NUREG-0332

HEALTH EFFECTS ATTRIBUTABLE TO COAL AND NUCLEAR FUEL CYCLE ALTERNATIVES

Draft

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Manuscript Completed: September 1977
Date Published: September 1977

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ABSTRACT

Estimates of mortality and morbidity are presented based on present-day knowledge of health effects resulting from current component designs and operations of the fuel cycles, and anticipated emission rates and occupational exposure for the various fuel cycle facilities expected to go into operation in approximately the 1975-1985 period. It was concluded that, although there are large uncertainties in the estimates of potential health effects, the coal fuel cycle alternative has a greater health impact on man than the uranium fuel cycle. However, the increased risk of health effects for either fuel cycle represents a very small incremental risk to the average individual in the public.

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ACKNOWLEDGMENTS

The author wishes to thank the numerous members of the Nuclear Regulatory Commission (NRC) Staff who provided support and assistance in preparing this report. In particular, the author would like to thank Lawrence Chandler for his tireless and invaluable assistance, and Jacqueline Lynch and Mark Doyle for their selfless help in assembling the data base used in preparing this report.

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I. INTRODUCTION

The National Environmental Policy Act of 1969 (NEPA) requires the Federal Government to use all practicable means, consistent with other essential considerations of national policy, to assure, among other things, that the Nation may:

Fulfill the responsibilities of each generation as trustee of the environment for succeeding generations.

Assure for all Americans safe, healthful, and productive and pleasing surroundings.

Attain the widest range of beneficial uses of the environment without degradation, risk to health and safety, or other undesirable and unintended consequences.

Further, with respect to major Federal actions significantly affecting the quality of the human environment, Section 102(2)(c) of the NEPA calls for consideration of, among other things:

The environmental impact of the proposed action.

Alternatives to the proposed action.

As a result of recent decisions by the Administration regarding the Nation's energy policy, it is clear that the major alternative to nuclear power for meeting the Nation's baseload electrical needs for the rest of this century is coal power.

NRC environmental statements have discussed the impacts of the coal fuel cycle in terms of economics, and generically address those impacts in terms of land and water use. However, on January 25, 1977, an Atomic Safety and Licensing Appeal Board rendered a decision which stated:

A disproportionately large part of the analyses comparing the and nuclear fuel cycles is focused on costs rather than environmental considerations.

While the effect on human and animal life of the emissions from the proposed nuclear plant are discussed in detail, there is no corresponding discussion with respect to the postulated coal plant.

No mention is made of the environmental effects of the coal fuel cycle.

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> Although exact identity in treatment with respect to every aspect of environmental comparison of alternatives may not be required, this kind of comparison goes to the heart of NRC's duty under NEPA, where coal and nuclear power are shown to be the only two feasible alternatives. (Tennessee Valley Authority (Hartsville Nuclear Plant, Units 1A, 2A, 1B, 2B), ALAB-367, 5 NRC 92).

As a result of the Hartsville decision, the NRC staff prepared testimony for ongoing hearings, and similar input for current environmental statements where such considerations were lacking.

That testimony, which has now been presented in numerous public hearings, is the basis for this draft NUREG report.

Following receipt of comments from Federal and State agencies, industry, and concerned members of the public, and review of a forthcoming report by the National Research Council Committee (National Academy of Sciences) on Nuclear and Alternative Energy Systems, the NRC staff will prepare a final NUREG report, incorporating as many of the comments and new NAS data as appropriate.

II. RESULTS OF THE HEALTH EFFECTS ASSESSMENTS

In making these assessments, the entire fuel cycle rather than just the power-generation phase was considered in order to compare the total impacts of each cycle. For coal, the cycle consists of mining, processing, fuel transportation, power generation, 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.

In preparing this assessment it has been recognized that there are large 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, while there may be as much as two orders of magnitude uncertainty in the assessments of the coal fuel cycle based on the range of published values. 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, and the effect of Federal laws on future performance of coal fired power plants, mine safety, and culm bank stabilization.

Health effects, as it is used here, is intended to mean excess** mortality, morbidity (disease and illness) and injury among occupational workers and the general public. The most recent and detailed assessments of health effects of the coal fuel cycle have been prepared by the Brookhaven (Refs. 1,2,3,4) and Argonne (Refs. 5,6) National Laboratories. 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) (Ref. 7)."

