
Air Toxics and Public Health

Exaggerating Risk and Misdirecting Policy

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Each of the leading legislative proposals for amending the Clean Air Act advocates a two-phased approach to regulating industrial emissions of toxic chemicals into the outdoor air. In the first phase emission control requirements will focus on technology; in the second phase they will focus on health.

More specifically, in the first phase industrial plants that emit hazardous air pollutants will be required by the various proposals to install either the maximum achievable control technology (MACT) or the best available control technology (BACT). The proposals differ, however, with regard to such issues as: the degree to which the Environmental Protection Agency will be allowed to consider cost, technical feasibility, and other nonhealth factors when determining the required effectiveness of control technologies; the applicability of the requirements to area sources (small stationary sources) and to mobile sources of emissions; and the compliance schedules stipulated for particular source categories.

In the second phase regulated sources will be required to implement additional controls that are sufficient to reduce to reasonable levels the esti-

mated residual risks to human health associated with population exposures to the emission levels achieved with the technology-based controls. Different proposals, however, specify different criteria for determining whether a particular source has achieved a reasonable level of risk. For example, both House bill H.R. 2585 and Senate bill S. 816 state that major sources of toxic emissions must ultimately reduce their residual risks to at most "one in 1,000,000 for the individual in the population who is most exposed to such emissions," although the Senate bill would allow sources that are unable to achieve the one in 1,000,000 level to continue operating if their residual risks can be limited to one in 10,000. In contrast, the administration proposal grants the EPA substantial discretion in assessing the reasonableness of the public health risks that remain after sources have installed particular technological controls.

To evaluate the potential effects of such legislation, it is instructive to examine the available scientific evidence about the health effects of specific hazardous air pollutants. Accordingly, in this article we first review the scientific data on the health outcomes associated with human exposure—both occupational and environmental—to coke oven emissions. Next, we present recent EPA estimates of the health effects associated with environmental exposures to benzene and to other toxic air pollu-

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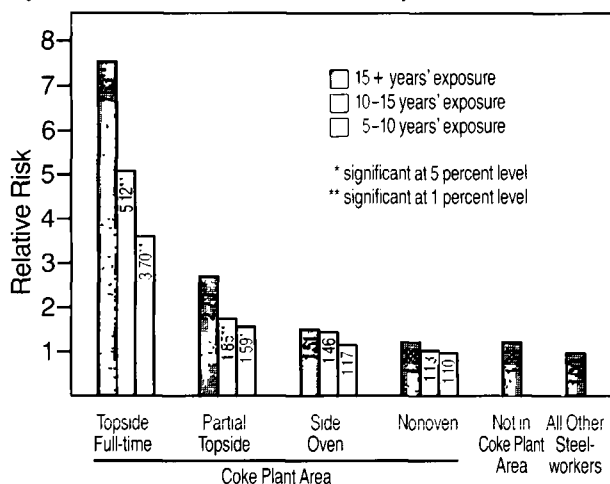
tants in general, and we consider them in relationship to the total incidence of comparable health outcomes nationwide. Finally, we evaluate the merit of the proposed amendments to existing federal law on hazardous air pollutants.

Empirical Evidence on Health Effects Associated with Occupational Exposure

The available scientific evidence on the health effects of occupational exposure to coke oven emissions comprises a substantial number of epidemiological studies of long-term exposures among coke plant workers in Allegheny County (Pittsburgh), Pennsylvania, and elsewhere in the United States and Canada, and among gas retort workers, steel and coke plant workers, and other coal carbonization workers in Japan, England, and Wales. The results of these studies show coherent patterns of excess risks of death due to cancers of the respiratory system (particularly, cancers of the lung, bronchus, and trachea) among coke oven workers.

These patterns are clearly illustrated in Figure 1, which depicts, for steelworkers in Allegheny County, Pennsylvania, the excess risks of cancer mortality

Figure 1: Comparative Risks of Death from Cancer by Work Area and Duration of Exposure



among coke plant workers relative to the risk of cancer mortality observed among all other steelworkers. This figure classifies coke plant workers on the basis of work area and duration of employment. The work-area groups, in decreasing order of their levels of exposure to coke oven emissions, are: topside full-time (workers who worked on the topside of the coke ovens full time), partial topside (those who worked on the topside of the ovens part-time and at the sides of the ovens part-time), side oven (those who worked at the sides of the ovens

full-time), nonoven (those who worked in the coke plant area, but not at the ovens), and not in the coke plant area (those who worked at the plant site, but not in coke-making operations). Workers in the nonoven group include those in the coal-handling and by-product recovery areas of the plant, as well as those in general coke-making operations who rarely work in the vicinity of the ovens. The duration-of-exposure groups are: workers with five or more, ten or more, and fifteen or more years of employment before 1953.

