# IMPACT OF INCREASED USE OF COAL ON HEALTH AND THE ENVIRONMENT

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*Introduction*

The United States — and the world in general — can anticipate a tremendous increase in the use of coal over the next 20 years. In the early 1970s, economists and energy people were suggesting that coal use in America could double by the year 2000. Now, estimates of a tripling by 2000 are commonly heard. Even with a "no growth" economy, the United States will need an additional 30 quads (1 quad = $10^{15}$ BTU) of energy by 2000. That additional energy will almost certainly come from some combination of coal and nuclear plants. Signs now point to coal shouldering the major burden of that need.

The contribution from geothermal or solar technologies cannot be expected to be significant over the next 20 years. Under any energy-use projection, coal plays a significant role, and at least a doubling of coal use by the end of the century seems likely.

A marked increase in the use of coal is certain to raise a number of national concerns — from problems of reclaming mining areas to questions about pulmonary dysfunction and air pollution. As a nation we must face these questions of environmental effects of increased use of coal. Certainly, an increase in coal use has the potential for causing a wide range of undesirable effects. This paper will deal with only one aspect of coal use, the effects on the environment especially those related to atmospheric emissions.

A major problem in discussing the environmental effects of increased coal use is the absence of enough data to document effects from present use. This is particularly true for questions about atmospheric pollution. We can see the effect of strip-mining on soil cover. We can tabulate the number of fatalities due to mine accidents. We can estimate the incidence of coal workers' pneumoconiosis. We have difficulty, however, in assessing the quantitative effect of stack emissions on population mortality or morbidity. Similarly, we cannot yet define the utilities' contribution to acidic precipitation or to visibility degradation.

Because of our inability to assess quantitatively the present impact of coal use on the environment, we are in no position to state with certainty the consequences of a two-fold or three-fold increase in coal burning. At best, we can point out general areas of concern and give an indication of what specific problems society may be facing. Such will be the approach used in this paper. The areas of concern to be considered are health effects, ecological damage, visibility degradation, and climatic change.

*Human Health Effects*

Expansion in coal combustion has led some investigators to predict significant health impacts on the general population. This must be considered if coal combustion is to be increased substantially. In these assessments only the effects of combustion of fossil fuel products were considered. Not considered were the sizable penalty of increased injuries and deaths in that most dangerous of occupations — coal mining, and the injuries and deaths associated with both the transportation of coal over long distances, and the construction of massive coal-burning facilities.

The two products of fossil fuel combustion which appeared to be of greatest concern to these investigators were sulfur dioxide ($SO_2$) and particulate matter, especially sulfates. Based on increased emissions of $SO_2$ and particulates, predictions have been made that significant effects on human health — particularly premature mortality — may be expected as a consequence. This, in part, is based upon historical experience. The fact that air pollution could adversely affect human health is a relatively recent concept. A most dramatic and well known example occurred in December 1952 in London when, during a week-long atmospheric inversion, combustion products were trapped near ground level and smoke and $SO_2$ (the only two pollutants then being measured) rose markedly.

Concomitant with the rise in combustion products, daily deaths jumped from the normally anticipated 250 per day to over 800.[1] During the week long inversion episode 4,000 more persons died than would normally have been expected to do so in that time period. Virtually all of these deaths occurred in persons with chronic cardiac and pulmonary disease whose respiratory tracts were already severely compromised. The deaths, in almost all cases, could be considered only an acceleration of a process already well underway.

Nevertheless, the fact that air pollution could precipitate premature mortality was dramatically illustrated, and led to the passage of a Clean Air Act designed to reduce the likelihood of subsequent episodes. In 1956 a Clean Air Act was passed in Britain requiring the introduction of cleaner fuels low in volatile matter and particulates. No attempt was made to limit either ambient air concentration of $SO_2$ or the amount of sulfur contained in the fuels used.

This resulted in a dramatic reduction in the smoke and smog traditionally considered part of the London scene.

