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HUMAN HEALTH RISKS ASSOCIATED WITH ENERGY PRODUCTION-RELATED ACTIVITIES AND INNOVATIVE TECHNOLOGY IMPLEMENTATION IN USAID-ASSISTED COUNTRIES

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Human Health Risks Associated with Energy Production-Related Activities and Innovative Technology Implementation in USAID-Assisted Countries

The goal of this report is to outline a way in which human health risk assessment can be incorporated into the innovative energy technology activities of the USAID Office of Energy and Infrastructure. Human health risk assessment is a decision-making tool that can be used to set priorities, to make choices among technology alternatives, and to evaluate the impact of cleaner technologies on human health. Energy production practices in developing countries often have adverse impacts on public health that are partly attributable to the air pollution that results from the use of poor-quality fuels and antiquated technologies. Incorporating human health risk assessment into programs intended to address energy production practices in developing countries would provide a means to improve the quality of public health while providing cleaner energy sources.

1. Background

Air pollution is a complex mixture of substances emitted to the atmosphere by both human and natural activities. The adverse health consequences of air pollution are multiple, ranging from eye irritation to death. Although air pollution related to human activities has been around since the cavemen first lit fires, development and industrialization have added new dimensions to air pollution, including power plants that burn fossil fuel to generate electricity and automobiles whose exhaust blankets cities. Increasing urban populations in many developing countries, accompanied by growth in transportation, energy consumption, and industrial activity, are contributing to the poor quality of urban air.

As the energy requirements of many developing countries expand to meet the increased needs of their populations and industrial sectors, further environmental decline, especially increased air pollution, is likely to result. The Office of Energy and Infrastructure promotes the improvement of energy consumption and production practices in USAID-assisted countries through the application of innovative, energy-efficient, and environmentally-benign technologies. In addition to being more environmentally sound, innovative energy technologies offer many developing countries opportunities to use previously undeveloped indigenous fossil fuel and renewable energy resources and to expand current fossil fuel utilization without undue environmental degradation. One of the primary impacts of implementing such innovative technologies will be a reduction in air pollution levels and its consequent adverse effects on human health.

Human health risk assessment is a methodology used to estimate the likelihood of adverse health outcomes from exposures to chemicals in the environment. The methodology is based on assumptions relating to the biology of human exposures to chemicals and their effects. Health risk assessment has become an important decision-making tool over the last

twenty-five years, although it was not until a National Academy of Sciences committee produced *Risk Assessment in the Federal Government: Managing the Process* in 1983, that a generally accepted framework and nomenclature for risk assessment was established in the United States. The four-step risk assessment process set forth by the report for determining whether adverse health effects are likely to occur as a result of a particular chemical exposure is described briefly below.

1. Hazard Identification: Determine the identities and quantities of environmental contaminants present that may pose a hazard to human health.

2. Exposure Assessment: Determine the conditions under which people could be exposed to the contaminants and the levels of exposure that could occur.

3. Dose-Response Assessment: Evaluate the relationship between exposure levels and the incidence of adverse effects in humans.

4. Risk Characterization: Estimate the likelihood of an adverse health outcome in the exposed population.

The outcomes of health risk assessments are estimates of the impact of a particular exposure on human health that can help guide choices among remedial alternatives. Specifically, such estimates would be useful guides to decisions regarding innovative energy and environmental technology alternatives: controlling pollution necessitates characterizing its impact prior to implementing remedial measures so that an appropriate alternative technology or course of action can be chosen and its health impact, if any, can be assessed. As the Office of Science and Technology Policy's states, "Risk assessment is used to maximize risk reduction in the same manner as cost assessments are used to define and minimize economic impacts. Engineering strategies for the future should incorporate risk assessment principles, if they are to be truly effective."

Health risk assessments can contribute to the mission of the Office of Energy in the following ways:

- Performing health risk assessments for a variety of energy production facilities or practices in a particular country or region would permit comparisons among them on the basis of the extent to which they present risks to human health, providing a basis for setting priorities when, for example, financial resources are limited and only one or a few of the potentially hazardous facilities can be addressed.

