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USE OF HEALTH EFFECT RISK ESTIMATES AND
UNCERTAINTY IN FORMAL REGULATORY PROCEEDINGS:
A CASE STUDY INVOLVING ATMOSPHERIC PARTICULATES

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ABSTRACT

Coal combustion particulates are released to the atmosphere by power plants supplying electrical energy to the nuclear fuel cycle. This paper presents estimates of the public health risks associated with the release of these particulates at a rate associated with the annual nuclear fuel production requirements for a nuclear power plant. Utilization of these risk assessments as a new component in the formal evaluation of total risks from nuclear power plants is discussed.

KEY WORDS: Particulate health effects; nuclear fuel cycle; risk assessment;
risk management; regulatory proceedings.

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1. INTRODUCTION

It has been estimated that 323 thousand megawatt-hours (Mwhr) of electricity are required to manufacture and process the average annual fuel requirements of a 1000 megawatt nuclear power plant.^{1,2} Because of the magnitude of this requirement, the environmental impacts of the air emissions from facilities generating this electricity have been included as a consideration in the overall impact of the operation of nuclear power plants. The results of these considerations have, however, previously in general been that these air emission impacts are not significant on the basis of their small contribution (less than 0.02%) relative to the total of other national atmospheric emissions.³ The impact of the atmospheric emissions on the ambient air quality would not be expected to cause violations of Clean Air Act requirements.

In the operating license hearings for the Harris nuclear power plant, the Atomic Safety and Licensing Board (ASLB) ruled in favor of the argument that further analysis is necessary to determine the environmental impacts of effluents released in the uranium fuel cycle. Specifically, further testimony was considered necessary to quantitatively address the health effects of the coal combustion particulates released during the generation of electricity utilized in the uranium fuel cycle.⁴ The purpose of this paper is to (1) describe the scientific basis and results of a health effects risk assessment performed in response to the ASLB directives,⁵ and to discuss some of the constraints or factors that must be considered in cases such as this in which a risk assessment that involves uncertainty provides direct input to the formal risk management (regulatory) process.

The foremost constraint imposed on the analysis was that the particulate emissions to the atmosphere are 1154 metric tons (MT) per year as listed in

Table S-3, "Table of Uranium Fuel Cycle Environmental Data," given in Title 10, Part 51 of the Code of Federal Regulations (CFR). This listed emission rate is based on out-dated information, and, as is discussed later, actual emissions are currently considerably lower. Also, the analysis was constrained by the ASLB hearing process to consider only primary particulate emissions, even though Table S-3 also listed emissions of sulfur oxides and other pollutants.

2. AIR QUALITY AND EXPOSURE ANALYSIS

Of the 323 thousand megawatt-hours (Mwhr) of electricity given in Table S-3 as the total annual requirement for the fuel cycle for the model LWR plant, approximately 96%, or 310,00 Mwhr, is required to perform the uranium isotope enrichment step of the fuel cycle.² At present, there are three facilities that could provide uranium enrichment for the fuel for the Harris plant. These are the gaseous diffusion plants (GDPs) located near Portsmouth, Ohio; Paducah, Kentucky; and Oak Ridge, Tennessee. Power for the GDPs is drawn from utility grids, and because of the interconnections it is not consistent with actual conditions to completely associate increased electrical generation, and thus increased particulate emissions, with any specific individual power plant. Allocating the generation to the mix of plants in the utility grid, including hydro, oil, gas, and nuclear would, however, be inconsistent with the constraints that the particulate emissions are fixed at a level of 1154 MT/yr and associated with coal-fired generation.

The approach used in this analysis was to compare the results of three separate analyses that each assume the total electrical generation, and thus the total 1154 MT/yr particulate emissions, occurs alternatively at one of three coal-fired power plants that were constructed primarily to provide power

to the GDPs. One of these is the Joppa plant in Massac County, IL, which has 735 Mw of its 1100 Mw capacity "dedicated" to the Paducah GDP. The additional two plants considered were the Kyger Creek and Clifty Creek plants with capacities of 1086 and 1304 Mw, respectively.⁶ The Kyger plant in Gallia County, OH, and the Clifty Creek plant in Jefferson County, IN, are dedicated to the Portsmouth GDP, which had a 1980 total power requirement of 2260 Mw. In the remainder of this paper, only the analysis and results related to the Kyger Creek plant are presented; similar results were obtained for the other two plants.

