compared to those from mining activities.

(2) [3.1/3, 5, 6, 8, 9]; 3.1 refers to Section 3.1 of this report. 3, 5, 6, etc., refer to the references cited in that section.

(3) [3.1/8, 9, 14].

(4) [3.1/14].

(5) [3.1/11, 12, 13, 16].

(6) [3.1/29].

(7) [3.1/3, 5, 6, 8, 9].

(8) [3.1/20, 22, 23].

(9) [3.1/29].

(10) [3.2/1, 4, 8].

(11) Approximately 20% of coal tonnage mined [3.2/1].

(12) [3.2/5, 6].

(13) [3.2/1].

(14) [3.2/1].

(15) [3.3/5].

(16) [3.4/1, 2, 3].

(17) Emission factor of 0.0218/ton [3.4/1, 2].

(18) For all cases considered, ash disposal is accomplished along with disposal of scrubber sludge. To extrapolate to cases where scrubber [illegible] not used, or where sludge and ash are disposed of separately, the la[illegible] required for ash disposal would be slightly less than half that requ[illegible]ombined sludge/ash disposal. The potential for ground water con[illegible]n is somewhat greater for ash than for sludge/ash mixed.

(19) [3.6/2, 5].

(20) Sludge leachates contain concentrations of certain trace metals which exceed drinking water standards and total dissolved solids in excess of Federal drinking water standards. [3.6/3, 4, 16].

(21) [3.6/3, [illegible], 5].

(22) Sludge pond supernant and landfill runoff can contain trace metals and dissolved solids in concentrations greater than drinking water standards. [3.6/16, 21].

(23) [3.6/21].

(24) Both the total amount of land used over the life of the plant and the total amount disrupted at any given point in time are extremely site-specific. Thus, even the wide range given (400 to 700 acres) should not be construed as encompassing the complete power plant population. [3.6/2, 5, 14].

(25) [3.6/2, 5, 7, 15].

(26) [3.6/18, 19].

TABLE A

[POWER GENERATION]

AIR EMISSIONS in tons/yr (metric tons/yr)*	EFFECT CURRENT	EFFECT PROPOSED	IMPACT
Particulate Matter[1]	2,755 (2,499)	827 (750)	Current standard: In combination with sulfur oxides, 0 to 20 excess deaths (urban site), 0 to 3.4 excess deaths (rural site); chance of increased rate of chronic respiratory disease, aggravation of cardio-vascular disease, and increased rate of asthma attacks. Ecological impact: See Trace Metals. Material damage (soiling) estimate: \$21,700. Reduction in visibility: 16% of that attributed to total ambient pollutant burden. Proposed standard: Negligible impact.
Sulfur Oxides[2]	33,065 (29,990)	16,532 (14,995)	Current standard: In combination with particulate matter: health impact (see above), sulfates: increased prevalence of chronic bronchitis (adults), acute lower respiratory disease (children), aggravation of lung function and cardiopulmonary disease in children and sensitive members of the population. Ecological impact: Contributor to fish kills/ecological disruption in northeastern lakes (acid rain), potential for acute injury to plants under worst-case condition. Materials damage (acid sulfates) estimate: \$447,000. Reduction in visibility: 49% of that attributed to total ambient pollutant burden. Proposed standard: Similar to above although reduced in magnitude (quantification not possible on the basis of existing data). Estimates of excess deaths do not apply to emissions under proposed standard.

* Unless noted otherwise.

TABLE A

[POWER GENERATION] (cont.)

AIR EMISSIONS in tons/yr (metric tons/yr)*	EFFECT CURRENT	EFFECT PROPOSED	IMPACT
Nitrogen Oxides[3]	18,779 (17,033)	16,532 (14,995)	Current standard: No adverse health impact except under rare periods of maximum short-term local concentrations which could lead to impairment of lung function in healthy adults. Ecological impact: Negligible. Materials impact (attacks textile dyes) estimate: $65,700. Reduction in visibility: 2% of that attributed to total pollutant burden. Proposed standard: No significant differences from those listed above. Nitrogen oxides are precursors of potentially more harmful secondary pollutants (e.g., PAN); however, rates of transformation (and therefore ambient concentrations attributable to the coal-fired power plant) are unknown.
Carbon Monoxide[4]	1,043 (946)	1,043 (946)	Current and proposed standard: No impact. CO emitted from all coal-fired plants less than 1% of nationwide emissions.
Hydrocarbons[5]	313 (284)	313 (284)	Current and proposed standard: Certain polycyclic aromatic hydrocarbons identified as carcinogenics (e.g., benzo (a) pyrene); although no quantified impacts is available, no "threshold level" has been identified and thus very low levels may be harmful.