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* Although the Administrations's announced energy policy opposes the implementation of commercial fuel reprocessing technology at this time, Table S-3 (10 CFR Part 51) assumes reprocessing. This tends to upperbound the radiological impacts since the recycle of uranium after reprocessing results in more radiological effects than no recycle of uranium from irradiated fuel.

** "Excess" is used here to mean effects occuring at a higher than normal rate. In the case of death it is used synonymously with premature mortality.

***Consistent with the Commission's announced intention to reexamine the rule from time to time to accomodate new information, (39 F.R. 14188, April 22, 1974, and 42 F.R. 13803, March 14, 1977), staff studies are underway 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, F.R. 45849, October 18, 1976).

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 March 14, 1977 revision of Table S-3, 10 CFR Part 51.*** 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 1 and 2, and some critical assumptions related to estimates are shown in Appendix A.

Since Table S-3 excludes radon releases from uranium mines, the health effects of such releases on the general public are not included in Tables 1 and 2. The effects of such releases would result in some small increases in the total risks of mortality and morbidity as discussed below under "Other Considerations."

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 (U recycle only option)*. In addition, the occupational dose commitments to workers in uranium mines, mills, uranium hexaflouride plants, uranium fuel plants and uranium enrichment plants were taken from GESMO I, since they are not considered in Table S-3. However, these dose commitments are comparable to those which would result from the radiological releases 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 (Ref. 8).

The impact of accidents in fuel cycle facilities (Ref. 9) and reactors (Ref. 8) 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.

Estimates of death, disease and injury from non-radiological causes for the uranium fuel cycle are from the Brookhaven (Refs. 1,2,3) evaluations, with the exception of transportation accident related deaths and injuries, which were taken from Table S-4, 10 CFR Part 51. The results of these assessments are shown in Tables 1 and 2. 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,

*See footnote * on page 1.

(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.

A. Health Effects of The Uranium Fuel Cycle

Currently the NRC estimates that the excess deaths per 0.8 gigawatt-year electric (GWy(e)) (i.e., per 1,000 MWe power plant operating at 80% of capacity for one year) 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. However, it is not greatly different from estimates by others such as Comar and Sagan (Ref. 10) (0.11 to 1.0), Hamilton (Ref. 1) (0.7 to 1.6), and Rose et al (Ref. 11) (0.50). The uncertainty in the estimate is about an order of magnitude.** 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 would estimate there would be about 1.1 to 5.4 excess deaths per 0.8 GWy(e). Of this total, about 0.63 to 4.9 excess deaths per 0.8 GWy(e) would be attributable to coal power. The uncertainty in the estimate is about one order of magnitude.

The total number of injuries and diseases which 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 such as falls, cave-ins and explosions account for 10 of the 14 cases (see Table 2). If 100% of the electrical power used by the uranium fuel cycle comes from coal-fired power plants, the NRC would estimate there would be about 17-24 injuries and diseases per 0.8 GWy(e). Of this total, about 3 to 10 excess effects per 0.8 GWy(e) would be attributable to coal power (See Table 2a). The uncertainty in the estimate is also about one order of magnitude.

Although anticipated somatic*** 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 non-fatal somatic effects (see footnote c, Table 2). At this time only light water cooled power reactors (Ref. 8) have been thoroughly evaluated. However, it should

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* Conservative is used here to mean that assumptions regarding atmospheric dispersion, deposition of particulates, bioaccumulation, and so forth generally result in estimates of impact that are typically "upper bound" estimates, and in most cases, the estimates would be lower for real plants.

** "Order of magnitude" uncertainty means the estimate could be as much as ten times higher or ten times lower.

*** Health effects of a non-reproductive nature (i.e.; non-genetic).

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 they represent 80 percent of all the fuel cycle facilities expected to be operating for the balance of this century (Ref. 7) and 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). There is some controversy over the probabilities of occurrence of serious accidents, such as discussed in WASH-1400 (Ref. 8). However, even if the risks were, for example, twenty times greater than estimated in WASH-1400, the excess mortality for the uranium fuel cycle would only increase from 0.47 to 0.87 per 0.8 GWy(e).

Transportation related accidents are estimated to contribute about 0.01 excess deaths per 0.8 GWY(e) (see Table 1a, footnote d).