An initial aspect of the risk assessment for this plant was the further characterization of the emission source. The value of stack parameters used in the estimation of plume rise for the Kyger Creek plant⁶ were: stack height, 305 m; inside stack diameter, 8.94 m; exit velocity, 33.5 m/s; exit temperature, 149° C.

The emission rate associated with the electrical generation for the uranium fuel cycle was assumed to be 1154 MT/yr as indicated in Table S-3. Table S-3, however, does not provide data on particulate size distribution, which is critical in the estimation of related health risks. Using available data for pulverized-coal fired boilers,⁷ an estimated 7900 MT of fly ash is emitted without controls, and approximately 10%, or 790 MT of the particles have diameters 2.5 microns (μm) or less; 35%, or 2760 MT of the particles have diameter in the range of 2.5 to 15 μm ; and the remaining 4350 MT of particles have diameters greater than 15 μm .

To obtain the Table S-3 particulate emission level of 1154 MT/yr, it must be assumed that only 85.4% of the 7900 MT/yr of ash carried in the flue gas is removed. This modest level of emission control can be achieved by various types of control devices. However, the relative rate of removal of different

particle sizes is dependent on details of control device design, which are not specified in Table S-3 or cited references. Because of the unknowns in the control device design used as a basis for Table S-3, a conservative approach was used in the analysis for this testimony in which it was assumed that all of the least harmful particulates greater than 15 μm are collected, none of the most harmful particulates less than 2.5 μm are collected, and the level of control on the midsize 2.5 to 15 μm particles is adjusted to give total emission rate of 1154 MT/yr. The result of this approach gives 790 MT/yr emissions of less than 2.5 μm and 364 MT/yr of emissions in the 2.5 to 15 μm range.

The above approach to characterizing the particulate emissions was designed to give an overall conservative result that overestimates health effects of the coal particulates. The actual Joppa, Clifty Creek, and Kyger Creek power plants emit particulates at a considerably lower rate than that given in Table S-3. For example, the Kyger Creek plant has an ESP with greater than 99.8% test efficiency and 99.4% design efficiency. This range of efficiencies gives estimated total particulate emissions of 16 to 114 MT associated with 323 thousand Mwhr generation. With the high removal efficiency of ESPs, a significant fraction of particles with diameters less than 2.5 μm is also removed. For example, using the calculation procedures given in Reference 7, it is estimated that approximately 70% of the 0-2.5 μm particle size range is removed with an ESP that has an overall removal efficiency of 96.5% for all particulates.

The air pollutant dispersion modeling conducted in the analysis was based on hourly data for wind speed and direction, temperature, and height of the surface mixing layer. For the Kyger Creek plant, this input data was obtained from surface and upper air data collected at Huntington, WV. The U.S.

Environmental Protection Agency (EPA) recommends that five consecutive years of data be used to obtain representative conditions and 1971-1975 data was used for the Kyger Creek site. A small difference in estimated concentration among the five years of analysis, as described below, indicates that selection of year of meteorological record does not change the overall conclusions of this testimony.

Topography can affect ground-level concentrations and was an input to the air pollutant dispersion model. At each location where the atmospheric particulate concentration was estimated, the elevation relative to the power plant was obtained from area maps compiled by the U.S. Geological Survey.

Ambient particulate concentration increments based on this data was estimated using the Industrial Source Complex (ISC) computer model.⁸ This is a standard model recommended by the U.S. EPA for use in air dispersion analysis for regulatory purposes. The ISC model has the capability to simulate particle removal by deposition, which results in lower concentrations, especially at distant receptor points. However, this feature was not utilized, which adds further to the conservatism of the analysis.