Figure 1 reveals direct relationships between excess risks of cancer mortality and both the intensity and the duration of exposure to coke oven emis-

On the basis of scientific evidence, workers experiencing occasional, low-level, or short-term exposures to coke oven emissions do not incur material excess risks of death from respiratory system cancers and do not face excess risk of death from any other forms of cancer.

sions experienced by coke oven workers. We do not, however, observe such coherent patterns of excess cancer risks for coke plant workers who have experienced comparatively low levels of exposure to coke oven emissions.

In addition, although epidemiological studies have estimated statistically significant excess risks of death from cancers of the kidney, prostate, and pancreas for specific groups of coke plant workers with comparatively *low* levels of exposure to emissions, these studies have not found comparable evidence for groups with *higher* levels of exposure. Thus, among all coke plant workers, the empirical evidence of excess mortality risk is highly incoherent with regard to these forms of cancer. Similarly, there is no coherent evidence—indeed, no evidence in studies of American steelworkers—that workers who are occupationally exposed to coke oven emissions experience statistically significant excess risks of death due to leukemias and lymphomas, skin cancers, or nonmalignant diseases of the respiratory system. Therefore, on the basis of the available scientific evidence, it would be reasonable to conclude that workers experiencing occasional, low-level, or short-term exposure to coke oven emissions do not incur material excess risks of death from respiratory system cancers and that occupationally exposed workers in general do not face

detectable excess risk of death from any other forms of cancer.

It is difficult, however, to extrapolate directly from these results to develop conclusions about how exposure to coke oven emissions affects the health of the general populations of communities adjacent to coke plants, because workers tend to be healthier, on average, than the general populace. Nevertheless, the long-term health outcomes observed among coke plant workers exposed to comparatively low levels of coke oven emissions—exposure levels that likely are most similar to the environmental exposure levels experienced by the residents of communities near coke plants—strongly suggest that it is unlikely that such residents incur any material excess risks of death due to certain cancers or nonmalignant diseases of the respiratory system as a consequence of their limited exposure to coke oven emissions.

Health Effects Associated with Environmental Exposure

Allegheny County, with one of the highest concentrations of coke plants in the country, is a prime location for investigating the health effects of environmental exposure to toxic chemical emissions. If such effects are not apparent in this county, they are unlikely to be measurable anywhere.

Direct evidence of the effect on public health associated with exposure to outdoor levels of coke oven

There is no coherent pattern of higher cancer rates in areas adjacent to coke plants in comparison with areas farther away from the plants. Indeed, it would be impossible to infer the location of the coke plants by looking at the spatial patterns of cancer incidence rates.

emissions is provided by data compiled by the National Cancer Institute in the *Third National Cancer Survey*. On the basis of these data we calculated age-adjusted cancer incidence rates for males and for females in thirty geographic areas within Allegheny County for the three-year period from 1969 through 1971. We computed separate incidence rates for numerous forms of cancer, including, most importantly, the forms of cancer shown to be associated with occupational exposure to comparatively high levels of coke oven emissions.