* Unless noted otherwise.

TABLE A

[POWER GENERATION] (cont.)

AIR EMISSIONS	EFFECT		IMPACT
	CURRENT	PROPOSED	
Trace Metals in lbs/yr (kg/yr) (6)			Annual releases of all trace elements expected to have negligible impact with the exception of known or suspected carcinogenic/mutagenics. The relative toxicities of the more hazardous trace elements are described qualitatively below.
Antimony	253 (415)	56 (25)	Suggested pulmonary carcinogen (unproven); highly toxic to animals but accumulates slowly in plants and animals.
Arsenic	3,284 (1,490)	485 (220)	As (III & IV), known human carcinogen; accumulates in marine organisms but not in terrestrial animals.
[illegible]llium	22 (10)	7 (3.2)	Produces cancer in animals; acute impact in humans and animals; produces inflammation of lung, no chronic impact.
Cadmium	33 (15)	10 (4.5)	Suspected carcinogen (unproven); accumulates in kidney and lung; highly toxic to plants and animals.
Copper	2,204 (1,000)	662 (300)	High toxicity in plants and marine organisms; complexes with other elements which reduces toxicity.
Fluorine	551 (250)	165 (75)	Dental fluorosis in animals (especially cattle); accumulates in plants and animals to produce chronic disease.
Lead	590 (268)	177 (80)	Animal carcinogen at abnormally high dosages; medium toxicity in animals and marine organisms.
Mercury	220 (100)	66 (30)	Methymercury possible mutagen; accumulates rapidly and is highly toxic to animals and marine organisms.
Nickel	5,510 (2,500)	1,654 (750)	Certain compounds identified as respiratory carcinogens; very mobile and highly toxic to plants and animals.
Selenium	336 (152)	101 (46)	Suspected carcinogen (unproven), highly toxic to animals particularly cattle.
Thallium	165 (75)	50 (23)	Chemically very toxic to humans, very mobile and highly toxic to plants and animals.

TABLE A

[POWER GENERATION] (cont.)

AIR EMISSIONS	EFFECT: CURRENT	EFFECT: PROPOSED	IMPACT
RADIOACTIVE RELEASES (mCi/yr)[7]			
U-238 Series	1,837		0.14 to 3.8 mrem/yr to the lung; 0.3 to 7.0 mrem yr to the bone; 1.9 mrem/yr whole body dose. Impact considered negligible in that natural background radiation dose equivalent roughly 100 mrem/yr. Negligible impact on soils, plants, and animals.
U-235 Series	41		
Th-232 Series	1,199		
K-40 Series	31		
ATMOSPHERIC COOLING TOWER EMISSIONS[8]			
Chemicals used as biocides Corrosion and scale inhibitors	Unknown		Could result in localized adverse impact on vegetation surrounding plant depending upon type of chemicals used in water treatment system. Could create ground fog under worst case meteorological conditions.

TABLE A

[POWER GENERATION] (cont.)

	EFFECT	IMPACT
WATER EFFLUENT[9]		
Cooling Tower Blowdown Waste Transport Water Boiler Blowdown Water Treatment Systems Metal Cleaning Wastes Low-Volume Wastes	Data lacking, wide variety in effluent rate and chemical composition; not quantifiable on a generic basis.	Unknown
ACCIDENTS[10]	0.01 TO 0.03 fatalities per 1,000-MWe plant-year 0.9 to 1.5 non-fatal injuries per 1,000-MWe plant-year	Range of 144 to 320 man-days lost.
NATURAL RESOURCES[11]		
Land, acres (hectares)	700 - 1,200 (283 - 486)	Site-specific, must be weighed against benefits of alternative uses.
Water, 10^9 gallons per year (10^9 liters per year)	6 - 8 (22.7 - 30.3)	Site-specific, depends on locally available supply, a portion returned to atmosphere.
Energy, 10^9 kWh	0.56	Necessary energy penalty to obtain benefits of cleaner environment.

Notes and References for Table A [Power Generation]

(1) Coal characteristics [3.5/15]; current standard (0.1 lb/MMBTU) requires 97.2% control, proposed standard (0.03 lb/MMBTU) requires 99.2% control [3.5/Table 3-44]. Health impact [3.5/18,65,73], materials impact [3.5/77], visibility reduction [3.5/78].