It is noteworthy that although smoke (particulate matter) measure in micrograms per cubic meter fell rapidly after the passage of the British Clean Air Act, a steady decrease in smoke had been in effect for many years previously as more efficient heating devices had been introduced into British homes. Although particulate matter consistently fell, $SO_2$ which the British made no effort to control, also decreased but to a much lesser extent. In part this was due to the lower sulfur content of the cleaner fuels used in British home fireplaces, but also because a decrease in smoke allowed greater penetration of sunlight with ground warming and dispersion of atmospheric inversion conditions.

A natural experiment occurred exactly 10 years later in London when in 1962 atmospheric conditions similar to those of December 1952 obtained and concentrations of $SO_2$ rose to almost identical levels. However, the smoke (i.e., particulate) levels during the 1962 fog were much lower. The premature deaths in 1962 were limited to 700 as opposed to 4,000 in 1952.[2] Today with introduction of cleaner anthracite and a considerable amount of centralized heating, both smoke and $SO_2$ levels have been reduced to a point where no further correlation can be discerned between respiratory disease or deaths and the varying peaks of air pollution that occur several times each year in London.

It is important to note that the earliest measures of air pollution were of $SO_2$. This was measured by decolorization of potassium iodide, and of particulates measured either as total particulates gathered by a high volume sampler over a 24 hour period, or as smoke shade measuring smaller particulates in the respirable range. These substances were monitored during the previously described acute pollution episodes when premature mortality was observed, and because simple techniques existed for their measurement. They were, however, by no means the sole constituents of the pollution prevailing throughout industrial conurbations.

Obviously many substances are released during fossil fuel burning. These include carbon dioxide, sulfates, oxides of nitrogen, nitrates, and numerous trace elements in varying chemical composition depending upon the composition and combustion conditions of the fossil fuel being burned. To these must be added the numerous effluents derived from industrial processes in the same area. Pollutants also are generated by the general activity of the population including transportation, space heating, and cooking.

It was assumed by the earliest investigators that the two pollutants most easily monitored ($SO_2$ and particulates) could be expected to bear a linear relationship to the presence of all these other compounds. Sulfur dioxide, and/or particulates, were thus used as surrogates for general atmospheric pollution. As time passed the continued reporting of air pollution levels in terms of $SO_2$ and particulates spread the impression — not intended by the pioneering investigators — that these compounds themselves were responsible for the health effects observed. This assumption led to serious errors in assessment of health effects of air pollution, and to drastic, and probably unnecessarily strict regulation of $SO_2$ emissions.

Both animal toxicologic and controlled human experiments do demonstrate transient changes in pulmonary function on exposure to $SO_2$ levels at five to ten times maximum levels presently measured in any urban area. There is no evidence from animal toxicologic studies, controlled human exposures or epidemiologic observations that $SO_2$ at prevailing levels, or at levels two or three times those presently permitted, pose any threat to human health.[3] Nevertheless, millions of dollars have been spent to reduce ambient levels of what virtually all scientists knowledgeable in this field now agree is an innocuous compound in the concentrations in which it is presently found in the air of our cities.

New Source Performance Standards mandated by the Environmental Protection Agency (EPA) will require an estimated expenditure of at least $200 billion between now and the end of the century to further control $SO_2$ emissions from coal combustion.[4] No one has been able to demonstrate that any comparable improvement in the public health will result from this enormous expenditure which will be borne by the general public through rising utility bills.

The experience of New York City in this respect has been instructive. In 1965 the New York City government decided to reduce ambient $SO_2$ levels by limiting the sulfur content of oil burned in the city to 1 percent. At considerable cost this was accomplished by paying premium prices for low sulfur coal and desulfured oil. In 1970 even stricter standards were mandated by the federal government which made it necessary to limit the maximum concentration of sulfur in New York City fuels to 0.3 percent. It is estimated that this represented an additional cost to New York City's citizens of $200 million per year at 1970 oil prices. Such an expenditure certainly could be justified if some concomitant improvement in health could be demonstrated as a result.