For each form of cancer, there is substantial vari-

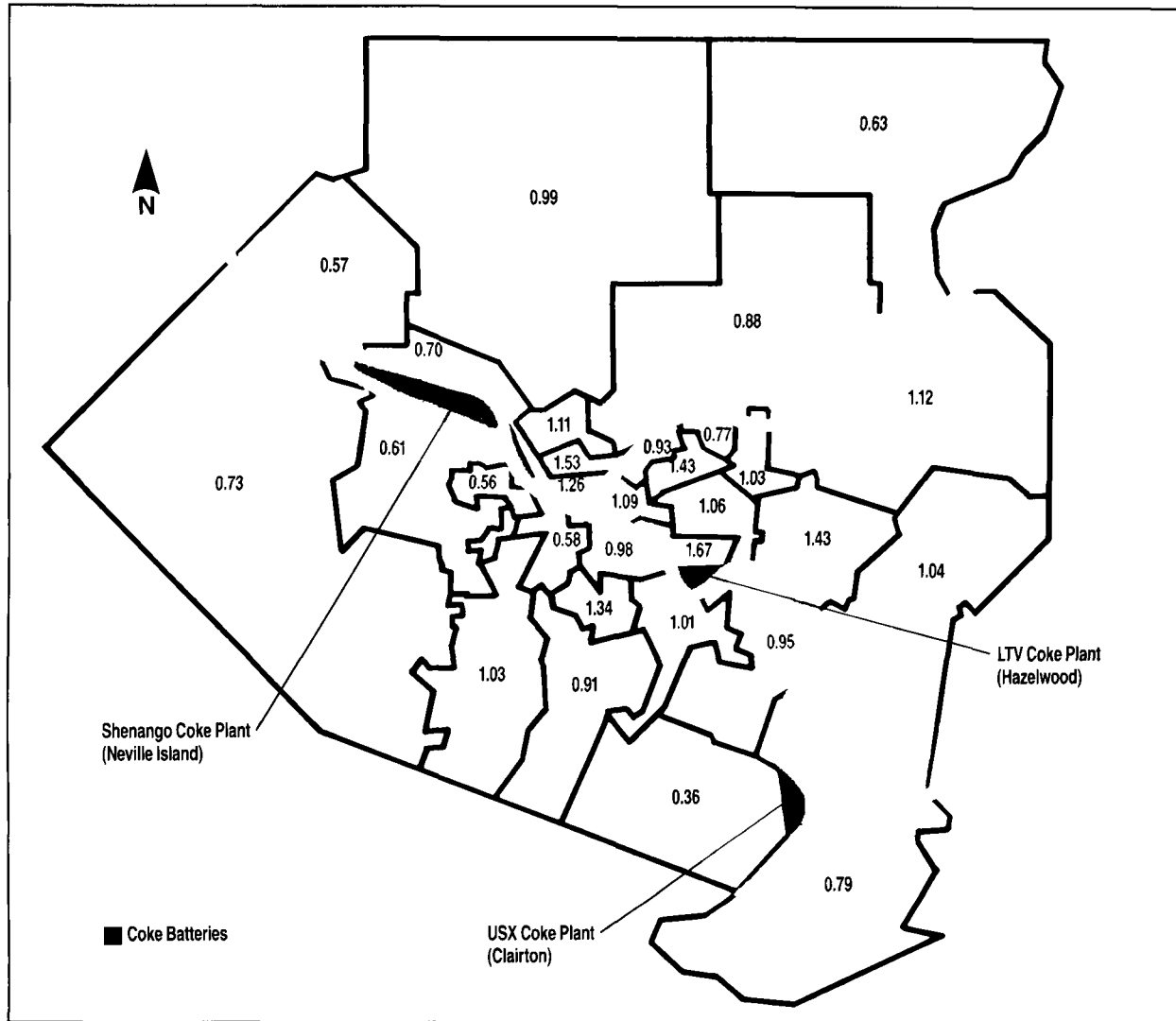
ation in incidence rates for both males and females among the thirty geographic areas within the county. But when we examine the spatial patterns displayed by the incidence rates across these areas, we find no coherent pattern of higher cancer incidence rates in areas adjacent to coke plants in comparison with the incidence rates in areas farther away from the coke plants. Indeed, by simply looking at the spatial patterns of cancer incidence rates and assuming that coke oven emissions contribute to excess cancer risks, it would be impossible to infer the locations of the three coke plants in Allegheny County.

This circumstance is illustrated in Figure 2 with reference to the average annual age-adjusted incidence rates calculated for cancers of the respiratory system among females residing in Allegheny County between 1969 and 1971. The figure contains a map of the thirty geographic areas in the county and specifies for each area the ratio of the incidence rate for that area to the incidence rate for the entire county. Ratios greater than 1.0 indicate areas with excess risk of respiratory system cancers relative to the whole county, and ratios less than 1.0 indicate areas with below-average risk. The locations of the three coke plants in the county are depicted in the figure as shaded sites.

The most notable result displayed in Figure 2 consists of the ratios shown for the areas adjacent to the USX Corporation coke plant at Clairton, located in the southeast portion of the county. The Clairton coke plant is the largest coke-making facility in the nation, yet the ratios calculated for the areas adjacent to the plant are substantially *below* the county average. In fact, the ratio for the area in which the plant is located is the smallest one computed for any of the thirty geographic areas. This result is especially important because cancers of the respiratory system are the forms of cancer that have been most consistently associated with high levels of occupational exposure to coke oven emissions, and because females most likely provide the purest indication of the health impact of environmental exposures to coke oven emissions because of the small probability that females have been occupationally exposed to such emissions.

We observe similar results for the areas adjacent to the Shenango coke plant located on Neville Island in the western portion of the county. The ratios calculated for those areas are uniformly less than the county average. In addition, the ratios tend to increase with distance from the plant, whereas one would expect risk gradients in the opposite direction if outdoor concentrations of coke oven emis-

Figure 2: Average Annual Age-Adjusted Incidence Rates for Females, 1969–1971, for Cancers of the Respiratory System: Ratio of Rates for Thirty Areas within Allegheny County to Overall County Rate



sions were an important factor contributing to the risk of respiratory system cancer.