The particulate concentration and population exposure analysis covered a circular area of 50 miles radius with the power plant emission source at the center. The circular areas were divided into 360 grid cells with boundaries formed by radials at 10° increments and 10 concentric rings.

The accuracy of the ISC model applied to a single source is dependent on the application. The annual average concentration is used to quantify health risks and it is for such long-term averages that the better model accuracy usually results. As an example, a recent comparison between ISC predictions and monitored annual averages for particulates was performed in the vicinity of an industrial source in Minnesota.⁹ After the computed background from other sources was subtracted from the observed monitoring data, the ISC-

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predicted annual averages at 6 locations ranged from an underprediction of 17% to an overprediction of 6%. For shorter term averages, such as the 24-hour maximums, a lesser predictive accuracy of within a factor of approximately 3 to 5 is usual.¹⁰

The averaging times that correspond to the National Ambient Air Quality Standards (NAAQS) for particulates are annual averages and maximum 24-hour average concentrations. For Kyger Creek, the maximum annual averages using the available 1971-1975 meteorological data were 0.010, 0.009, 0.013, 0.011 and 0.013 $\mu\text{g}/\text{m}^3$, respectively, and 0.60, 0.53, 0.51, 0.47, and 0.71 $\mu\text{g}/\text{m}^3$ for the 24-hour maximum. Assuming the particulates are conserved in the atmosphere (no deposition or transformation) the particle size distribution in the atmosphere is the same as for the emission source, i.e., 68% less than 2.5 μm in diameter and 32% in the 2.5 to 15 μm diameter range.

For comparison the NAAQS primary standards (intended to protect public health) for particulates is 75 $\mu\text{g}/\text{m}^3$ for annual averages and 260 $\mu\text{g}/\text{m}^3$ for 24-hour maximums. Based on the estimates obtained in this analysis, the concentrations associated with the Table S-3 level of emissions would contribute only a very insignificant increment relative to the NAAQS.

An additional base for evaluating the significance of these concentrations is in comparison to increments allowable in "pristine" areas designated as Class I areas under the regulations for prevention of significant air quality deterioration.¹¹ In Class I areas the maximum increment in particulate concentrations allowable from new development is 5 $\mu\text{g}/\text{m}^3$ for annual average and 10 $\mu\text{g}/\text{m}^3$ for 24-hour maximum. Although there are no designated Class I areas within 100 miles of any of these power plants considered, the increment in particulate concentration from the Table S-3 level of emissions would not be cause for concern relative to these stringent standards even if they did apply.

No estimates were made of incremental particulate concentration beyond the 50-mile radius surrounding the power plants. This was not done for reasons similar to those expressed in EPA statements related to implementation of regulations for prevention of significant deterioration (PSD)¹¹: "the [EPA] Administrator intends to limit generally the application of air quality models to a downwind distance of no more than 50 kilometers. This is because dispersion parameters commonly in use are based on experiments relatively close to sources, and extending these parameters to long downwind distances results in great uncertainty as to the accuracy of the model estimates at such distances. Also, since the air quality impact of many sources falls off rapidly to insignificant levels, EPA does not intend to analyze the impact of a source beyond the point where the concentrations from the source fall below certain levels [$1 \mu\text{g}/\text{m}^3$ for annual average particulates]." From the computer calculations, for the 1154 MT/yr emissions, nowhere within the vicinity of the three power plants does the estimated annual average incremental concentration approach the $1 \mu\text{g}/\text{m}^3$ annual average recommended cut-off for PSD modeling and in the outer 40-50 mile (65-80 kilometer) band the mean of the annual average incremental concentration is only $0.003 \mu\text{g}/\text{m}^3$ for the Kyger Creek plant. Thus, based on EPA guidelines for PSD, estimation beyond 50 miles (80 kilometers) is not recommended.

The basic approach for computing human exposure resulting from the incremental ambient particulate concentrations was to estimate the population in each of the 360 receptor grid cells surrounding each of the three power plants. The estimated population in each cell is assumed to be exposed to the particulate concentration increment estimated for the cell midpoint.

