COMPARATIVE EFFECTS OF COAL AND NUCLEAR FUEL ON MORTALITY

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While information upon which to base risk assessment is often scanty, assembling the data available, organizing them in a way to facilitate choices among energy policy options, including evaluation of uncertainties, is a useful aid to decision-making. Since decisions usually involve choosing among different technologies, standardized comparisons are essential to avoid misleading results. For technologies producing the same form of energy (e.g., electricity) a standardized unit of production can be used, for instance, a 1000 mWe power-plant year. When comparisons must stretch across technologies producing different energy forms, (e.g., coal electric versus coal gasification versus coal liquefaction) the proper basis of comparison is not always obvious. Indeed, there may not be a totally satisfactory basis. Streams of electricity, gas, and oil with the same energy content are not really equal; they are used by the consumer for different purposes and with different efficiencies. This difficulty can largely be overcome by examining the impacts of complete energy systems made up of different technological mixes. Risk assessment must attribute risk to each component of the energy system. Valid comparisons can be made only between entire fuel cycles or between alternative energy systems. While we are not yet able to completely analyze environmental and health impacts from quantitative data for the entire energy system, current economic- and technology-oriented models use this integrated framework.[1]

A key part of risk assessment is estimation of population exposure. This might ideally be a compilation of the number and characteristics of people exposed to given kinds, levels, and combinations of risk. The compilation ideally would be sufficiently disaggregated to allow calculation of the joint frequency of various combinations of risk to which a single population might be exposed. The number of people exposed at each level of risk is important since the true health damage function (or dose-response function) is likely to be nonlinear. Joint frequencies of risk are important since combined exposures from multiple agents may have synergistic effects. Information on pertinent population characteristics would allow differences in susceptibility within the total population to be considered.

This ideal compilation would be very complex. Knelson[2] has suggested the framework of such a compilation which remains complex although synergisms among pollutants were not considered. Even were we to establish such a framework for analysis, however, current knowledge of dose-response relationships is insufficient to calculate effects of specific mixes of exposure levels to specific population subgroups except in rare situations. Available data are inadequate, for example, to adequately allocate the observed effect of air pollution to specific pollutants.

At this point, in our models, we are not considering synergisms. We attempt to define the population exposed and the degree of exposure, but treat the population at each exposure level as a single class. We also use linear damage functions. While these probably do not adequately represent the true effects over a wide range of exposure, we believe they are adequate to predict the effect of small changes of exposure within the general range of previous observation. Moreover, in our air pollution models we are generally allocating part of the total effect of air pollution to a specific source. A linear model seems completely appropriate for this use.

We measure mortality in "excess" or attributable deaths per power-plant year. "Excess deaths" is a convenient way to express changes in mortality rates. Although one expects only one death per lifetime, there can be more than the expected number of deaths in a population during a given time period. The time period we take is a year. Thus, an excess death represents at least one person-year of life lost, although for the most part we have only poor estimates of how much more than a year has been lost. If 130 coal miners are killed in accidents in the process of mining 300 million tons of coal, then there are 130/300 = 0.4 deaths per million tons of coal mined that would not have occurred had the coal not been mined. We can then apportion the attributable deaths based on the annual coal consumption of a power plant. In a strict sense this is not quite correct since there are competing risks. The miners would face other risks were they not in the mines. In this case the correction would not seem to be a major one and the years lost might be approximated by the expected remaining lifetime of the rest of the population in the age group. Other classes of effects are not as simple. Excess deaths due to air pollution are derived from linear regression models relating mortality rates in Standard Metropolitan Statistical Areas with air pollution and socioeconomic variables.[3]

We are not very happy with excess deaths as a measure of health impact. It withholds much important information about the impact being measured. One cannot distinguish among an accidental death, a heart attack and a cancer, or among the death of a child, a young adult or a senior citizen. It is not exactly clear how one should weigh these factors or what other factors should be included, but we would like to include more information of this type. There is a problem in the data as well as in the conceptual formulation. In many instances we do not have sufficient knowledge to estimate years of life lost per death very well for example.