In contrast, in the areas adjacent to the LTV Steel Company coke plant in Hazelwood, located near the center of the county, the ratio for the area in which the plant is situated is the largest one computed for any of the thirty areas in the county. In addition, proceeding toward the Northeast (the normal direction of the prevailing wind), the ratios steadily decline. Conversely, for males, we have found that the ratios for areas downwind from the coke plant are roughly at or below the county average; whereas, for areas upwind from the plant, the ratios are considerably higher than average. It would be biologically implausible to conclude that environmental exposures to coke oven emissions contribute materially to these diametrically opposite health

outcomes observed for males and for females.

Moreover, we have derived comparably incoherent results for all other forms of cancer examined. The observed risk patterns are often contrary to expectations. Cancer incidence rates for the same geographic area are frequently inconsistent for males and for females in that they indicate above-average risks for one sex and below-average risks for the opposite sex. Also, cancer incidence rates in the areas adjacent to the three coke plants are generally inconsistent with the relative levels of emissions from the plants.

Together, the foregoing evidence strongly indicates that factors other than exposures to outdoor concentrations of coke oven emissions are the predominant sources of the observed variations in cancer incidence rates throughout the county. Such

factors include occupational exposures to toxic chemicals, smoking and dietary behavior, and socioeconomic characteristics.

Finally, it is important to realize that the available evidence pertains to the period from 1969 to 1971. That period predates both the installation of most air pollution controls currently in place at the coke plants and the severe decline in domestic steelmaking and coke production during the early 1980s. Thus, the evidence relates to levels of coke oven emissions *many times higher* than those occurring now. Accordingly, the risks of respiratory system cancers associated with current levels of coke oven emissions doubtless are substantially lower than the negligible risks of such cancers indicated by the evidence that is now available.

The Flawed EPA Procedure for Estimating Health Effects

The EPA acknowledges that the levels of cancer risk that may be associated with the “extremely low concentrations” of hazardous air pollutants to which people are exposed in outdoor environments are so low that they cannot be directly measured by epidemiological studies of environmental exposures. Indeed, as demonstrated by the empirical evidence on cancer incidence in Allegheny County, the risk levels are so low that they cannot even be detected in epidemiological studies of population exposures to outdoor concentrations of coke oven emissions that were substantially higher than those prevalent currently.

Consequently, the EPA has concluded that estimation of the levels of cancer risk associated with environmental exposures to low concentrations of hazardous air pollutants must be based on extrapolation of the available scientific evidence about

nevertheless, routinely uses mathematical extrapolation models to produce estimates of the levels of cancer risk associated with population exposures to outdoor concentrations of hazardous air pollutants.

In general, the analytic procedure the EPA uses to develop its estimates involves three steps. First, using the available scientific evidence on the levels of cancer risk associated with exposure to high concentrations of a particular hazardous air pollutant, the agency develops an estimated exposure-risk relationship, a mathematical model that relates a unique level of cancer risk to any specified concentration of the pollutant. Second, using long-term projections of both the rate of pollutant emissions from the source under consideration and the meteorological conditions in the area adjacent to the source, the EPA models air dispersion to estimate the outdoor concentrations of the pollutant at specific locations in the vicinity of the source. Finally, combining the estimated exposure-risk relationship, the estimated pollutant concentrations at the specified locations, and estimates of the numbers of people residing in the districts encompassing those locations, the agency computes estimated levels of cancer risk for the various districts and, by summing over the districts, for the total area surrounding the source.

In using this analytic procedure to assess the cancer risks associated with environmental exposures to a particular hazardous air pollutant, the EPA uniformly adopts conservative assumptions that cause its estimates of the cancer risks of low pollutant concentrations to be much higher than the most likely values indicated by the evidence.

In developing its estimated exposure-risk relationships for specific hazardous air pollutants, the EPA generally assumes that there is a directly proportional relationship between incremental levels of cancer risks and incremental concentrations of the pollutant under consideration, without any threshold level of exposure below which there is no excess risk of cancer. The agency assumes that this relationship exists for all concentrations of the pollutant below the high levels of exposure for which the available scientific evidence indicates that excess cancer risks occur. The relationship associates a person's estimated total lifetime probability of contracting a specific form of cancer with his continuous lifetime exposure to a particular concentration of the pollutant. The EPA uses this relationship to determine the unit risk estimate for the pollutant. The unit risk estimate implicitly states that a *constant* increase in the probability of contracting

The EPA uniformly adopts conservative assumptions that cause its estimates to be much higher than those directly measurable.

the health effects of exposures to high concentrations of the pollutants. Such evidence has generally been developed in epidemiological studies of occupational exposures or in laboratory experiments on lifetime exposures of test animals. The EPA also admits, however, that there is “no solid scientific basis” for any mathematical model that might be used to perform the extrapolation. The agency,

cancer during a person's lifetime is associated with each unit (microgram per cubic meter) increase in the person's continuous exposure to the pollutant, regardless of how large or how small the person's initial exposure may have been.