Early and latent non-fatal somatic effects which might be expected after high radiation dose effects include a variety of effects (see footnote c, Table 2). It is possible that non-fatal somatic effects could be an order of magnitude greater than excess deaths resulting from accidents (Ref. 8), 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 2. The number of non-fatal 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), while other non-fatal cancers would be less than or equal in number to fatal cancers (about 0.2 per 0.8 GWy(e)) (see footnote c, Table 2 and footnotes ** and ***, Table 2a).

It is believed (Refs. 6,12) that genetically related diseases* 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; this could add another 0.3 health effects per 0.8 GWy(e) among workers and 0.1-0.2 health effects per 0.8 GWy(e) among the general public (see footnote c, Table 2).

In assessing the impact of coal power used in the uranium fuel cycle, Table S-3 was the basis for the assumption that 100% of the electricity used in the uranium fuel cycle, primarily for uranium enrichment and reactor

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*Includes diseases such as cystic fibrosis, hemophelia, certain anemias, and congenital abnormalities such as mental retardation, short-limbed dwarfism and extra digits. (See footnote c, Table 2) operation, came from coal fired plants. Adding 4.5% of the health effects from the coal fuel cycle per 0.8GWy(e) significantly increases the health effects for the uranium fuel cycle per 0.8 GWy(e), as shown on the second lines of Tables 1 and 2.

B. Health Effects of 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, as discussed in more detail below, 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), while 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) (Refs.1,5). In addition, more coal in the years ahead is expected to be produced by strip mining which results in lower mortality rates (Ref. 1). As a result, the frequencies of both types of events is 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 (Ref. 5). 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.

In the case of the general public*, there is also considerable uncertainty in the estimation of health effects. 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 such banks to prevent slides. (Ref. 13). Current estimates of excess deaths in the public from sulfates from such fires range from 1 to 10 per 0.8 GWy(e) (see footnote g,

* In the case of coal plant effluents, considerations of health effects was limited to the population within 80 km of such plants.

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Table 1). Power generation is estimated to result in 3 to 100 excess deaths per 0.8 GWy(e) (see footnote g, Table 1), while excess morbidity ranges from about 10-100 per 0.8 GWy(e) (see footnote g, Table 2).

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. (Ref. 10) 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 (Ref. 14) such as arsenic, antimony, cadmium, lead, selenium, manganese, and thallium, (Ref. 5) significant quantities of berylium, chromium, nickel, titanium, zinc, molybdenum, and cobalt (Ref. 15), and traces of radium-226, 228 and thorium-228, 232. (Ref. 16).

2. Hydrocarbons: Includes very potent carcinogens (cancer causing substances) such as benzo(a)pyrene.

3. Sulfur oxides

4. Nitrogen oxides

5. Other gases: Includes ozone ,carbon monoxide, carbon dioxide, mercury vapor, and radon-222.

Of the preceeding list of pollutants, there are no well established epidemiologic cause-effect relationships which can be used to accurately estimate total health effects 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. (Ref. 17) The most widely quoted studies are those by Lave and Seskin (Ref. 18), Winkelstein et al (Ref. 19), and an unpublished study by EPA which was used in the NAS/NRC study for the U.S. Senate (1975). (Ref. 17)

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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, while morbidity from long-term exposure also includes children. Although widely accepted cause-effect relationships were not derived from acute air pollution episodes in London (1952) (Ref. 20), Donora, Pennsylvania (1948), (Ref. 21), and New York (Ref. 22), 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 has failed to provide any new or definitive cause-effect relationships for any of the pollutants from coal-fired plants which can be used to provide better estimates of health effects than are currently available (see for example Ref. 23).

Assuming that new coal-fired plants in the 1980's can meet EPA New Source Performance Standards (which could require on the order of 99% particulate removal, and 90% sulfur removal for high sulfur coal), 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 coal may be reduced by about half to 8 to 60 per 0.8 GWy(e).

Recently, Argonne National Laboratory has developed a predictive model for total 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. (Ref. 6) Such effects, while 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 1.

Probably the most reliable estimates of deaths associated with the coal fuel cycle are those associated with transporation accidents. Since a 1000 MWe coal-fired plant consumes about 3 million tons of coal per year,

* This $22 million study attempted to correlate air pollution data collected from six U.S. cities with a variety of health problems.

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 10 trains in the U.S. is a coal train going to a coal-fired power plant. (Ref. 24) These trains are estimated to travel an average distance of about 300 miles from the mines to the plants. (Ref. 13) As a result, there are about 1.2 deaths per 0.8 GWy(e) among workers and the general public. Further, since 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 non-fatal 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 the 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, since occupational sickness and injury currently account for about half of the total non-fatal health effects.