- At a particular energy production facility, there may be a number of processes, practices, or components that contribute to the total health risk associated with the facility in different ways; a health risk assessment can evaluate the relative contributions of the different processes, practices, or components to the overall risk, so that the riskiest can be targeted first for mitigation/remediation.

- When several remedial measures/technology alternatives are possible in an area or at a facility, the extent to which each is expected to reduce health risks can be assessed, so that the decision among technologies can be based partly on health risk considerations.

- The risks to human health resulting from a particular facility or practice can be assessed prior to and following USAID-implemented remedial action/technology implementation, demonstrating the impact that the USAID-assisted program has on the health of the region.

2. Air Pollution-Related Health Effects

Air pollution can contribute to the occurrence and aggravation of disease. The diseases that are associated with air pollution include acute upper respiratory disease (the "common cold"), chronic bronchitis, chronic obstructive ventilatory disease, pulmonary emphysema, bronchial asthma, and lung cancer (Amdur 1991). Most of these outcomes appear to be related to exposure to mixtures of air pollutants, not with one substance in particular, with the interactions among air pollution components of critical importance.

There are a variety of substances in air pollution that contribute to morbidity and mortality rates in exposed populations. The air pollutants with the greatest impact on the respiratory system are sulfur dioxide, nitrogen dioxide, ozone, carbon monoxide, polycyclic aromatic hydrocarbons, and suspended particulates. In addition, lead is often found in urban air at levels that can have an impact on intelligence levels in children.

Sulfur dioxide is formed when materials containing sulfur are burned, and it is therefore emitted to the environment as a result of the burning of fossil fuels. Its toxicity is related to the fact that it is not emitted alone, but along with a variety of particles. Many of these particles are capable of promoting the conversion of sulfur dioxide to the more irritant sulfuric acid. Short-term exposures to sulfur dioxide lead to irritation of the mucous membranes and constriction of the respiratory tract; people with asthma experience respiratory constriction at doses one order of magnitude lower than people without asthma (Sheppard 1986, Amdur 1991). When sulfuric acid is inhaled, it is a potent respiratory irritant that produces functional, biochemical, and morphologic changes in the respiratory tract. Sulfuric acid produces bronchial obstruction due to both constriction and increased mucous secretion; it alters the clearance of particles from the lung, thereby interfering with a major defense mechanism; and, it ultimately produces chronic bronchitis. When exposure to sulfuric acid as a surface layer on fine respirable particles occurs, such as in the vicinity of some coal-fired power plants, chronic irritation occurs in addition to the other symptoms (Amdur 1991).

Nitrogen oxides are produced as a result of combustion and, like sulfur oxides, are respiratory irritants. Elevated ambient nitrogen dioxide levels appear to be associated with acute respiratory symptoms and impaired lung function (Abramson and Voigt 1991). For

example, exposure to nitrogen dioxide is thought to increase susceptibility to respiratory infection (Amdur 1991). More important than their roles as direct toxicants, however, may be the role nitrogen oxides play in the formation of ozone. When nitrogen dioxide reacts with ultraviolet light in the atmosphere, a series of photochemical reactions takes place that produces ozone. Ozone production is also catalyzed by the presence of hydrocarbons.

Ozone exposure is associated with a variety of toxic effects, including morphologic, functional, and biochemical alterations in respiratory characteristics (Amdur 1991). These effects occur at exposure levels found in urban areas, and are suspected to be cumulative. Ozone is a respiratory irritant that decreases pulmonary function and increases susceptibility to allergens and infection.

Polycyclic aromatic hydrocarbons are also products of combustion as well as contributors to photochemical pollution production. A number of these compounds are carcinogenic in laboratory animals and suspected to be carcinogenic in humans as well. Exposure to atmospheric hydrocarbons in urban areas is thought to account for the greater incidence of lung cancer in these areas as compared to rural areas (Abramson and Voigt 1991). Tobacco smoking acts synergistically with air pollution in the production of lung cancer, with the increase in lung cancer among smokers caused by air pollution estimated to be four times greater than that among nonsmokers (Wilson et al. 1980).