The unit risk estimate that the EPA has developed for coke oven emissions is based on the empirical results from the epidemiological studies of occupational exposures among coke plant workers that we summarized above. That unit risk estimate specifies that the incremental lifetime probability of contracting respiratory system cancer that is associated with continuous exposure to an additional unit of coke oven emissions is one in 1,621 for all ambient concentrations of coke oven emissions, regardless of how low the concentration may be. Characterizing the incremental risk of respiratory system cancers as a constant value for all ambient concentrations of coke oven emissions is fundamentally inconsistent with the results from the studies of occupational exposures to such emissions that provide no coherent evidence of excess cancer risks among coke plant workers who have experienced comparatively low levels of exposure to emissions. In addition, this characterization leads to a substantial overestimate of the risks at low exposure levels if the underlying relationship is not linear.

Indeed, in the process of developing its unit risk estimate, the EPA obtained results that uniformly indicated that the exposure-risk relationship is not linear, rather people have a continually increasing incremental risk of contracting respiratory system cancers at successively higher levels of exposure to coke oven emissions. Nevertheless, the EPA persisted in assuming a linear relationship between exposure and risk.

Another factor that caused the EPA to overestimate the effects of exposure was its use of a statistically biased (the upper bound of the 95 percent confidence interval) estimator rather than an unbiased (maximum likelihood) estimator in deriving its recommended composite unit risk estimate. The statistical technique the EPA used leads to a large overestimation of risk, even if the underlying relationship between exposure and risk were linear. Had the EPA used the unbiased estimator in its calculations, it would have computed a recommended composite unit risk estimate of one in 25,510 instead of one in 1,621. Thus, the EPA overestimated the risk by a factor of nearly 16.

Next, to use its recommended unit risk estimate to develop estimates of the excess cancer risks that individuals might experience as a result of their exposure to outdoor concentrations of coke oven

emissions, it was necessary for the EPA to make an assumption about the degree to which individuals are exposed to those outdoor concentrations. In this regard, the agency adopted the extremely conservative assumption that all individuals living within 50 kilometers of any coke plant are continuously exposed to the outdoor concentrations of coke oven emissions at their places of residence throughout their entire lives. More specifically, the EPA assumed that exposures occur 24 hours per day and 365 days per year for 70 years. Yet, numerous studies of people's daily activity patterns have uniformly shown that people, on average, spend only a small percentage of their time outdoors and spend a considerable portion of their time away from their homes (for example, at work, in transit, or in recreational activities). Thus, the EPA's assumption about people's exposures to the outdoor air doubtless causes substantial additional overestimation of the cancer risks associated with people's environmental exposures to coke oven emissions.

In addition, the agency assumes that individuals experience no risk of mortality from any other cause during their 70 years of exposure to coke oven emissions. The exposed population is supposedly not depleted by deaths due to accidents, diseases other

The EPA assumes that individuals within 50 kilometers of any coke plant are exposed to outdoor concentrations of emissions for 24 hours per day 365 days a year for 70 years.

than respiratory system cancers, or respiratory system cancers from sources other than coke oven emissions, throughout the 70-year period. Especially with regard to diseases with long latency periods, such as cancers of the respiratory system, this assumption too will cause noticeable overestimation of incremental risk levels related to coke oven emissions.

The final major assumption involved in the EPA's estimation of cancer risk pertains to the air dispersion models that it applies to projections of pollutant emission rates and areal meteorological conditions for individual sources, which it uses to develop estimates of outdoor concentrations of the hazardous air pollutant at various locations within 50 kilometers of each source. In analyzing coke oven emissions, the agency first applied its human exposure model (HEM) to produce such estimates for

the 43 coke plants that were in operation at the time of the analysis. But for two plants—the USX Corporation coke plant in Clairton, Pennsylvania, and the LTV Steel Company coke plant in southeastern Chicago, Illinois—the EPA also used more sophisticated, site-specific air dispersion models that produce more accurate estimates of pollutant concentrations. For both of these plants, the more sophisticated models estimated outdoor concentrations of coke oven emissions that were uniformly lower than those derived by using HEM for all locations within 50 kilometers of the plants. For the Clairton coke plant the maximum estimated concentration decreased by 80 percent, and for the Chicago plant the maximum estimated concentration declined by 65 percent. The EPA would quite probably also derive comparable decreases in estimated exposure levels and associated levels of cancer risks for the other 41 coke plants if it applied more sophisticated, site-specific atmospheric dispersion models to their situations.