The traditional measure of premature mortality which had been used for many years in association with acute air pollution episodes was applied to the New York City population for this time period by Schimmel and his colleagues. By exhaustive statistical analysis, no impact whatever could be demonstrated on total death rates in New York City as a result of the lowered ambient $SO_2$ levels.[5]

When deaths from respiratory, heart, circulatory diseases, and cancer as a group (diseases which might most logically be associated with air pollution) were compared with $SO_2$ levels, again no correlation could be demonstrated. Interestingly enough, the lack of any correlation between $SO_2$ levels and daily mortality in the 1970s could also be demonstrated in the 1960s before sulfur content of fuel oil was restricted.

*Acid Sulfates*

As the innocuous nature of $SO_2$ at prevailing ambient levels has become widely accepted by the scientific community, those attempting to incriminate sulfur emissions as hazardous to human health have focused their attention on the more highly oxidized states of sulfur and particularly sulfates. With restriction of sulfur content of fuels, ambient air concentration of sulfates also showed a marked decline, although not as great as $SO_2$. As early as 1957, Dr. Mary Amdur demonstrated a wide range of irritant potency of sulfates in a sensitive guinea pig model.[6] Sulfuric acid ($H_2SO_4$) was found, not surprisingly, to be the most irritating of the sulfate species.

Ranking below sulfuric acid were sulfates with various metallic cations of which the transition metals prove to be the most irritating. Irritant potency descended rapidly to an extremely low level with ammonium sulfate and other less reactive cations. Ammonium sulfate proved to have less than one tenth of the irritant potency of sulfuric acid.

These animal toxicology studies become of tremendous importance when translated to the real world since the vast majority of sulfate ($\geqslant$90 percent) in ambient air is in the form of the innocuous ammonium sulfate ($(NH_4)_2SO_4$). Exposure of both healthy and asthmatic volunteers for two hours in controlled environmental exposure chambers has failed to elicit any demonstrable effect on health by exposure to $(NH_4)_2SO_4$ at levels 10 times those reached in the most polluted cities.[7] A small fraction of sulfate ($\sim$3-5 percent) is present as $H_2SO_4$. Even this fraction, however, would appear to have little significance for human health since recent human experimental work has demonstrated ammonia production in the secretions of the upper respiratory tract is more than sufficient to neutralize any sulfuric acid which may be inhaled before it can reach the lung.[8]

Ammonium sulfate and, to a much less extent sulfuric acid, comprise the vast amount of sulfates present in ambient air. Typically, less than 5 percent of sulfates are found with a metallic cation. Although most transition metals are found in most coals, they are present only in minute amounts. The sources of these metals in ambient air are therefore more likely to arise from industrial processes other than coal combustion, or as effluents from various human activities.

Antedating the fall in $SO_2$ levels in New York City air has been a marked decrease in particulates. As in London, this decrease long preceded our Clean Air Act. This steady decrease can be attributed to many factors: among them a substantial change from coal to oil and gas for home heating and power generation; phasing out of individual apartment house incinerators; and improved control technology for particulate emissions.

The introduction of electrostatic precipitators and other control technology ensures that a return to coal for power generation will not result in the heavy particulate loadings of 40 years ago. Unlike $SO_2$, fine particulate levels in ambient air appear to show a small correlation with several measures of health effects, but the specific compounds responsible for any of these effects remain to be identified. Study should be directed to whether there may be greater health benefit in removing fine particulate matter (which includes sulfates) from fossil fuel flue gases with a baghouse or other fabric filter, than could be expected from wet scrubbing of effluents to remove $SO_2$ as proposed by EPA.

Since some of the sulfate and nitrate compounds present in fine particulates have been shown to be innocuous in human-controlled studies at levels well above present ambient levels in our most polluted cities,[9] increased attention is being directed to the metallic cation associated with the sulfate or nitrate. Since most of the transition metals are highly reactive and readily enter into biologic reactions, their role in disease causation needs to be assessed further.

*Oxides of Nitrogen*

In addition to the sulfur oxide-particulate complex, another class of pollutants produced in fossil fuel combustion are the oxides of nitrogen. Of these, nitrogen dioxide ($NO_2$) carries the greatest potential for adverse effects on human health. Only half of ambient air $NO_2$ can be ascribed to stationary sources since the automobile is also a major contributor. Oxides of nitrogen produced whenever any substances burn at high temperatures in air can be controlled to a large extent by altering combustion conditions. Virtually all of the oxides of nitrogen derive from the elemental nitrogen present in air, rather than from the nitrates present in coal. They would be, therefore, formed in any combustion process regardless of what substance is burned to provide energy.