Estimates of the population in each grid cell are derived from data collected by the U.S. Bureau of Census for block groups (in urban areas) and

enumeration districts (in rural areas). The population for each of the geographic units whose centroid is located within a grid cell is assumed to be totally located within that cell. The various other census data, e.g., population by age, sex, occupation, education, is also available. For this analysis the 1980 census data was used.

Within a 50-mile radius of the Kyger Creek plant the total estimated 1980 populations was 870,000. The total computed population exposure (sum over all grid cells of population times concentration) using the annual average concentrations was 2174 for Kyger Creek (mean of 1971-1975). The total computed population exposure using the maximum 24-hr concentration in each grid cell was 47,200 for Kyger Creek (mean of 1971-1975). The population-weighted average (sum of exposures divided by population) over all grid cells was $0.0025 \mu\text{g}/\text{m}^3$ for the incremental annual average particulate concentration and $0.054 \mu\text{g}/\text{m}^3$ for the maximum incremental 24-hour concentration (mean of 1971-1975). The population-weighted averages can be interpreted as the concentration to which the average individual in the area of analysis is exposed.

3. ASSESSMENT OF POPULATION HEALTH EFFECTS

In this section is quantified the likely extent of population health risks within the 50-mile radius of the power plants resulting from the primary particle emissions of 1154 MT/yr. Various morbidity and mortality health outcomes were considered, including both, chronic and acute* effects. Acute respiratory disease incidents and hospital respiratory disease emergency

* Acute (respiratory) morbidity indicates short-term illness such as pneumonia, influenza and common coughs, while chronic (respiratory) morbidity indicates persistent, long-term illness such as chronic bronchitis, bronchial asthma or other obstructive lung disease.

admissions were among the morbidity health outcome variables studied. For chronic morbidity, chronic respiratory disease prevalence was considered.

For acute mortality effects of particle pollution, daily long-term (time-series) mortality risk coefficients were used. For chronic mortality effects, cross-sectional mortality coefficients relating annual mortality and annual average pollution in a large number of Standard Metropolitan Statistical Areas (SMSAs) in the U.S. were employed. Finally, toxicologic evidence regarding exposures to particles at or near the projected pollution levels were reviewed.

Basically there were two available approaches to characterize the health impacts associated with the emitted particles. One was to rely heavily on EPA's recent criteria document on particulate matter and sulfur oxides,¹² and the second was to conduct or rely on a risk analytic approach oriented toward providing numerical exposure-response information.

The second approach was selected primarily because neither the EPA's criteria document nor the EPA Office of Air Quality Planning and Standards (OAQPS) staff review of the criteria document¹³ provide quantitative exposure/response information for concentrations as low as those projected for this study. The EPA documents were, however, used to guide the selection of toxicologic and epidemiologic data bases that could be used to derive exposure-response coefficients or relationships.

If the EPA criteria document had been used solely we could only have concluded, and only qualitatively, that the projected health effects associated with the particulate emissions would most likely be negligible and undetectable. To illustrate, Table 1 summarizes the levels of baseline and

(Table 1 about here)

incremental particle pollution impacts in the geographic area studied. Since most of the projected concentration impacts are extremely small, the changes in the ambient particulate levels surrounding the three plants are negligible, and the baseline or background plus incremental concentration is on the average, are less than $70 \mu\text{g}/\text{m}^3$ (annual average) for Total Suspended Particulates (TSP) and less than $25 \mu\text{g}/\text{m}^3$ for Fine Particulates ($< 2.5 \mu\text{m}$). A recent Federal Register notice by the EPA¹⁵ proposes an annual PM_{10} particle (those particles with an aerodynamic diameter smaller than or equal to a nominal $10 \mu\text{m}$) standard in the range of 50 to $60 \mu\text{g}/\text{m}^3$ based on its staff assessment of long-term epidemiologic studies which support "no significant effects" in the concentration range of 80 to $110 \mu\text{g}/\text{m}^3$ TSP or in equivalent PM_{10} levels, 40 to $55 \mu\text{g}/\text{m}^3$.