(2) Coal characteristics [3.5/15]; current standard (1.2 lb/MMBTU) requires 60.3% control, proposed standard (0.6 lb/MMBTU "emission floor") requires 80.2% control [3.5/Table 3-44]. Health impact [3.5/18,65,73] sulfates [3.5/64]. Ecological impact: acid iron [3.5/23,75], acute plant injury [3.5/23]. Materials impact [3.5/77], visibility reduction [3.5/78].

(3) Coal characteristics [3.5/15]; current standard (0.7 lb/MMBTU) requires no control, proposed standard (0.6 lb/MMBTU) requires 12% control [3.5/Table 3-44]. Health impact [3.5/26,67], materials impact [3.5/77], visibility reduction [3.5/78]. Rate of atmospheric transformation unknown [3.5/67].

(4) Emission factor [3.5/13], CO emissions from coal-fired power plants less than 1% of nationwide emissions [3.5/12].

(5) Emission factor [3.5/13], carcinogenesis [3.5/29,32,67,68], no threshold level of response [3.5/69].

(6) Coal characteristics [3.5/34], emission rates adjusted for amount of fly ash released under current and proposed standards [3.5/28,31,37]. High level of uncertainty in the correlation between emission rates and dose to humans, plants, and animals precludes any quantitative estimate of impact. However, the literature indicates operation of a 1,000-MWe power plant for a year would result in a negligible impact with the possible exception of carcinogenic/mutagenic trace elements [3.5/18,19,68]. Relative toxicity of the more hazardous trace elements as follows: antimony [3.5/38,68],

arsenic [3.5/19,72], beryllium [3.5/19,38,68], cadmium [3.5/62,68,72], copper [3.5/38,68], fluorine [3.5/19,38,68], lead [3.5/68,72], mercury [3.5/19,62,68], nickel [3.5/68], selenium [3.5/19,68,72], thallium [3.5/38,68,72].

(7) Coal characteristics 1.7 ppm U-238, -235, 4.5 ppm Th-232, 16 ppm K-40 [3.5/40]. Assume secular equilibrium with exception of enrichment of U by a factor of 2, Ra-226 by a factor of 1.5, and Po-210 and Pb-210 by a factor of 5 each [3.5/40]. All radon originally present in coal is released. Estimates of releases from Bec , et al. [3.5/40]. Impact: dose to lung [3.5/40], dose to bone and whole body [3.5/40,43]; worst case assuming completely soluble particles and 100% of diet from area with highest level of contamination yields 18.2 mrem/yr to bone [3.5/43], not shown in table.

(8) Effects unknown due to wide variety of chemicals used in recirculating utility water systems [3.5/11,49] that cannot be quantified on a generic basis. Potential impact on vegetation [3.5/50]. Ground fog [3.5/11].

(9) Estimate of data quality [3.5/Section 3.5.2.2 "Summary"]. Soon to be promulgated chemical discharge standards [3.5/53] should eliminate any potential adverse impacts.

(10) Frequency of fatal/non-fatal accidents [3.5/73]. Estimates of man-days lost: 6,000/death and 93/injury [3.5/79], range pertains to high and low accident rates found in the literature.

(11) Land requirement [3.5/36,54,56], includes solid waste disposal; water requirements [3.5/19,21,56,58], roughly 70% consumed by cooling tower; energy requirement [3.5/59] represents 9.2% of total annual plant output (70% capacity factor).

Final

environmental statement

related to operation of

OYSTER CREEK NUCLEAR GENERATING STATION

JERSEY CENTRAL POWER AND LIGHT COMPANY

DOCKET NO. 50-219

EXCERPT

DECEMBER 1974

UNITED STATES ATOMIC ENERGY COMMISSION
DIRECTORATE OF LICENSING

10.2 SUMMARY OF COSTS (PRESENT STATION)

10.2.1 Capital Cost and Related Resource Commitments

Construction of the station cost about $90 million. A distribution between labor and materials typical for nuclear plants shows about $20 million for labor, $17 million for site materials, and $34 million for factory equipment. Permanent resource commitments include the construction materials used, particularly materials in and around the reactor. They probably will be unavailable for other uses for decades because of creation of long half-life radioisotopes through neutron activation.

The land west of U.S. Route 9, occupied by the reactor and turbine buildings probably is committed permanently to industrial use. Demoliton and removal of the massive concrete foundation and shielding structures would be more costly than the present value of the land. Obsolescence of the existing facilities, however, does not preclude modification of the buildings and contents to accommodate future industrial activities.