Clearly, each step of this procedure causes the EPA's assessments of the cancer risks associated with environmental exposures to coke oven emissions to overestimate the actual cancer risks associated with such emissions by a sizeable amount. It appears likely that, in combination, the assumptions result in the overestimation of those cancer risks by at least a multiple of 100 for most if not all coke plants and for the entire nation.

EPA Cancer Risk Estimates for Coke Oven Emissions

Despite being substantial overestimates, the levels of respiratory system cancer risk that the EPA estimates are associated with environmental exposures to coke oven emissions are quite small, especially when viewed in relation to the total levels of respiratory system cancer risk that are observed within the same populations. The EPA generally develops two distinct estimates to describe the levels of cancer risk associated with environmental exposures to emissions of a specific hazardous air pollutant from particular sources. The two estimates are the maximum individual risk and the annual incidence of the specific form of cancer associated with exposure to that pollutant.

The maximum individual risk relates to a hypothetical person who lives at the location where the EPA projects that emissions of the pollutant from a particular source will produce the largest increase in the outdoor concentration of the pollutant. It is defined as the lifetime probability that this hypo-

thetical person will contract the pertinent form of cancer if exposed continuously to the estimated maximum increase in pollutant concentration for 70 years.

The annual incidence relates to the total population living within 50 kilometers of a particular source. It is defined as the average number of cases of the pertinent form of cancer that occur annually within that population as a result of environmental exposures to emissions of the pollutant from that source. The reciprocal of the annual incidence indicates the average number of years that elapse between those cancer cases.

Table 1 presents estimates of the cancer risks associated with environmental exposures to coke

Table 1: EPA Estimates of Respiratory System Cancer Risks Associated with Coke Oven Emissions

Control Status	Location	Maximum Individual Risk	Annual Incidence (cancer cases per year)	Years per Cancer Case
Baseline Emission Controls	Allegheny County	0.0117	0.848	1.2
	United States	0.0339	6.86	0.15
Best Available Technology	Allegheny County	0.00782	0.586	1.7
	United States	0.00143	4.03	0.25

oven emissions. The EPA developed these estimates to support its 1987 proposal to establish National Emission Standards for Hazardous Air Pollutants (NESHAP) that would limit coke oven emissions from wet-coal charged by-product coke oven batteries in the iron and steel industry. The table contains estimates of maximum individual risk, annual incidence, and cancer cases per year for Allegheny County and the nation. In addition, the table reports separate sets of estimates for the baseline situation involving the emission controls that were in place when the EPA developed its estimates and for the proposed situation involving the use of incremental controls embodying the best available technology.

The evidence in Table 1 indicates, first, that coke plants involve estimated maximum individual risks that are much greater than the levels advocated in the recent legislative proposals. The largest maximum individual risk estimated for any of the three coke plants in the county is one in 85 (0.0117). In contrast, recent legislative proposals advocate levels such as one in 1,000,000 or, in specific contingencies, one in 10,000.

Considered more comprehensively, however, the

evidence also shows that, even in this county with its high concentration of coke plants, the estimated annual incidence of respiratory system cancers associated with environmental exposures to coke oven emissions is extremely small. In an exposed population of more than 2 million people, the estimated annual incidence of such cancers for the three plants in combination is less than one case per year in the baseline situation, and less than 0.6 case per year in the proposed situation. Similarly, for the nation in the aggregate, the estimated annual incidence of such cancers is less than seven cases per year in the baseline situation, and about four cases per year in the proposed situation. Moreover, as explained above, even these small numbers of cases per year represent gross overestimates of the most probable annual incidence of such cancers within the county and nationwide.

For purposes of comparison, the total annual incidence of respiratory system cancers in Allegheny County is approximately 900 cases, and the total annual incidence of lung cancer nationwide is roughly 152,000 cases. Thus, the EPA overestimate of the annual cancer incidence associated with environmental exposures to coke oven emissions from the three coke plants in the county is a mere 0.094 percent of the total annual incidence of respiratory system cancers in the county in the baseline situation and just 0.064 percent of that total annual incidence in the proposed situation. Similarly, the EPA overestimate of the annual cancer incidence from environmental exposures to coke oven emissions nationwide is only 0.0045 percent of the total annual incidence of lung cancer nationwide in the baseline situation and just 0.0027 percent of that total annual incidence in the proposed situation.

Implementing the NESHAP for coke oven emissions that was proposed by the EPA in 1987 will therefore reduce the annual incidence of respiratory system cancers in Allegheny County by *at most* 0.262 case, or 0.0029 percent, and will reduce the annual incidence of such cancers nationally by at most 2.83 cases, or 0.0019 percent of the total annual incidence of lung cancer throughout the nation.