Most of the up-to-date information on airborne particle toxicity and epidemiologic information regarding the population-based exposure-response relationships used in the risk and analytic approach in this study are contained in the recent Harvard Health and Environmental Effects Document (HEEDs) on airborne particles.^{15,16,17} The airborne particle HEEDs are the product of a multi-disciplinary DOE study and are intended to summarize results to-date of continuing analyses of the nature, magnitude and uncertainty of potential health impacts of airborne particles. One of the main objectives of Harvard's assessments, reported in these HEEDs, is the identification of: limitations, gaps in knowledge, and research needs in the area of health risks resulting from population exposures to ambient particles. Also used were results from a recent EPA study on benefit analysis of alternative ambient standards for particulates.¹⁸

3.1 Morbidity Effects Analysis

In an attempt to quantify the morbidity effects of 1154 MT/yr coal particle emissions, several well regarded studies that provided quantitative estimates for air pollution concentration and morbidity outcomes were selected. A study of hospital visits conducted by Samet and his co-workers¹⁹ addresses a concentration range for particles that is relevant to air pollution levels in the study area. The other studies (Ferris et al.^{20,21} and Saric et al.²²) address relatively high particulate levels, and one must extrapolate using linear exposure-response models beyond the range of observed concentrations in these studies in order to derive a risk coefficient. However, this approach must be taken cautiously as very little evidence exists to indicate whether or not the relationships observed at higher particle concentrations hold at lower concentrations. Although the EPA has excluded this study from its criteria document, other researchers have included it to allow the projection of conservative estimates.^{16,18}

With these qualifications, the coefficients used for predicting acute morbidity included a coefficient for excess emergency room visits for respiratory disease, derived from the Samet et al. study,¹⁹ with a value of 13 ± 6.5 cases/year/100,000 persons per $\mu\text{g}/\text{m}^3$ TSP. The conservative (i.e., near upper-bound) age-specific coefficients used to project acute respiratory disease incidents obtained from the Saric et al. study²² were:

<u>Age</u>	<u>Risk Coefficient*</u>
0 - 24 years	540
25 - 54 years	100
55+ years	121

* Acute respiratory disease incidents/year/100,000 per $\mu\text{g}/\text{m}^3$ TSP.

Due to uncertainties in the application of the Saric results to this study, zero was used as the lower-bound limit and 1.5 times the estimated coefficient was used to compute the upper 95% confidence limit.

In addition to the extrapolation problem, the range of coefficients presented above logically include zero because there are other important contributors to the uncertainties of the morbidity risk estimates. These can be categorized into sampling and non-sampling errors associated with the epidemiologic studies of both the morbidity and the mortality effects of air pollution. Sampling errors refer to the lack of precision of a sample result. If a sample were to be collected without sampling error, then one could reproduce from the sample the results which would have been obtained if the entire population had been included. To the extent that this is not true, sampling error exists. Non-sampling errors include a variety of factors that influence the uncertainty of the estimated airborne particle concentration-response relationships. They include: confounding factors (e.g., cigarette smoking, socio-economic status, occupational exposures, race, prior exposures and residence); collinearities with other pollutants (e.g., particles and sulfur dioxide); changing measures of particle pollution that are not entirely comparable [e.g., British Smoke (BS)* or Coefficient of Haze (COH)** versus TSP]; oversimplifications in estimating personal exposures from data collected at fixed-site monitors; and biases due to historical and cross-community

* British Smoke. An optical aerosol measurement used more commonly in Europe and expressed in $\mu\text{g}/\text{m}^3$. It is obtained by measurement of the decreased reflectance of a filter paper after the passage of a measured volume of air.

** Coefficient of Haze. An optical aerosol measurement used to quantify the mass of particle deposit on a filter tape sampler by measuring the percent transmission of white light through it.

differences in particle and source composition.

Due to potential contributions by the factors noted, the standard errors of the estimates have typically been defined half as large as the estimates themselves.¹⁵ Using these standard errors, the 95% confidence limits are estimated by adding (or subtracting) twice the standard error to the mean risk estimate. Negative lower-bound estimates, if obtained, are set at zero, since beneficial effects of air pollution are not readily plausible.