10.2.2 Operating Cost and Related Resource Commitments

The operating cost for the station is estimated to be about $8,300,000 annually, including nuclear insurance. About one-half is labor costs and the rest is mostly materials. The fuel elements are Zircaloy clad uranium oxide rods with stainless steel support and guide mechanisms. Miscellaneous operating materials include items such as office supplies, protective clothing and water treatment chemicals. Maintenance materials are typical, e.g., oils, greases, paints and repair parts.

10.2.3 Land Utilization

The land within the site has characteristics similar to the vacant land in the surrounding environs. Except for the land east of U.S. Route 9, there is little demand for land within the site. The land east of the highway not committed permanently to power production could be sold for as much as $40,000/acre. About 45 acres of that land was saltmarsh, an important part of the bay's ecology. As a result of construction, the land was covered with dredge spoils, resulting in a loss to the bay's ecology of 400 tons/yr of primary productivity. Economically the loss is about $180,000 annually, assuming a value of $4,000/acre for the "ecological life-support value."[4]

SIGNIFICANT COSTS OR ENVIRONMENTAL IMPACTS	ENERGY SOURCES			EXISTING PLANT							
					ALTERNATE COOLING METHODS						
							COOLING TOWER 23° APPROACH			FRESHWATER LAKE	
	OYSTER CREEK (BASE CASE)	OIL FIRED STATION WITH ONCE THROUGH COOLING	COAL FIRED STATION WITH ONCE THROUGH COOLING	MODIFIED RAD WASTE SYSTEM WITH ONCE THROUGH COOLING	OCEAN INTAKE AND DISCHARGE SYSTEM	DILUTION	SALTWATER	TOMS RIVER	SEWAGE EFFLUENT	700 ACRE POND SEWAGE EFFLUENT	SPRAY POND SEWAGE EFFLUENT
COSTS (ALL COSTS IN $ MILLIONS)											
CAPITAL COSTS	49.9	396	424	94	311	96.6	126	128	128	153	139
DESIRED RETURN ON INVESTMENT (%/YR)	13.5	13.25	13.25	13.5	13.5	13.5	13.5	13.5	13.5	13.5	13.5
RETURN ON INVESTMENT	12.1	53	63	12.7	42	12.2	17.1	17.2	17.2	20.7	18.8
ANNUAL OPERATING COST[a]	2.7	2.5	3.2	2.9	3.3	2.8	4.8	4.8	5.5	*	7.2
ANNUAL FUELING COST	5.6	9.5	30	5.6	5.6	5.6	5.6	5.6	7.5	5.6	5.6
LAND USE											
SHORELINE USE	NONE	NONE	NONE	NONE	NONE EXCEPT DURING CONSTRUCTION	NONE	NONE	NONE	NONE	NONE	NONE
LAND REQUIREMENT	352 ACRES	452 ACRES	257 ACRES	352 ACRES	352 ACRES	352 ACRES	362 ACRES	362 ACRES	362 ACRES	1082 ACRES	652 ACRES
REDUCTION IN WILDLIFE HABITAT	25 ACRES	100 ACRES	400 ACRES	25 ACRES	25 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER 300 ACRES	25 ACRES	35 ACRES	35 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER ADDITIONAL 400 ACRES	35 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER ADDITIONAL 800 ACRES	730 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER ADDITIONAL 800 ACRES	200 ACRES WITH TEMPORARY DISTURBANCE DURING CONSTRUCTION OVER ADDITIONAL 800 ACRES
EFFECT ON TERRESTRIAL BIOTA	NO EFFECT	NO CHANGE FROM BASE CASE	POSSIBLE EFFECT DUE TO ACREAGE LOST	NO CHANGE FROM BASE CASE	NO SIGNIFICANT CHANGE AFTER REVEGETATION	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	NO SIGNIFICANT CHANGE AFTER REVEGETATION	NO SIGNIFICANT CHANGE AFTER REVEGETATION	PROBABLE EFFECTS DUE TO ACREAGE LOST	POSSIBLE EFFECTS DUE TO ACREAGE LOST