The difficulty in using excess deaths as our measure is compounded by the confusion over the goal at which we are aiming. It has become general practice to total up the number of deaths that can be attributed to nuclear power or coal or to auto accidents, smoking, etc. Since the analysis is done to affect decisions, the implicit notion is that we should act to reduce the total numbers of deaths. I believe a major philosophical question arises over whether one should treat well-defined deaths such as accidental fatalities among coal miners the same as deaths that can only be calculated by extrapolation, such as deaths in the general population caused by air pollution or radiation exposure. To some degree, this can be handled by taking the level of uncertainty associated with the estimated number of deaths into account. The level of individual risk can have importance as well as the total number of deaths. A high risk of accidental death among a few coal miners may be perceived differently than an infinitesimally small additional risk assumed by a large population, even though the absolute number of annual excess deaths may be the same. In some cases this may be a function of the state of knowledge. Coal miners are a well-defined group and the 100 or so that die annually in mine accidents are easily counted and attributable to coal mining. There may be a group within the general population exposed to air pollution from coal combustion that has a particular, but undetected, constitutional susceptability to air pollution health damage. People in that group may face an individual risk as high as a coal miner. Until such a population can be defined and its level of risk determined, however, we perveive the effects of air pollution as spread over the entire population at a very low individual risk level. There have been some attempts to derive damage functions for specific groups believed to be at high risk to air pollution, to determine the exposure level of these groups and calculate the impact in that manner.[4] One might also hypothesize, however, that everyone is affected at least to some degree.

Table 1 provides two measures. The total risk, in excess deaths per power-plant year, and the individual risk, in excess deaths per power-plant year per person. The latter might be taken as the increased probability that an individual in the exposed population will die in a manner attributable to the operation of a power plant or part of its supporting fuel cycle for a year. To the extent that attributable deaths from different causes in different populations are considered equal, the total effects are additive. The individual risks are additive only when the same population is involved in each case. In addition to a goal of decreasing total attributable deaths, disproportionately high levels of individual risk should indicate areas of concern.

The level of individual risk in Table 1 provides only a crude estimate of the range of effect on the individual. The number of people exposed to the risks of an activity, particularly among the public, and the distribution of exposures among that population varies greatly according to the location and the specific design of the facility. Average population density alone differs by more than two orders of magnitude between the Middle Atlantic and the West North Central regions of the country. Differences among individuals in the exposed population are not considered in the tabulation. These differences could include individual activity patterns that enhance exposure, concurrent exposure from other sources (e.g., smoking or occupational exposures), or individual variations in susceptability to a given environmental stress. Thus the individual risk levels given must be taken as merely crude guidelines subject to much more uncertainty and variability than the total effects.

Most of the kinds of health impacts quantified in Table 1 are either occupational effects that occur frequently enough in well-defined populations so that sufficient data are available from which to make reasonable estimates of risk or, particularly in the case of radiation exposures, exposure situations for which established methods of estimating health impacts are available.

Underground mining is a dangerous occupation as can clearly be seen from the risk levels for underground coal mining in Table 1. Underground and surface mining are combined for uranium mining in the table since the fuel from both are combined in the cycle well before the power plant. A coal-fired power plant, on the other hand, is usually served from one or from a well-identifiable group of mines. The major difference in total deaths between coal and uranium miners stems from the higher energy content of the nuclear fuel. It requires only about one-tenth the man-days of effort in the mines to fuel a 1000 mWe nuclear plant compared to a similar coal plant. The wide range in estimates of disease-related deaths in coal miners stems from a wide range of disease rates among different coal mining regions, difficulty in attributing an appropriate share of observed disease deaths among miners to their occupation, and uncertainty in the efficacy of recently mandated improvements in the mines.

Transport accidents in the coal fuel cycle range from mine-mouth plants with essentially no transport to fairly long distance transport by rail involving the risk of railroad associated accidents. The largest share of these are train-auto collisions at grade crossings. Although the individual risk level in the table is calculated as if the entire population of the country were at risk, the true exposed population is probably limited to people living near major coal train routes. The individual risk might then be an order of magnitude or more higher. The routine impact of transporting nuclear fuel is very small relative to coal because of the much smaller mass of material to be handled.

An exception to the notion that the risk estimates are fairly well defined is the health impact of air pollution from coal combustion. We have spent considerable effort attempting to estimate this impact and to define the uncertainty associated with these estimates.[5,6] Our models are based on the currently held theory that the principle agents of health damage are sulfate compounds mainly resulting from SO_2 emitted from tall stacks undergoing chemical reaction in the atmosphere.[7] Uncertainties in both the toxicological and epidemiological studies linking sulfate compounds with health effects are such that the possibility of no effect is not foreclosed. The bulk of the evidence, however, suggests that there is an effect. Local estimates are based on stocastic models developed at Brookhaven by Morgan, <u>et al</u>.[6] They are based on typical 1000 mWe power plants with tall stacks in the western Pennsylvania area. (These plants have an average of 2-4 million people within the 80 km radius.) Emission rates have been adjusted to match current New Source Performance Standards. Although the range is from 0-24 excess deaths annually, the expected value is about 4. Due to limitations in the meteorological model, rather than any physical break-point, the exposed population is limited to an 80 km radius. Current work with long-range transport models being developed in Brookhaven's Atmospheric Sciences Division suggests that the effect on more remote populations may exceed the local effects by as much as an order of magnitude.[8]