Table 2 summarizes the most likely acute morbidity effects associated with airborne particles emitted from the Kyger Creek power plants. Table 3

(Tables 2 and 3 about here)

provides the corresponding uncertainty limits for these projected health effects. For the area surrounding the Kyger Creek facility, the incremental excess emergency room visits for respiratory disease would be about one case every two years (0.5 per year). Whereas, the expected number of incremental annual acute respiratory disease incidents for the same areas are about 11 per year.

Estimates for chronic morbidity effects were not included since the available coefficients are derived from the studies of Ferris and his colleagues^{20,21} based on ambient levels typically greater than $130 \mu\text{g}/\text{m}^3$, and thus significantly larger than the baseline plus incremental in this analysis.

3.2 Results of Mortality Effects Analysis

In order to quantify the acute and the chronic exposure mortality effects of airborne particles, mortality coefficients derived from time-series and cross-sectional analysis reported in the Harvard^{15,16} and the Mathtach¹⁸ reports were chosen. In addition, an upgraded cross-sectional mortality

analysis was performed using the 1980 census and vital statistics data in conjunction with FP (fine particles, i.e., aerodynamic diameter smaller than $2.5 \mu\text{m}$) data for the same period.

Only the effects of particle pollution on total mortality i.e., changes in the mortality from all causes, were analyzed. From time-series analyses providing daily mortality risk coefficients, the following coefficients derived from the analysis of 14 years of daily New York City mortality and air pollution records were considered:

$$0.02 \pm 0.005 \text{ deaths/day/100,000 persons per unit COH}^{15}$$

$$0.046 \pm 0.007 \text{ deaths/day/100,000 persons per unit COH}^{17}$$

Both of these time-series coefficients were used to present a range. Before application, the coefficients were converted to representative TSP levels by scaling with a factor of 0.01. (This was based upon site-specific analysis using 500 same-day measurements, conducted at the City College of New York, of COH and TSP.) The coefficient was further adjusted to account for the difference in the size distribution of the projected power plant particle emissions. The conversion used was a scaling upward by a factor of $1/0.54$, since IP (i.e., smaller than $15 \mu\text{m}$) mass is, on the average, 54% of the TSP mass.²³

From cross-sectional mortality analysis, the following sets of coefficients were considered:

$$0 - 0.47 \text{ deaths/year}/\mu\text{g}/\text{m}^3 \text{ TSP per 100,000 persons}^{18}$$

$$0.4 \pm 0.24 \text{ deaths/year}/\mu\text{g}/\text{m}^3 \text{ TSP per 100,000 persons}^{16}$$

$$2.31 \pm 0.81 \text{ deaths/year}/\mu\text{g}/\text{m}^3 \text{ FP per 100,000 persons}^{17}$$

The final range of cross-sectional mortality coefficients selected were 0 to 2.31 ± 0.81 deaths/year/100,000 persons per $\mu\text{g}/\text{m}^3$ FP (since all the other coefficients, if used, would project mortality impacts within the range generated by these risk coefficients).

Although the latest fine particle coefficient¹⁷ should provide an improvement over the previously reported cross-sectional mortality coefficients of particle pollution, there are still large uncertainties surrounding any such damage coefficient. Indeed, despite the fact that the coefficient is statistically greater than zero, uncertainties which are not considered by such analyses [e.g., non-sampling errors such as in the measurement of the exposure variable] make it possible that the particle mortality risk coefficient might be zero.

Tables 2 and 3 summarize the predicted mortality impacts and their associated uncertainties, respectively. The most likely annual mortality risks associated with emissions from the Kyger Creek plant are less than 0.03 per year within the 50-mile radius of the plant. Predicted average daily mortality risks from the Kyger Creek plant would likely be 0.8×10^{-5} to 1.9×10^{-5} deaths per day associated with the 1154 (MT/yr) particle emissions. These daily projections, if multiplied by 365, are still less than one-third of the annual mortality projections based upon using risk coefficients derived from cross-sectional mortality studies.