The Brookhaven estimates, which form the basis of this testimony, show a range of uncertainty of about one order of magnitude. They are well within the range of values reported in the literature which range over about two orders of magnitude for the coal fuel cycle.

C. Other Considerations

Although the Reactor Safety Study (Ref. 8) has helped to 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, while the Reactor Safety 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, since the consequences can be severe. In fact, it appears that some people (Ref. 25) more readily accept, for example, having 55,000 people actually killed each year in violent highway accidents, one or two at a time, than would consider acceptable 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 radon-222 release increases from 74.5 Ci to about 4,800 Ci when releases from mines are included. This increase would result in a small increase in the total number of excess deaths shown in Table 1, although the moratality 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 which 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. Reference 5 provides a detailed discussion of these and other effects of sulfur and nitrogen oxide emissions. However, as more coal plants come on line, these effects can be expected to expand to surrounding areas.

2. Damage of materials, such as paints, building surfaces, statuary, and metals, from sulfur oxides, ozone and nitrogen oxide emissions. A 1976 review of such effects indicates that the costs could range into billions of dollars per year in the U.S. alone. (Ref. 26)

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 which has not been completely evaluated at this time. Some recent studies have attempted to deal with these extremely complex issues, (Refs. 27,28) and concluded 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.

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6. The possibility of the so-called "Greenhouse Effect;" this phenomenon is expected by some (Ref. 29) to result sometime early in the next century at the present and future anticipated production rates of carbon dioxide from the combustion of fossil fuels. Since each 1000 MWe coal plant produces about 7.5 to 10.5 million tons of carbon dioxide per year (Ref. 1) it is believed these emissions from hundreds of fossil fuel fired 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. Since 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 since coal has essentially no carbon-14. The stable carbon in effect dilutes the carbon-14 in the biosphere, resulting in a reduction in the radiological impact of both naturally occuring and man-made carbon-14.

7. An additional consideration which has not been evaluated for the coal cycle is 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. While Pohl (Ref. 30) has shown that this is not a problem with some 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 about 50 times higher than most eastern coal (Refs. 31,32). Combustion of the coal and disposal of the remaining ash leads to approximately the same health effects calculated by Pohl from radon-222 emissions as uranium mill tailings piles per GWy(e).

   These releases would account less than 0.01 excess deaths per 0.8 GWy(e) from 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 (Ref. 33) that when the physical and biological properties of the radium released from conventional coal powered plants burning coal (with 1-2 ppm uranium-238 and Th-232) are considered, such plants discharge relatively greater quantities of radioactive materials into the atmosphere than nuclear powered plants of comparable size. EPA has estimated radiation doses from coal and nuclear powered plants of early designs and reached similar conclusions (Ref. 16). Even if the health effects from radioactivity released by the coal fuel cycle are greater than the health effects from radioactivity released in the nuclear fuel cycle, the total health effects from coal would not change significantly since these effects would be only a small percentage of the total health effects from the coal cycle.

III. SUMMARY AND CONCLUSIONS

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, 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 1 and 2, with some important assumptions inherent in the calculations of health effects listed in Appendix A.

While 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. (Refs. 1,2,3, 4,5,10,11,27,28,33,34,35,36) As shown in Tables 1 and 2, the coal fuel cycle alternative may be more harmful to man by factors of 4 to 260 depending on the effect being considered, for an all nuclear economy, or factors of 3 to 22 with the assumption that all of the electricity used by the uranium fuel cycle comes from coal powered plants.

It should be noted that although there are large uncertainties in the estimates of most of the potential health effects of the coal cycle, 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.

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However, lest the results of this analysis 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 individual in the public. For example, Comar and Sagan (Ref. 10) 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 from the National Research Council Committee on Nuclear and Alternative Energy Systems in 1977 (Ref. 37). This study may assist substantially in reducing much of the uncertainty in the analysis presented.