One of the best known toxic effects associated with vehicle exhaust results from carbon monoxide production. Excess carbon monoxide leads to the formation of excess carboxyhemoglobin and reduced oxygen transport by the blood. Consequences of excess carboxyhemoglobin formation are psychomotor disturbances, cardiovascular toxicity and, ultimately, asphyxiation.

Particulate matter is often associated with many types of air pollution sources. Elevated levels of particulate matter are associated with decreased lung function and increased prevalence of respiratory illness (EPA 1982). Interestingly, an association between air pollution measured as particulate matter and overall mortality has been reported in several different locations and over a wide range of climates and populations (Ostro 1993). Studies of the simultaneous occurrence of daily fluctuations in air pollution and mortality provide the strongest evidence of a true association. It is as yet unclear whether it is the particles themselves, the acid aerosols with which they are associated, or some other pollutant that occurs in association with particulates that is responsible for the adverse health effects. Particulates are irritants and can exacerbate the respiratory toxicity of other substances.

Another common component of air pollution that is not associated with respiratory effects is lead. Lead occurs naturally in the environment, although most of the lead dispersed throughout the environment results from human activities. Combustion of leaded gasoline is the primary source of human exposure to lead in areas where it is still used. Children are at the highest risk of health effects from lead exposure (ATSDR 1992). When

children are exposed to lead either before or after birth, it may produce effects on normal growth and development, leading to height and weight deficits, intelligence deficits, and attention deficits. The U.S. EPA believes that there may be no threshold, or safe exposure level, for lead exposure and intelligence deficits in children (IRIS 1993). In adults, lead can be toxic to the central nervous system, producing weakness in the fingers, wrists, and ankles. It can increase blood pressure and cause anemia. It can damage the kidneys of both children and adults. Lead may increase the rate of spontaneous abortion and damage the male reproductive system, leading to sterility. Evidence in laboratory animals indicates that lead exposure can be associated with kidney cancer (ATSDR 1992).

3. Role of Energy Production in Creating Air Pollution

Air quality in much of the developing world is poor and has been deteriorating (OTA 1991). For example, Figures 1 and 2 show that concentrations of sulfur dioxide and airborne particulates in major cities throughout the developing world are considerably above World Health Organization guidelines. Photochemical smog has become a recurrent seasonal problem in many large tropical and subtropical cities.

Table 1 summarizes the primary and secondary air pollutants that have an impact on human health and their energy production-related sources. Some of the agents in Table 1 are primary air pollutants; that is, they are produced directly as a result of fuel combustion. Others, such as nitrogen dioxide and ozone, are secondary air pollutants produced in the atmosphere in the presence of ultraviolet radiation and hydrocarbons. The sources of these pollutants vary. Electric generating units rely on the combustion of oil, gas, or coal. Coal is also used for both industrial and domestic heat and sometimes cooking. Mobile sources are the major sources of pollution in urban areas.

Indoor air pollution can also occur in developing countries as a result of heating and cooking practices. Toxic smoke can be generated by open fires fueled by biomass such as wood, crop wastes, and dung. Such fires generate carbon monoxide, particulates, and hydrocarbons.