Sulfates are not the only pollutant of health concern from coal power plants. Lundy has estimated the impact of polycyclic hydrocarbon emissions to be in the range of 0-4 excess deaths per power-plant year.[9] Various toxic trace metal emissions could be of concern, but probably have a much smaller direct impact than the sulfur and polycyclic hydrocarbon compounds.[10]

An additional impact which has considerable uncertainty and controversy associated with it is the possibility of major radiation releases associated with catastrophic events, particularly from nuclear power plants. These are not shown explicitly in the table, but the annual expected value of these highly unlikely events is so low that it does not significantly affect the totals. The major work in this area has been the Atomic Energy Commission sponsored Reactor Safety Study (Rasmussen study) which estimated the expected annualized loss of life from nuclear power plant accidents as 0.02.[11] One can argue that the population is strongly a risk avoider for very large accidents. One way to take this into account is to multiply the annualized impact by a weighting factor before comparing it with effects which happen routinely. A weighting factor of 100 (which seems very high) is needed to even put accidents into the range of routine effects.

It has been suggested that the Rasmussen estimates may be too low. Most suggestions are by a factor of 2 to 10. The recent report of the Nuclear Energy Policy Study Group states that "...the WASH-1400 estimate could be low by a factor of as much at 500."[12] With this estimate, fatalities due to nuclear fall within the range of estimated effects of coal, but a direct comparison is not a fair one. This was not put forth as a best estimate as the Rasmussen number was, but as an upper limit. It is based on the very pessimistic assumptions that (1) the probability of a core meltdown is 5×10^{-3} per reactor year, 100 times more likely than estimated by Rasmussen and high enough that were it the true value we have been quite lucky not to have had a core meltdown yet; (2) the probability of emergency core cooling system (ECCS) failure of 1.0; (3) probability of breach of containment of 0.2 (twice the Rasmussen estimate) and (4) three to four times the average fatalities predicted by Rasmussen given a major accident. The fact that an estimate very far out on the tail of the nuclear effects distribution intersects the coal effects distribution does not negate the clearly significant difference between the estimated health effects of the two energy forms.

There is a fair possibility that coal electric has a relatively much greater impact on mortality than nuclear. The reverse does not seem to be true. Some degree of perspective is necessary, however. Neither coal nor nuclear has a very big impact on mortality relative to other factors. Were the high end of the coal range to prove correct, a large increase in coal fired electric power might bring the impact up to 5 to 7 percent of total mortality--a big effect. This could be reduced considerably by stricter controls on sulfur emissions, a step already being considered by the Environmental Protection Agency. It is more likely that the effects are considerably lower, around 1 percent of total mortality attributable to coal and nuclear power. This must be compared to 2 to 3 percent from automobile accidents and 17 percent attributable to smoking. It is my personal conclusion that while we must continue to do our best to reduce the total effects from both coal and nuclear electric generation, the primary emphasis should be placed on areas such as coal and uranium mining where the highest individual levels of risk are faced.

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Table 1

MORTALITY RISKS IN COAL AND NUCLEAR FUEL CYCLES
(TOTAL RISKS ARE PER 1000 mWe PLANT YEAR)

ACTIVITY	COAL		NUCLEAR	
	INDIVIDUAL RISK	TOTAL RISK	INDIVIDUAL RISK	TOTAL RISK
Mining				
Underground - Accident	1×10^{-3}	0.5 - 1.1		
Surface - Accident	7×10^{-4}	0.2	3×10^{-3}	0.09 - 0.2
Underground - Disease	$4 \times 10^{-4} - 3 \times 10^{-2}$	0.2 - 13	8×10^{-4}	0.04
Processing				
Occupational Accidents	6×10^{-4}	0.04	$\sim 1 \times 10^{-5}$	0.004
Occupational Disease	-	-	$0\text{-}1 \times 10^{-4}$	0 - 0.03
Transport				
Accidents	$0\text{-}4 \times 10^{-8}$	0 - 4	$\sim 10^{-10}$	0.01
Electric Generation				
Occupational Accidents	1×10^{-4}	0.01	1×10^{-4}	0.01
Local (80 km) Disease	$0\text{-}8 \times 10^{-6}$	0 - 24	$0\text{-}3 \times 10^{-9}$	$0\text{-}6 \times 10^{-2}$
Global Disease	$(0\text{-}3 \times 10^{-6})$	(0 - 240)	$0\text{-}2 \times 10^{-11}$	0 - 0.1
Waste Management				
Disease	-	-	-	0 - 0.04
Totals		0.3 - 300		0.1 - 0.5