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APPENDIX A

Some Important Assumptions Affecting the Fuel Cycle Health Effects Evaluations:

1. The Uranium Fuel Cycle (Ref. 7)

   a. For mine nd mill emissions it was assumed there was a population density om 7.5 persons/sq.mi. in the west, to 160 persons/sq.mi. in the east, all uniformly distributed. For all other facilities, assumed 160 persons/sq.mi. density.*

   b. Used "box" atmospheric dispersion model with vertical dispersion limited to 1,000 m, 2 m/sec windspeed, and 1 cm/sec deposition velocity for particulates.

   c. Calculated the dose commitment from one year of operation for each type of fuel cycle facility. This dose commitment represents the sum of the 50 year dose commitments from the year of operation and each of the subsequent 39 years (i.e., a 40 year environmental dose commitment). The total impact of the fuel cycle to the U.S. population for the years 1975-2000 was calculated using the needs for all types of facilities in order to meet current projections of power plants.

   d. Radioactive materials were not considered to be removed from food chains except by radioactive decay. Only in the case of carbon-14 was an environmental sink assumed to be acting upon biological availability.

   e. Krypton-85 and carbon-14 not removed from the plume in the U.S. was assumed to mix uniformly in the world's atmosphere. Tritium is assumed to be mixed uniformly in the world's circulating water volume after depletion of the plume on its first pass over the U.S.

   f. Resuspension of deposited particulates was considered.

   g. Bioaccumulation of radioactivity in food chains was considered (generally upper bound estimates).

   h.. Assumed an 80% capacity factor.

2. The Coal Fuel Cycle (Refs. 1,2,3)

   Since the major impact of the coal fuel cycle results from power plant emissions, only those critical assumptions will be discussed:

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* It should be noted that most of the calculated health effects would occur outside the 80 km radius of the plant. The mortality rate for the U.S. population is about 2,000,000 per year from all causes.

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a. Used actual population distributions within 80 km of several nuclear plant sites; the average population was 3.8 million people.*

b. Used actual meteorology data from the same plants to calculate inhalation exposures to sulfates out to 80 km.

c. Assumed a 1,000 foot stack for emissions.

d. Assumed use of 3% sulfur coal with 12% ash and 12 thousand BTU per lb (eastern coal) for an upper bound estimate of health effects; assumed 0.4% sulfur coal with 3% ash and 12 thousand BTU per lb (eastern coal) for a lower bound estimate (approximately the same sulfur emission as would result from use of high sulfur coal with flue gas desulfurization).

e. Assumed 99% particulate removal from plant emissions.

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

g. The dose-response relationships of Lave and Seskin (Ref. 18), Winklestein et al (Ref. 19) and others (as discussed in Refs. 1,2,3) were used to calculate excess mortality and morbidity; adjustments were made for fractions of sulfates in the total suspended particulates.

h. Resuspension of deposited particulates was not directly considered, although deposition was.

i. Assumed a 75% capacity factor.

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* Experiences about 36,000 per year mortality rate from all causes. Additional health effects from coal combustion are expected to occur outside this area, but have not yet been estimated.

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Table 1. Current Energy Source Excess Mortality Summary per Year per 0.8 GWy(e)

	Occupational		General Public		Totals
	Accident	Disease	Accident	Disease	
Nuclear Fuel Cycle (all nuclear)	0.22 [a]	0.14 [b]	0.05 [c]	0.06 [b]	0.47
(with 100% of electricity used in the fuel cycle produced by coal power (U.S. population for nuclear effects; regional population for coal effects)	0.24-0.25 [a,d]	0.14-0.46 [b,e]	0.10 [c,f]	0.64-4.6 [g]	1.1-5.4
Coal Fuel Cycle (Regional Population)	0.35-0.65 [d]	0-7 [e]	1.2 [f]	13-110 [g]	15-120

Ratio of Coal to Nuclear: 32-260 (all nuclear)

14-22 (with coal power)[h]

(a) Primarily fatal non-radiological accidents such as falls, explosions, etc.
(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 51) and serious nuclear accidents.
(d) Primarily fatal mining accidents such as cave-ins, fires, explosions, etc.
(e) Primarily coal workers pneumoconiosis (CWP) and related respiratory diseases leading to respiratory failure..
(f) Primarily members of the general public killed at rail crossings by coal trains.
(g) Primarily respiratory failure among the sick and elderly from combustion products from power plants, but includes deaths from waste coal bank fires.
(h) 100% of all electricity consumed by the nuclear fuel cycle produced by coal power; amounts to 45 MWe per 0.8 GWy(e).