In any case a wider margin of safety exists between ambient air levels of $NO_2$ and levels at which toxic effects may appear than for any other regulated air pollutant. Since some oxides of nitrogen will end up as nitrates, pulmonary studies are being carried out to determine the possible effects of these compounds on human health. Initial studies indicate that as with sulfates, ammonium nitrate, the commonest species formed, is also innocuous to human health.[9] Further studies using various metallic cations are presently being carried out.

From the above evidence, it can be deduced that $SO_2$ at prevailing ambient air levels is an innocuous substance with no implications for human health. It can also be deduced that sulfate in ambient air also carries no significant implication for human health. In fact, of all components of fossil fuel combustion only fine particulate matter (particle sizes below 10 $\mu$m) appear to have even a slight correlation with adverse health effects. Since particulate emissions can be controlled by appropriate techniques, it follows that even a doubling of our present combustion of coal would produce no detectable adverse human health effects. I am confident that none of the statistical indices by which we customarily measure human health would show any significant perturbation should our use of coal be doubled or even tripled when burned with appropriate control technology.

In any case, numerous studies by many investigators have repeatedly shown air pollution to be a far smaller contributor to disease causation than weather, socio-economic and demographic factors, occupational exposures, and personal health habits. All of these overshadow community air pollution by at least an order of magnitude in association with disease or death in man.

Some investigators have claimed that hidden within the nearly two million deaths occurring yearly in the United States are more than 100,000 premature deaths which can be related to fossil fuel combustion products — particularly sulfates.[10] These figures are obtained by taking death rates for Standard Metropolitan Statistical Areas (SMSA) and regressing them against a series of socio-economic and demographic factors for each area and against two measures of air pollution. Using this technique they have claimed to find a positive relationship between air pollution levels and numbers of deaths. However, the data base from which these conclusions are drawn is severely flawed.[11] Furthermore, the same technique can be used to show that socio-economic factors alone can account for all of the variance in mortality between different SMSA.

In turning to coal to supply an increased portion of our energy needs, we can do so with confidence that usage of appropriate control technology will prevent any significant adverse effect on the health of our population. However, because of the costs of pollution control, be they fuel cleaning, use of lower sulfur fuels, or control of gas effluents, we must be certain that our controls are effectively reducing those components of pollution that may be related to adverse health effects. We should guard against the expenditure of large sums of money to remove components of stack gas effluents which may be of no significance to human health.

Using these criteria the expenditure of billions of dollars to remove sulfur oxides is difficult to justify. Also, from a health standpoint, removal of large particulates which have no relation to human health or functioning is similarly difficult to justify.

Control of small particulates in the respirable range, however, may well be an appropriate step to take.

This discussion is concerned only with possible adverse effects on human health of fossil fuel combustion products. Other effects such as possible acid deposition or reduction in visibility may be related to some of the pollutants discussed. Whether society wishes to pay the costs of removal of specific pollutants for benefits in these areas is a societal judgment. If the answer be "yes", we should admit that it is for one of these reasons that we are interested in control technology. Unless adverse effects on human health can be clearly demonstrated by pollutants at present ambient levels, human health should not be cited as the rationale for their control.

One additional important factor relating to electric power generation should also be considered in any assessment of health costs of power generation. This is the impact on health from a shortage of electricity due to reduced power generation, or to substantial increases in the cost of electricity and in the cost of fuel for home heating due to attempts to further lower $SO_2$ levels in stack emission either by installing expensive control technology, or by mandating expensive low sulfur fuel. Directly observable health effects may be anticipated from such actions.

Episodes of excess mortality such as those occasionally observed with the acute air pollution episodes of past decades are now only seen in two instances: influenza epidemics and heat waves. The impact of an influenza epidemic on a community is customarily measured by excess deaths reported from pneumonia and influenza.[12] Such epidemics, in spite of immunization programs and antibiotics, occur with deadly regularity every few years and take a toll of tens of thousands on each occasion.