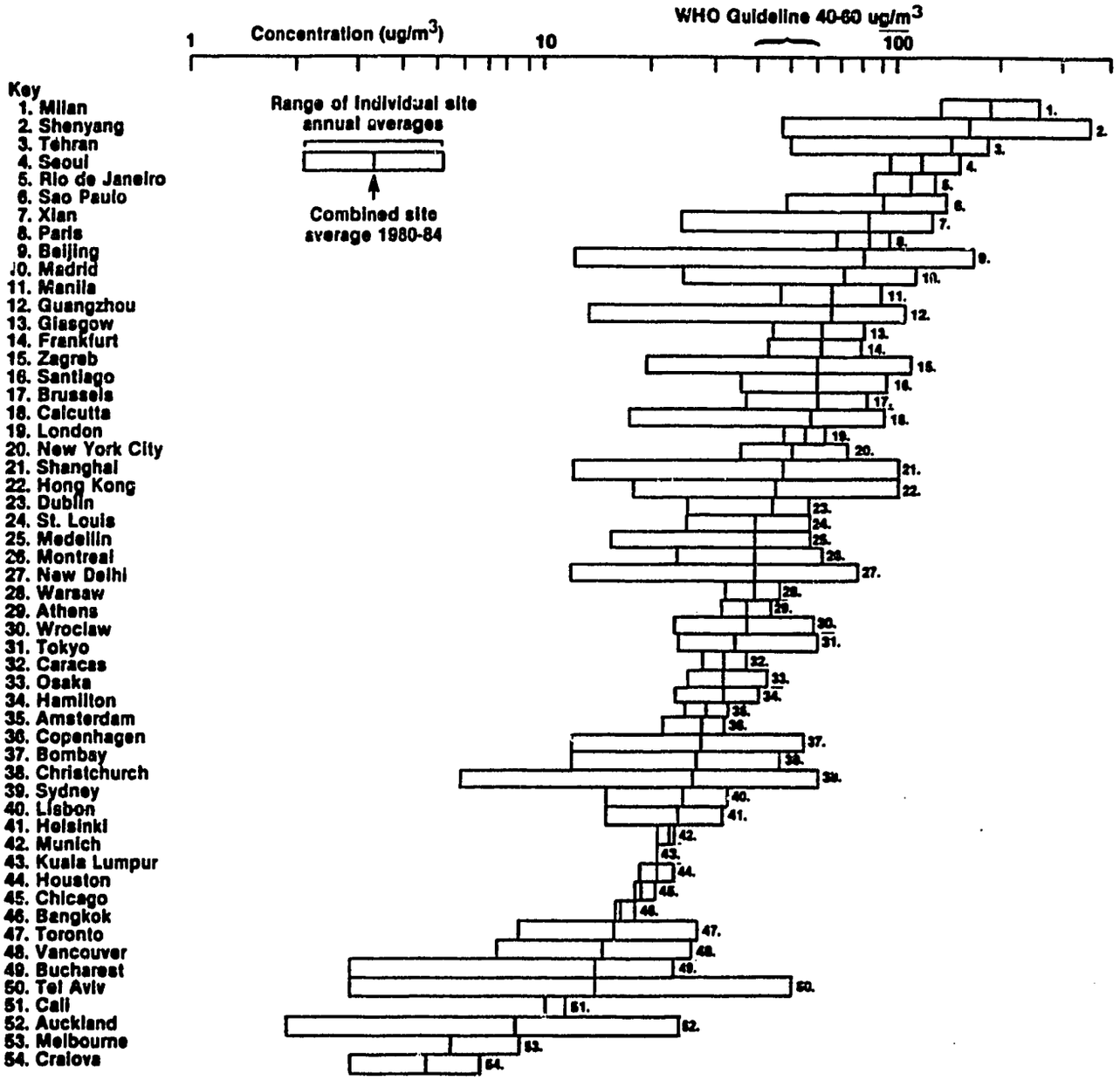
4. Extent to Which Human Health Effects Can Be Attributed to Energy Production

While it is known that energy production generates substances associated with adverse human health effects, it is difficult to attribute specific proportions of morbidity or mortality rates within an exposed population to a particular energy production source. The adverse human health effects associated with the substances produced as a result of energy production can also be caused by other factors and, conversely, the substances generated by energy production can have other sources as well.

For example, respiratory cancers, as well as many acute and chronic respiratory diseases, can be attributed largely to cigarette smoking. Attempts to assign proportions of these disease burdens to separate causal agents, such as air pollution, are frustrated by the

Figure 1
Sulfur Dioxide Levels in Selected Cities, 1980-1984

Shown is the range of annual values at individual sites and the composite 5-year average for the city.