Table 1a
(Breakdown of Table 1)

NUCLEAR — EXCESS MORTALITY per 0.8 GWy(e)

FUEL CYCLE COMPONENT	OCCUPATIONAL		GENERAL PUBLIC		TOTAL
	ACCIDENT (a)	DISEASE (b,c,d,)	ACCIDENT (d,e,)	DISEASE (b)	
RESOURCE RECOVERY (Mining, Drilling, etc.)	0.2	0.038	~0	+	
PROCESSING (f)	0.005**	0.042	*	0.002	
POWER GENERATION	0.01	0.061	0.04	0.011	
FUEL STORAGE	*	~0	*	~0	
TRANSPORTATION	~0	~0	0.01	~0	
REPROCESSING	*	0.003	*	0.050	
WASTE MANAGEMENT	*	~0	*	0.001	
TOTAL	0.22	0.14	0.05	0.064	0.47

+These effects are not included in Table S-3, 10 CFR 51. Ref. 7 would indicate about 0.023 excess deaths per 0.8 GWy(e) due to radon-222 emission.

*The effects associated with these activities are not known at this time. While such effects are generally believed to be small, they would increase the totals in this column.

**Corrected for factor of 10 error based on referenced value (WASH-1250)

(a) Ref. 1
(b) Ref. 7
(c) 10 CFR 51, Table S-3
(d) 10 CFR 51, Table S-4
(e) Ref. 8
(f) Includes milling, uranium hexaflouride production, uranium enrichment, and fuel fabrication.

Table 1b
(Breakdown of Table 1)

COAL FUEL CYCLE COMPONENT	EXCESS MORTALITY per 0.8 GWy(e) OCCUPATIONAL ACCIDENT	 OCCUPATIONAL DISEASE	 GENERAL PUBLIC ACCIDENT	 GENERAL PUBLIC DISEASE	 TOTAL
RESOURCE RECOVERY (Mining, Drilling, etc.)	0.3-0.6	0-7	*	*	
PROCESSING	0.04	*	*	10	
POWER GENERATION	0.01	*	*	3-100	
FUEL STORAGE	*	*	*	*	
TRANSPORTATION	*	*	1.2	*	
WASTE MANAGEMENT	*	*	*	*	
TOTAL	0.35-0.65	0-7	1.2	13-110	15-120

Ref. 1

*The effects associated with these activities are not known at this time. While such effects are generally believed to be small, they would increase the totals in this column.

Table 2. Current Energy Source Summary of Excess Morbidity and Injury per 0.8 GWy(e) Power Plant

	Occupational		General Public		Totals
	Morbidity	Injury	Morbidity	Injury	
Nuclear Fuel Cycle (all nuclear)	0.84 [a]	12 [b]	0.78 [c]	0.1 [d]	14
(with 100% of electricity used by the fuel cycle produced by coal power) (U.S. population for nuclear effects; regional population for coal effects)	1.7-4.1 [e]	13-14 [b]	1.3-5.3 [g]	0.55 [h]	17-24
Coal Fuel Cycle (Regional population)	20-70 [e]	17-34 [f]	10-100 [g]	10 [h]	57-210

Ratio of Coal to Nuclear: 4.1-15 (all nuclear)

3.4-8.8 (with coal power)[i]

(a) Primarily non-fatal cancers and thyroid nodules.
(b) Primarily non-fatal injuries associated with accidents in uranium mines such as rock falls, explosions, etc.
(c) Primarily non-fatal cancers, thyroid nodules, genetically related diseases, and non-fatal illnesses following high radiation doses such as radiation thyroiditis, prodromal vomiting, and temporary sterility.
(d) Transportation related injuries from Table S-4, 10 CFR Part 51.
(e) Primarily non-fatal diseases associated with coal mining such as CWP, bronchitis, emphysema,etc.
(f) Primarily injuries to coal miners from cave-ins, fires, explosions, etc.
(g) Primarily respiratory diseases among adults and children from sulfur emissions from coal-fired power plants, but includes waste coal bank fires.
(h) Primarily non-fatal injuries among members of the general public from collisions with coal trains at railroad crossings.
(i) 100% of all electricity consumed by the nuclear fuel cycle produced by coal power; amounts to 45 MWe per 0.8 GWy(e).