If higher electricity or fuel costs result in inadequate heating as is often the case for the aged and poor in our cities, pneumonia rates and deaths will predictably rise.

The only other dramatic perturbation in daily death rates is the instantaneous tripling, or more, of deaths accompanying a heat wave.[13] An abrubt rise in temperature in summer in major cities has been repeatedly shown to be associated with an immediate rise in deaths, largely among the already ill and the elderly. In recent years as air conditioning has become more widely spread in nursing homes and hospitals such peaks have largely disappeared. A significant increase in electricity costs, however, could force some such institutions to curtail this amenity and an immediate rise in deaths during heat waves would be the result.

Less dramatic, but equally real health costs which can be anticipated with more expensive electricity and more costly fuels are deaths from hypothermia, and deaths associated with attempts at supplemental heating such as burns and carbon monoxide poisoning.

Each year many thousands of elderly persons living in inadequately heated homes are found dead. Although their deaths are usually listed as due to heart attack, stroke or arteriosclerosis, careful investigation has demonstrated that many are actually due to hypothermia from inadequate heating.[14]

Each winter fires also take a toll of small children in poorly heated buildings when attempts are made to supplement heating with kerosene stoves or other dangerous substitutes. A further toll is also exacted by deaths from carbon monoxide poisoning when supplemental home heaters are inadequately ventilated.

All these health costs are real and must be balanced against any anticipated benefit from reduced $SO_2$ levels achieved by costly scrubbing of stack effluents, or by burning of expensive desulfured fuel. Since no detectable excess mortality can be found ascribable to $SO_2$ or sulfates at presently prevailing levels, money used to reduce these levels still further might be better used for other public health purposes.

*Ecology*

The effect of coal burning on ecosystems is a concern for three reasons: (1) the operation of cooling systems may affect quatic biota; (2) terrestrial flora may be affected if ground water becomes contaminated by drainage from ash-disposal areas; and (3) acid precipitation may be harmful to ecosystems.

Acid precipitation is probably the one greatest concern at present. People are concerned about acid precipitation because the burning of coal adds sulfur and nitrogen oxides to the atmosphere. These oxides, by some physico-chemical process, are incorporated into water drops which then become acidic and later cause acid precipitation. The acidic precipitation may then affect plant growth and acidify surface water, thereby increasing mortality of aquatic species. Increasing acidity has been reported in lakes in the Adirondack Mountains of New York State and fish kills have also been reported from that area.

Before coal combustion can be cited as causing the deleterious effects, however, a certain sequence of events should be documented. Firstly, we must show that the lake acidity killed the fish; secondly, that the rainfall caused the lake acidity; thirdly, that power plant emissions are responsible for acid rain. In some parts of the world, we know that fish kills have occurred[12] but we do not know the mechanism by which the mortality was increased, even if we can document that acid rain in itself caused the lake to become acidic. Finally, we have no idea how acid rain is actually formed, hence we cannot identify the role of coal burning in its formation.

Extensive research is underway over the North Sea to study the in-cloud processes that cause acid rain to form. A major effort is also in progress to study causes of lake acidity in the Adirondacks — a challenging area of study because of the proximity of three lakes to each other, each lake having different pH values yet each receiving nearly identical rainfall.

Some claims have been made that rainfall over the past 20 years has been getting more acidic in the eastern U.S. and that the area receiving acid rain is getting larger. A careful examination of the data in the published papers, however, shows that such conclusion cannot be fully supported. Before one can postulate changes for different time periods, one must compare the nature of rainfall at identical stations. If data only from identical stations are compared, no trend in changing acidity of rainfall can be discerned. We know that acid rain falls but we cannot quantify damage to ecosystems nor do we understand the mechanism by which such rain is formed. As a result, we cannot assess the impact of coal burning in causing acid precipitation, hence we cannot evaluate what role the increased use of coal will play.

The concern over damage to aquatic biota from cooling operations is real; however, again the net effect of power plant operation cannot yet be specified. The complexity of population dynamics makes any net assessment difficult until more research on the subject is completed. Similarly, the effect of waste disposal on ground water chemistry and then on terrestrial ecosystems is very poorly understood. We do not yet understand the physico-chemical nature of solid waste (ash and sludge), hence we cannot predict what toxic components will be leached. Nor can we calculate sorption by soil or plant uptake from soil of many trace metals. Again, we face a complex problem with many facets, few of which are quantitatively understood.