Based upon analysis of the daily population exposure projections within the 50-mile radius surrounding the Kyger Creek plant, the maximum 24-hour IP exposure is 49,000 person-ug/m³ to give a maximum daily mortality of 4.2×10^{-4} excess deaths.

3.3 Estimated Incremental Health Risk Compared to Baseline Values

Scientifically, the significance of the health risk projections can usually be demonstrated by comparison with the baseline morbidity and mortality rates in the areas studied. However, even in terms of absolute effects, both the concentration and the mortality effects are significantly

below the detectable or observable levels in the region studied. Projected morbidity effects are also very small and well below the sampling error in most epidemiologic surveys.

To compare the projected mortality and the morbidity risks to expected baseline values, the socio-demographic profile of the population near these three plants was thoroughly examined. It was determined that: (a) the population characteristics are typical of the national average; and (b) national disease incidence rates and the cross-sectional mortality model developed using a national data base can be applied reliably in projecting the baseline risks in the region studied.

The 1980 cross-sectional model was first used to predict the area-specific total mortality rates (TMR) using the socio-demographic information obtained from the 1980 census for the areas surrounding the three plants. These predictions were then checked for consistency with the observed mortality rates in 14 cities in Indiana and Ohio. It was found that the results were in excellent agreement.⁵

The model that was used to predict the annual TMR was obtained from a multiple-regression analysis of the 1980 U.S. census and air pollution data. The regression coefficients of the model chosen accounted separately for the contribution of the following independent variables to the predicted TMR: percentage of the population over 65 years old; median age of population; percentage of population which is non-white; decimal logarithm of the population density; percentage of population with more than 1 year of college; percentage of families with an annual income less than \$5,000; and estimated fine particle mass. The predicted total mortality rates are noted to vary between 814 and 1,084 deaths per 100,000 persons per year and are consistent with the observed Midwest average, 895 ± 108 .

A rate for the daily hospital emergency room visits from all causes was derived from the Samet, et al., study¹⁹ to be 24.5/20,000, or 1.22×10^{-4} visits per day per person.* For annual acute respiratory disease incidence rates, the age-specific rates used were:¹⁸ 1.52 (0 - 24 years), 1 (25 - 55 years), and 0.7 (55+ years) annual acute respiratory disease incidents per person in the U.S.

Expected excess emergency room visits due to respiratory conditions were 389,000. The expected annual acute respiratory incidents are 979,000 for this area. Total annual mortality are estimated to be 7,500 deaths in the Kyger Creek area. These absolute values in the Kyger Creek area are quite large due to the size of the population and the magnitude of the expected incidence or prevalence rates.

The percentage of change in the expected incidence of total morbidity resulting from the incremental 1154 MT/yr particle emission in the Kyger Creek area is very small (0.0001 to 0.005 percent). The likely percentage of change in the expected annual total mortality resulting from the incremental particle emissions is less than 0.0004 percent. Both in terms of absolute numbers and in terms of relative proportions compared to baseline health impacts in the areas analyzed, the projected impacts are very small. Furthermore, concentration as well as health impacts are so small that they could not even be detected with the state-of-the-art monitoring, survey design, and analysis techniques. Finally, all of the projected health impacts are much smaller than the uncertainties associated with the available risk assessment models

* These rates are somewhat higher than the national average since the hospital used in this study was in Steubenville, Ohio, which is in an industrial valley town with iron and steel plants, coal-fired power plants, and chemical plants.

and the predictions resulting from their use.