The EPA estimates that the total annualized cost of complying with the proposed NESHAP will be \$19.3 million per year. This amounts to *at least* \$6.8 million per life prolonged, and undoubtedly would amount to much more if the substantial overestimation of the annual cancer incidence associated with environmental exposure to coke oven emissions were properly taken into account. Surely, there are other ways in which \$19.3 million can be spent annually that will have a much greater effect on

cancer risk than the prolonging of fewer than three lives per year.

Finally, it is instructive to extrapolate the EPA estimates of cancer risks to determine the estimated annual incidence that corresponds to a maximum individual risk equal to one in 1,000,000 for individual coke plants, and for coke plants in the aggregate. For the three Allegheny County plants in combination the corresponding estimated annual incidence is, therefore, 0.000166 case, or one case every 6,020 years; and for the entire nation it is only 0.00249 case, or one case every 402 years. Moreover, once again, even these minute risk estimates substantially overstate the actual annual incidence. Even a maximum individual risk equal to one in 10,000 would therefore involve an estimated incidence of at most one case every four years nationwide, and the actual incidence would doubtless be a small fraction of that low frequency. In comparison with the total annual incidence of lung cancer nationwide, this very low level of residual risk does not merit special attention. Indeed, considering the EPA's marked overestimation of risk, estimated maximum individual risks that are much greater than one in 10,000 or even one in 1,000 should be considered tolerable.

EPA Cancer Risk Estimates for Benzene and Other Hazardous Air Pollutants

The EPA has also developed estimates of the cancer risks associated with population exposures to outdoor concentrations of benzene emitted from particular categories of stationary industrial sources. The agency derived the estimates by using its standard analytic procedures for assessing the levels of cancer risk associated with environmental exposures to hazardous air pollutants and included the estimates in notices of NESHAP rulemaking actions on benzene that were published in September 1989.

The EPA estimates indicate that the annual incidence of leukemia associated with environmental exposures to benzene emitted from the designated source categories is, in total, between 3.88 and 3.93 cases per year nationwide in the baseline situation and will decline to 0.51 case per year nationwide after the implementation of specific incremental emission controls. The incremental controls will therefore reduce the estimated annual incidence of leukemia nationwide by between 3.37 and 3.42 cases. Since the total annual incidence of leukemia nationwide is approximately 27,000 cases, the estimated reduction represents only between 0.012 and 0.013 percent of the total incidence.

The EPA estimates that the total annualized cost of implementing the specified controls will be approximately \$200 million per year. This amounts to more than \$58 million per life prolonged. It should not be difficult to find other applications for \$200 million per year that would achieve much larger reductions in cancer risk than the avoidance of fewer than four cases of leukemia per year.

Moreover, the EPA's cancer risk estimates are again extreme overestimates of the actual levels of leukemia risks associated with environmental exposures to benzene emissions from the designated source categories. The probable magnitude of the overestimation is most clearly indicated by results derived in the Total Exposure Assessment Methodology (TEAM) studies sponsored by the EPA. In the TEAM studies, direct measurements were made to evaluate, for benzene and other volatile organic chemicals, the outdoor concentrations adjacent to specific individuals' homes, the concentrations inside those homes, the individuals' personal exposures to the chemicals within their breathing zones, and the concentrations of the chemicals in the people's exhaled breath. The studies were conducted primarily in urban areas containing major stationary sources of benzene emissions.

The results from the studies have consistently shown that: indoor concentrations of benzene are generally higher than outdoor concentrations, especially in the homes of smokers; measured personal exposures to benzene are significantly correlated with measured concentrations of benzene in exhaled breath samples; measured concentrations of benzene in exhaled breath are greater than outdoor concentrations; and, most important, outdoor concentrations of benzene are *not* statistically significantly correlated with measured concentrations in people's exhaled breath. Considered within the context of the available evidence on people's daily activity patterns, these results are totally coherent and comprehensible. Moreover, the results clearly imply that the effects on people's total exposures to benzene that will actually result from reductions in outdoor concentrations will be much smaller than those the EPA assumed in estimating reductions in leukemia risks associated with incremental emission controls. Accordingly, the EPA estimates of the decline in the total annual incidence of leukemia that will result from implementing the incremental controls undoubtedly are extreme overestimates.

The EPA estimates also indicate that more than half of the estimated annual incidence of leukemia associated with environmental exposures to benzene in the baseline situation (specifically, two cases

per year) relates to benzene emissions from coke by-product recovery plants. As explained previously, however, the epidemiological studies of occupational exposures to hazardous air pollutants among coke plant workers in Allegheny County included the workers in the by-product recovery areas of the plants, and the studies found no statistically significant excess risk of leukemias among any of the groups of workers. Thus, the estimated annual incidence of leukemia associated with environmental exposures to benzene emissions from coke by-prod-

Emission controls for coke plants will reduce the annual incidence of leukemia by 1.98 cases per year nationwide and will involve costs of \$16 million per year.

uct recovery plants is quite probably a substantial overestimate.