*Visibility Degradation*

Atmospheric sulfate occur in a size range that can scatter light enough to impair visibility. But again, the quantitative relations are lacking. A number of correlations between visibility and ambient sulfate levels have been reported. Trijonas[15], for example, related sulfate concentrations to visibility at airports. Such correlative relations have two problems. Firstly, the visibility values themselves have a large uncertainty; secondly, the sulfate values are based on early measurement techniques which we now know tended to result in more sulfate being reported than actually was present (because of sulfate formation from $SO_2$ on the collecting device). Admittedly, it has been observed that visibility increased in the Southwest during a smelter strike when no $SO_2$ was being emitted, but increased visibility has also occurred when the smelters were operating.

The visibility question centers around quantification and our ability to relate degradation to coal burning. Admittedly, sulfate will affect visibility but a quantitative relationship in the real world is still wanting. More obscure is the quantitative relation between atmospheric sulfates and their emitted precursor, $SO_2$ and ambient concentration of sulfate, hence we cannot assess how sulfate levels will change as a function of $SO_2$ emissions.

Many examples can be cited of reduction in $SO_2$ concentration but no concomitant reduction in sulfate level. The sulfate concentration in the atmosphere apparently depends on a number of factors, among which meteorological conditions are very important. As a result, even though we can calculate the effect of increased coal burning on $SO_2$ emissions, we cannot know what effect those emissions will have on sulfate concentrations, hence on visibility degradation.

*Climatic Change*

Over the past 2 to 3 years, a noticeable interest in $CO_2$ emissions (and in atmospheric $CO_2$ levels) has developed. The interest centers around the concern that high $CO_2$ levels in the troposphere would block thermal radiation from the earth's surface, thereby increasing surface temperatures. Such temperature increases could cause major global climatic perturbations.[16] Many climatologists feel that a 1 to 2 degree rise in temperature might not be serious. A 4 to 5 degree rise, however, could be disastrous.

An important need is to establish what temperature changes might occur if we continue burning fossil fuels at an increasing rate. Unfortunately, making such a prognostication is fraught with many uncertainties. We know (from limited but high-quality observations) that atmospheric $CO_2$ concentrations have increased from about 315 ppm to about 335 ppm over the past 20 years.[16] And that increase can be accounted for if one allows half the $CO_2$ from fuel burning to stay in the atmosphere. Based on the observed increase, many scientists have projected a doubling of the pre-industrial $CO_2$ level by about the middle of the 21st century. Such a doubling could then cause an increase in global temperatures.

It should be obvious that any future temperature prediction is based on a number of contributing factors, each of which has an uncertainty. To make a prediction on temperature increases or climatic disturbance, we must first know energy demand over the next 50 to 100 years, as well as the fuel mix which satisfies that demand. And the demand, of course, is based on projected growth rates.

Knowing demand and fuel use, we should be able to predict $CO_2$ levels, assuming a particular global $CO_2$ cycle. Using such an approach, the doubling of the pre-industrial $CO_2$ level is estimated to occur between 2020 and 2090.[16, 17, 18] Taking into consideration the different uncertainties, Laurmann[19] has tried to approach the problem from a probability viewpoint. For example, for a 3 percent growth rate, the temperature rise in 2040 would be 2.5 degrees, with a standard deviation of about 100 percent. The likelihood of a 5 degree rise by 2040 is perhaps 20 percent. As great as these uncertainties are, they still assume a linear relation between $CO_2$ concentration and $CO_2$ production from fossil-fuel burning, i.e., approximately half the $CO_2$ produced by combustion remains in the atmosphere.