Table 2a
(Breakdown of Table 2)

NUCLEAR — MORBIDITY AND INJURY per 0.8 GWy(e)

FUEL CYCLE COMPONENT	OCCUPATIONAL MORBIDITY	OCCUPATIONAL INJURY (a)	GENERAL PUBLIC MORBIDITY	GENERAL PUBLIC INJURY (b)	TOTAL
RESOURCE RECOVERY (Mining, Drilling, etc.)	**	10	***	~0	
PROCESSING (c)	**	0.6	***	~0	
POWER GENERATION	**	1.3	***	~0	
FUEL STORAGE	**	*	***	~0	
TRANSPORTATION	**	<1	***	0.1	
REPROCESSING	**	*	***	*	
WASTE MANAGEMENT	**	*	***	~0	
TOTAL	0.84	12	0.78	0.1	14

(a) Ref. 1
(b) Table S-4, 10 CFR 51
(c) Includes milling, uranium hexaflouride production, uranium enrichment, and fuel fabication.

*The effects associated with these activities are not known at this time. While such effects are generally believed to be small, they would increase the totals in this column.

**Non-fatal cancers $\leq$ fatal cancers (excluding thyroid) = 0.14
Non-fatal thyroid cancers and benign nodules = 3X fatal cancers = 0.42
Genetic defects 2X fatal cancers = 0.28

***Reactor accidents 10X fatalities = 0.40 non-fatal cases
Normal operations: Non-fatal cancers $\leq$ fatal cancers = 0.064
Non-fatal thyroid cancers and nodules = 3X fatal cancers = 0.19
Genetic effects = 2X fatal cancers = 0.13

Table 2b
(Breakdown of Table 2)

COAL	MORBIDITY per 0.8 GWy(e)				
FUEL CYCLE COMPONENT	OCCUPATIONAL		GENERAL PUBLIC		TOTAL
	MORBIDITY	INJURY	MORBIDITY	INJURY	
RESOURCE RECOVERY (Mining, Drilling, etc.)	20-70	13-30	*	*	
PROCESSING	*	3	*	*	
POWER GENERATION	*	1.2	10-100	*	
FUEL STORAGE	*	*	*	*	
TRANSPORTATION	*	*	*	10	
WASTE MANAGEMENT	*	*	*	*	
TOTAL	20-70	17-34	10-100	10	57-210

Ref. 1

*The effects associated with these activities are not known at this time. While such effects are generally believed to be small, they would increase the totals in this column.

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References

1. L.D. Hamilton (ed.), "The Health and Environmental Effects of Electricity Generation - A Preliminary Report," Brookhaven National Laboratory (July, 1974).

2. L.D. Hamilton and S.C. Morris, "Health Effects of Fossil Fuel Power Plants," In: Population Exposures - Proceedings of the Eighth Midyear Topical Symposium of the Health Physics Society, (October, 1974).

3. L.D. Hamilton, "Energy and Health," In: Proceedings of the Connecticut Conference on Energy (December, 1975).

4. S.C. Morris and K.M. Novak, Handbook for the Quantification of Health Effects from Coal Energy Systems," draft report, Brookhaven National Laboratory (December 15, 1976).

5. "Health and Ecological Effects of Coal Utilization," Draft Report, Argonne National Laboratory (November, 1976).

6. "An Assessment of the Health and Environmental Impacts of fluidized - Bed Combustion of Coal as Applied to Electrical Utility Systems," Argonne National Laboratory, Draft Report (January 25, 1977).

7. "Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors," NUREG-0002, U.S Nuclear Regulatory Comission (August, 1976).

8. "Reactor Safety Study," WASH-1400 (NUREG-75/014), U.S. Nuclear Regulatory Commission (October, 1975).

9. "The Safety of Nuclear Power Reactors (Light Water-Cooled) and Related Facilities," U.S. Atomic Energy Commission, WASH-1250 (July, 1973).

10. C.L. Comar and L.A. Sagan, "Health Effects of Energy Production and Conversion," In: J.M. Hollander (ed.), Annual Review of Energy, Vol. 1, p. 581-600, (1976).

11. D.J. Rose, P.W. Walsh, and L.L. Leskovjan, "Nuclear Power -- Compared to What?," American Scientist 64:291-299 (May-June, 1976).

12. D. Grahn, "Cost-Benefit as Weighed on Genetic scales." In: Energy and the Environment-Cost-Benefit Analysis, R.A. Karan and K.Z. Morgan (ed.), Pergamon Press, N.Y., P. 371-386 (1976).

13. "Energy and the Environment," Council on Environmental Quality p. 43, (August, 1973).