The EPA further estimates that implementing the incremental emission controls that have been designated for coke by-product recovery plants will reduce the annual incidence of leukemia by 1.98 cases per year nationwide and will involve annualized costs of \$16 million per year. Using the EPA's overestimate of the reduction in leukemia risk, we find that this amounts to more than \$8 million per life prolonged. The actual cost per life prolonged will undoubtedly be much greater, and certainly could be spent on activities that would produce much larger improvements in cancer risks.

Finally, in September 1989 the EPA released for external review a draft report containing its estimates of the total annual incidence of cancers nationwide that are associated with environmental exposures to approximately ninety hazardous air pollutants emitted from about sixty categories of major stationary sources, area sources, and mobile sources. Because the EPA used its standard analytic procedure to develop the estimates, they probably overestimate the corresponding actual annual incidence by a considerable amount. Even with that likely overestimation, the EPA estimates indicate that, in total, only between 1,700 and 2,700 cancer cases per year are associated with population exposures to outdoor concentrations of those chemicals emitted from these sources. Obviously, any cancer case is cause for compassion. In formulating practical public health policy, however, it is essential to maintain proper perspective so that

the resources can be allocated where they will be most effective. The total annual incidence of cancers nationwide is approximately 985,000 cases. Thus, on the basis of the EPA's estimates, total elimination of emissions of those hazardous air pollutants from those sources will reduce the total annual incidence of cancer by, at most, between 0.18 and 0.27 percent.

Furthermore, the EPA estimates that only 20 percent of the estimated total cancer incidence from outdoor exposures to hazardous air pollutants is associated with emissions of the pollutants from major stationary sources. On the basis of this estimate, we can conclude that only between 350 and 540 cancer cases per year nationwide are associated with outdoor exposures to those chemicals emitted from major industrial sources. Accordingly, total elimination of emissions of those hazardous air pollutants from major industrial sources will reduce the total annual incidence of cancer nationwide by, at most, between 0.035 and 0.055 percent. Practicable controls applied to the sources will not completely eliminate these emissions, and, hence will produce even smaller percentage reductions in total cancer risks. It is difficult to comprehend why such a tiny portion of the nation's overall public health problems relating to cancer risks should continue to command such a large amount of legislative, regulatory, and public attention and concern.

Implications for Practical Public Health Policy

The available scientific evidence summarized in this article strongly indicates that, when considered at appropriate levels of aggregation and placed in proper perspective, the cancer risks associated with people's exposures to outdoor concentrations of hazardous air pollutants emitted from major stationary industrial sources are extremely small. The estimated annual cancer incidence associated with environmental exposures to hazardous air pollutants emitted from individual sources is generally quite small, particularly in comparison with the total incidence of the same forms of cancer within the same exposed population. Similarly, the annual cancer incidence associated with environmental exposures to emissions of hazardous air pollutants from sources in the aggregate is, in general, a very small percentage of the total annual incidence of the same cancers, individually or collectively, within the same geographic area.

Indeed, the only available data that appear to provide any substantial basis for concern about environmental exposures to hazardous air pollu-

tants from major industrial sources are the EPA estimates of maximum individual risk, which routinely receive wide dissemination. Even these estimates of cancer risk are typically seen to be minuscule when placed into proper perspective as a minor portion of the small annual incidence associated with such exposures throughout the entire exposed population. Moreover, as we have explained, the EPA estimates of maximum individual risk relate to hypothetical individuals who are continuously exposed throughout their lives to the highest outdoor concentrations of specific hazardous air pollutants that are estimated to result from emissions from particular sources. To the degree that cancer risks incurred by small groups of people are regarded as valid bases for public health policy, the evaluation of those public health risks should not be derived from models containing totally unrealistic assumptions about people's activity patterns and associated exposures to health risks. Instead, it should be accomplished through direct measurements of exposures to hazardous air pollutants actually experienced by individuals in those groups and of the empirical importance of outdoor concentrations as origins of those personal exposures.

Finally, even if it is agreed that any public health risks that are associated with environmental exposures to hazardous air pollutants should be mitigated, it does not necessarily follow that the mitigation should be accomplished by installing incremental emission controls that will limit the environmental exposures. Exposure avoidance is not necessarily the most constructive means of risk management, particularly in a dynamic society where useful but potentially hazardous new chemicals are continually being developed and introduced into commerce. Rather, public health might be better served, in general, by allocating additional resources to medical research aimed at discovering effective therapies for preventing or treating the diseases of concern.

Selected Readings

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