WATER USE											
EFFECT ON AQUATIC BIOTA											
WINTER FLOUNDER	24,000 INDIVIDUALS/YR	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	SIGNIFICANT REDUCTION	SAME AS BASE CASE	1400 INDIVIDUALS/YR	0	0	0	0
OTHER FISH	138,000 INDIVIDUALS/YR						6000 INDIVIDUALS/YR	0			
CRABS	32,000 INDIVIDUALS/YR						2000 INDIVIDUALS/YR	0			
MENHADEN	10^6 - 10^8 INDIVIDUALS/YR				0		0	0			
ZOOPLANKTON											
KILLED BY CHLORINE	150 TONS/YR				0[b]		0[b]	0			
KILLED BY TEMPERATURE	320 TONS/YR				90 TONS/YR		50 TONS/YR	0			
BAY PRODUCTIVITY	540 TONS/YR				0	0	0	0			
HEAT ADDITION TO BAY	1310 MW	1040 MW	1550 MW	1310 MW	NONE - 1310 MW TO OCEAN	1310 MW	~91 MW	~23 MW	~23 MW	~23 MW	~23 MW
ARTIFICIAL RADIOACTIVITY RELEASED TO BAY	0.55 MAN-REMS/YR	0	0	0.55 MAN-REMS/YR	NONE - 0.06 MAN-REMS/YR TO OCEAN	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR	0.55 MAN-REMS/YR
RELEASES TO THE BAY, Na_2SO_4	18 TONS/YR	18 TONS/YR	18 TONS/YR	18 TONS/YR	NONE 18 TONS/YR TO OCEAN	18 TONS/YR	18 TONS/YR	18 TONS/YR	18 TONS/YR	18 TONS/YR	18 TONS/YR
AIR USE											
ARTIFICAL RADIOACTIVITY RELEASED IN THE AIR	410 MAN-REM/YR			4.4 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR	410 MAN-REM/YR
PARTICULATE RELEASES	2.5 TONS/YR	1,700 TONS/YR	1,700 TONS/YR[c]	5.0 TONS/YR	2.5 TONS/YR	10 TONS/YR	40 TONS/YR	40 TONS/YR	40 TONS/YR	40 TONS/YR	40 TONS/YR
CHEMICAL RELEASES - SO_2	13.2 TONS/YR	13,600 TONS/YR	20,500 TONS/YR	27.0 TONS/YR	13.2 TONS/YR	90 TONS/YR	330 TONS/YR	330 TONS/YR	330 TONS/YR	330 TONS/YR	330 TONS/YR
NO_x	32.9 TONS/YR	5,200 TONS/YR	11,800 TONS/YR	66.0 TONS/YR	32.9 TONS/YR	60 TONS/YR	120 TONS/YR	120 TONS/YR	120 TONS/YR	120 TONS/YR	120 TONS/YR
ATMOSPHERIC EFFECTS - FOGGING	NONE	NONE	NONE	NONE	NONE	NONE	~10% INCREASE IN FREQUENCY	~10% INCREASE IN FREQUENCY	~10% INCREASE IN FREQUENCY	~10% INCREASE IN FREQUENCY	~10% INCREASE IN FREQUENCY
ICING	NONE	NONE	NONE	NONE	NONE	NONE					
EFFECT ON COMMUNITY											
AESTHETIC	MINOR IMPACT	MINOR IMPACT	MAJOR IMPACT FROM COAL HANDLING FACILITIES	MINOR IMPACT AFTER CONSTRUCTION	MINOR IMPACT AFTER CONSTRUCTION	MINOR IMPACT	MEDIUM IMPACT	MEDIUM IMPACT	MEDIUM IMPACT	MINOR IMPACT	MINOR IMPACT
RECREATIONAL IMPACT	SHIPWORM DAMAGE TO RECREATIONAL FACILITIES AND EQUIPMENT	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	NO CHANGE FROM BASE CASE	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION	NO CHANGE FROM BASE CASE	PARTIAL ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT THERMAL DISCHARGE	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION	ELIMINATION OF SHIPWORM DAMAGE ASSOCIATED WITH PRESENT STATION OPERATION
NOISE	QUIET	QUIET	NOISY	QUIET	QUIET	QUIET	QUIET	QUIET	QUIET	QUIET	QUIET
TRANSMISSION LINES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES	11.1 MILES

(a) INCLUDES COSTS RESULTING FROM ADDITIONAL POWER REQUIREMENTS AT [illegible]

(b) INCLUDED WITH TEMPERATURE EFFECT

(c) COAL FIRED STATION EMISSIONS ARE BASED ON EPA LIMITS[5]

TABLE 10-3 OYSTER CREEK ALTERNATIVES