Without pressing the issue further, we can recognize a number of uncertainties: (1) the projected energy demand, (2) the mix of fuels needed to satisfy that demand, (3) the relation between $CO_2$ output and atmospheric concentrations, (4) the temperature rise resulting from an increase in $CO_2$ levels, and (5) the effect of a given temperature change on climate. Point 3 involves the overall global carbon cycle — a cycle for which much research is needed, especially the oceanic/atmosphere exchange, before meaningful projections can be made. Point 5 is also critical. Perhaps one of the weakest links in our ability to predict climatic perturbations is the uncertainty in existing climatic models.

Certainly, fossil-fuel burning will result in changes in atmospheric $CO_2$ concentrations but, with the present uncertainties in our knowledge, we cannot judge what the changes will be, what they will do to climate, or what the effect on society will be. By the year 2000, we do not anticipate drastic effects of increased $CO_2$ concentrations; however, the question of climatic change cannot be ignored. Further, the entire $CO_2$ question is a global, not national, problem.

*Conclusions*

The use of coal will almost certainly increase over the next 20 years, and that use will have an effect on the environment. At our present state of knowledge, however, we cannot quantify many of the anticipated effects. At best, we can identify potential hazards to the physical and biological environment and we can carry out a continuing research program to assess that potential in order to take corrective actions where needed. Such a research effort is actively underway by both industry and governmental groups. Hopefully, that research will provide the data needed to insure the environmental acceptability of increased coal use.

## REFERENCES

1. "Mortality and Morbidity during the London Fog of December 1952," Ministry of Health, London: Her Majesty's Stationery Office, (1954).
2. Scott, J. A., "The London Fog of December, 1962," *Medical Officer* 109:250 (1963).
3. Frank, N. R., M. O. Amdur, J. Worcester, and J. L. Whittenberger, "Effect of acute controlled exposure to $SO_2$ on respiratory mechanics in healthy male adults," *J. Appl. Physiol.* 17:252 (1962).
4. Eisenbud, M., *Environment, Technology, and Health*. New York University Press, New York, 1978. p. 284.

5. Schimmel, H., "Evidence for possible acute health effects of ambient air pollution from time series analysis: methodological questions and some new results based on New York City's daily mortality, 1973-1976," *Bull. New York Academy of Medicine* 54(11):1052 (1978).

6. Amdur, M. O., "The physiological response of guinea pigs to atmospheric pollutants," *Intern. J. Air Poll.* 1:170 (1959).

7. Hackney, J., W. Linn, and K. Bell, "Experimental studies of the human health effects of sulfur oxides," *Bull. New York Academy of Medicine* 54(11):1177 (1978).

8. Larsen, T., D. Covert, R. Frank, and R. Charlson, "Ammonia in the human airways: neutralization of inspired acid sulfate aerosols," *Science* 197(4299):161 (1977).

9. Kleinman, M. T., W. S. Linn, R. M. Bailey, M. P. Jones, and J. D. Hackney, "Effect of ammonium nitrate aerosol on human respiratory function and symptoms," Environmental Research (in press).

10. Lave, L., and E. Seskin, *Air Pollution and Human Health*, The Johns Hopkins University Press, Baltimore, 1977.

11. Landau, E., "Pitfalls in geographic pathology," *The Nation's Health* (1978).

12. Kilbourne, E., "Influenza pandemics in perspective," *J. Amer. Medical Assoc.* 237(12): (1977).

13. Buechley, R. W., J. VanBruggen, and L. E. Truppi, "Heat island = death island?" *Environ. Res.* 5(1):85 (1957).

14. Taylor, G., "Hypothermia in the elderly," *Brit. Med.* J 2(supplement):162 (1964).

15. Trijonas, J. and K. Yuan, Visibility in the Southwest, *EPA Environmental Research Series EPA-600/3-78-039,* 1978.

16. National Research Council, *Energy and Climate,* Nat'l. Acad. Sci. Washington, DC.

17. Niehaus, F., A non-linear tandem model to calculate the future $CO_2$ and $C^{14}$ burden to the atmosphere, *Intern. Inst. Applied Systems Analysis,* Rpt. RM-76-35, 1976.

18. Siegenthaler, U. and H. Seschger, Predicting future atmosphere $CO_2$ levels, *Science,* 199, 388, 1978.

19. Laurmann, J. A., Climatic change from carbon dioxide released by fossil fuel combustion (in press).