14. D.F.S. Natusch, J.R.Wallace, and C.A. Evans, "Toxic Trace Elements: Preferential Concentration in Respirable Particles," Science 183; 202-204 (January 18, 1974).

589 276

15. S.T. Cuffe and R.W. Gerstle, "Emissions from Coal-Fired Power Plants: A Comprehensive Summary" U.S. Department of Health, Education and Welfare, Public Health Service, PHS-999-AP-35 (1967).

16. J.E. Martin, E.D. Harward and D.T. Oakley, "Radiation Doses from Fossil Fuel and Nuclear Power Plants," In: D.A. Berkowitz and A. M. Squires (eds.), Power Generation and Environmental Change, MIT Press, Cambridge, Mass (1971).

17. "Air Quality and Stationary Source Emission Control," Committee on Natural Resources, National Academy of Sciences, National Research Council, for the U.S. Senate Committee on Public Works, Serial No. 94.4, p. 599-610 (March, 1975).

18. L.B. Lave and E.P. Seskin, "An Analysis of the Association Between U.S. Mortality and Air Pollution," J. Am. Statistical Association 68: 284-290 (1970).

19. W. Winkelstein, Jr., et al, "The Relationship of Air Pollution and Economic Status to Total Mortality and Selected Respiratory System Mortality in Men: I. Suspended Particulates," Arch. Environ. Health 14: p. 162-171 (January, 1967).

20. "Mortality and Morbidity During the London Fog of December, 1952," Ministry of Health, Report No. 95, London, Her Majesty's Stationary Office (1954).

21. H.H. Schrenk, et al, "Air Pollution in Donora: Epidemiology of the Unusual Smog Episode of October, 1948," Preliminary Report, Public Health Bulletin No. 306 (1959).

22. H. Schimmel and L. Greenburg, "A Study of the Relation of Pollution to Mortality; New York City, 193-1968," J. Am. Pollution Control Association 22 (No. 8): 607-616 (August, 1972).

23. C. Norman, "Castles in the Air," Nature 264: 394 (December 21, 1976).

24. L.A. Sagan, "Health Costs Associated with the Mining, Transport and Combustion of Coal in the Steam-Electric Industry," Nature 250: 107-111, (July 12, 1974).

25. B. Commoner, "the Poverty of Power," Alfred A. Knoff, Inc. (Subsidiary of Random House, Inc.), New York, N.Y. (May, 1976).

26. J.E. Yocon and N. Grappone, "Effects of Power Plant Emission on Materials," The Research Corporation of New England, for Electric Power Research Institute (July, 1976).

589 277

27. S.M. Barrager, B.R. Judd, and D.W. North, "The Economic and Social Costs of Coal and Nuclear Electric Generation," Stanford Research Institute, (March, 1976).

28. D.W. North and M.W. Merkhofer, "A Methodology for Analyzing Emission Control Strategies," Comput & Ops. Res 3:187-207, Pergamon Press, Great Britain 1976).

29. C.F. Baes, Jr., et al, "The Global Carbon Dioxide Problem," ORNL-5194 (August, 1976).

30. R.O. Pohl, "Health Effects of Radon-222 from Uranium Mining," Search 7(5), 345-350 (August, 1976).

31. N.W. Denson, et al, "Uranium in Coal in the Western United States," U.S. Geological Survey Bulletin 1055 (1959).

32. R.F. Abernathy and F.H. Gibson, "Rare Elements in Coal," Info. Circular 8163, U.S. Department of Interior, Bur. of Mines (1963).

33. M. Eisenbud and H.G. Petrow, "Radioactivity in the Atmospheric Effluents of Power Plants that Use Fossil Fuels," Science 148:288-289 (1964).

34. L.B. Lave and L.C. Freeburg, "Health Effects of Electricity Generation from Coal, Oil and Nuclear Fuel," Nuclear Safety 14(5): 409-428 (September-October, 1973)

35. "Comparative Risk-Cost Benefit Study of Alternative Sources Electrical Energy" WASH-1224, U.S. Atomic Energy Commission (December, 1974).

36. K.A. Hub and R.A. Schlenker, "Health Effects of Alternative Means of Electrical Generation," In: Population Dose Evaluation and Standards for Man and His Environment, International Atomic Energy Agency, Vienna (1974).

37. "Interim Report of the National Research Council Committee on Nuclear and Alternative Energy Systems," Assembly of Engineering, NRC/NAS, Washington, D.C. (January, 1977)

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