4. DISCUSSION AND CONCLUSIONS

The following additional general conclusions can be made regarding the coal particulates health risk analysis presented in this paper, and in particular the use of similar analysis in formal regulatory proceedings:

1. Risk management through the formal regulatory hearing, or similar legal process, is the mechanism by which scientific risk assessment has a direct impact on societal decisions. Scientists involved in risk assessment should thus have an awareness of the demands and constraints of the process.
2. The regulatory process can force resolution of scientific issues. A foremost example is the extent to which the linear dose-response model should be utilized. Exposures of large populations to low concentrations of hazardous pollutants can lead to exaggerated estimates of health effects with the linear model if caution is not used. Also, during cross-examination in this hearing the need for dose-response data based specifically on coal particulates was emphasized, although the uncertainty limits used for the coefficients in the analysis were intended to take into account variability in particulate characteristics.
3. Legally defined constraints of the regulatory process may limit development of more comprehensive perspectives. For example, in the risk assessment presented in this paper, the analysts were constrained to consider only previously defined obsolete emission estimates; effects of other pollutants, such as secondary particulates from sulfur emissions, were not considered; and the health effect benefits/costs from coal plants being displaced by the nuclear plant were excluded from consideration at this hearing.

4. Uncertainty analysis is a necessary component of risk assessments that are to be used in the risk management (regulatory) process, however, there is a natural tendency to misuse extreme values in the ranges to support particular views. Central or most-likely estimates should thus be derived when possible and clear explanations of the basis for the uncertainty limits should be provided.

At the date of the writing of this paper no decision on the significance of the health effects of the coal particulates in the uranium fuel cycle has been made by the ASLB.

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Table 1
Comparison of Area-Specific Baseline Particle Pollution Concentrations
and Population Exposures to Impacts Associated with the
Kyger Creek Power Plant*

Baseline Values**				Projected Increments			
Annual Average (ug/m ³)		Population Exposures (ug/m ³ x persons)		Annual Average*** (ug/m ³)		Population Exposures (ug/m ³ x persons)	
TSP	FP	TSP	FP	IP	FP	IP	FP
68	24	5.9 x 10 ⁷	2.1 x 10 ⁷	0.003 - 0.004 (mean = 0.0033)	0.002 - 0.003 (mean = 0.002)	1,990 - 2,436 (mean = 2,174)	1,353 - 1,656 (mean = 1,478)

* 50-mile radius around the power plant defines the study area. Projected range of impacts is based upon 5 years of meteorology (1971-1975).

IP refers to the mass of Inhalable Particles (aerodynamic diameter < 15 um) and typically, IP is 54% of TSP in the ambient atmosphere.²³ FP refers to the mass of Fine Particles (aerodynamic diameter < 2.5 um.)

** Mean TSP concentrations are based on: 1) NASN data for counties surrounding and including the power plants (data for years 1978-1981), 2) EPA Inhalable Particle Network data for (urban) sites near the power plants (data for years 1978-1982), and 3) EPRI/SURE measurements at nearby (rural) class 1 sites (data for 1977-1979).

*** Annual averages are calculated by averaging over all grid cells.

Table 2
Summary of Most Likely Projected Population Health Effects
Associated with Airborne Particles Emitted from the
Kyger Creek Power Plant Supplying Electricity
to the Uranium Fuel Cycle*

Acute Morbidity Effects		Mortality Effects	
Annual No. of Emergency Room Visits for Respiratory Disease	Annual Acute Respiratory Disease Incidents**	Daily Mortality	Annual Mortality
0.5	11	$0.8 \times 10^{-5} - 1.9 \times 10^{-5}$	0 - 0.03

* Uncertainties due to sampling and non-sampling errors are not included here. Therefore, zero risks are also possible.

** These are tentative results and should be considered to be conservative due to inherent problems associated with the interpretation of the Saric et al. study²² which was used in developing the health risk coefficients.

Table 3
Uncertainty Limits (95% Confidence) for the Projected
Health Effects (Kyger Creek)

<u>Acute Morbidity Effects</u>		<u>Mortality Effects</u>	
Annual No. of Emergency Room Visits for Respiratory Disease	Annual Acute Respiratory Disease Incidents	Daily Mortality*	Annual Mortality
0 - 1.0	0- 17	0.4×10^{-5} - 2.5×10^{-5}	0 - 0.05

* Uncertainties due to non-sampling errors not included, i.e., the possibility of zero as a lower limit is not excluded.