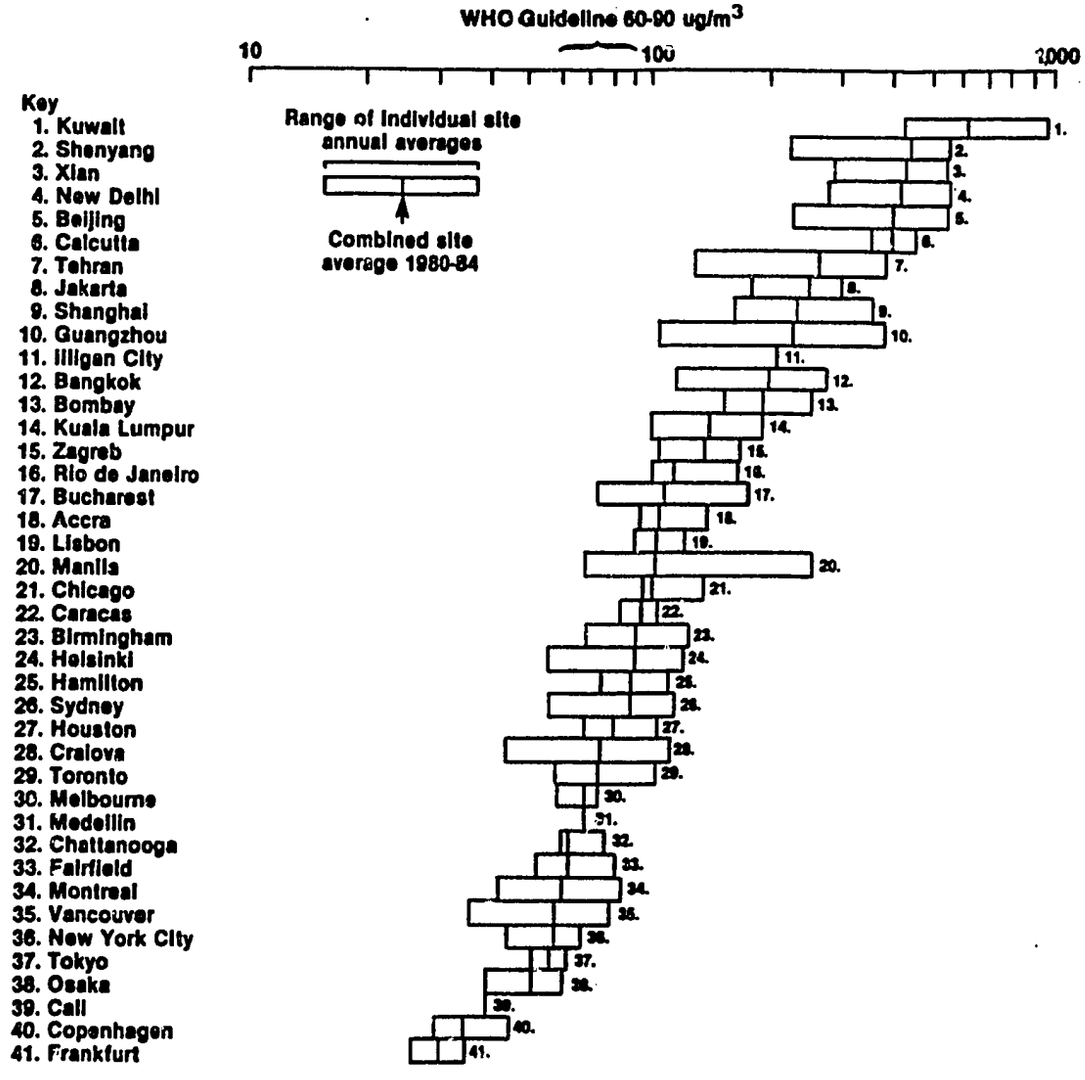


*Note logarithmic scale.

SOURCE: World Health Organization and United Nations Environment Programme, *Global Pollution and Health* (London: Yale University Press, 1987), figure 2, p. 5. (Logarithmic scale.)

Figure 2
Suspended Particulate Matter Levels in Selected Cities, 1980-1984

Shown is the range of annual values at individual sites and the composite 5-year average for the city.



*Note logarithmic scale.

SOURCE: World Health Organization and United Nations Environment Programme, *Global Pollution and Health* (London: Yale University Press, 1987), figure 3, p. 6. (Logarithmic scale.)

Table 1
Energy Production-Related Sources of Air Pollutants[a]

Source	Air Pollutant
Gas combustion	Nitrogen oxides Polycyclic aromatic hydrocarbons Sulfur dioxide
Diesel exhaust	Polycyclic aromatic hydrocarbons Carbon monoxide Suspended particulates
Coal and oil combustion	Sulfur dioxide Suspended particulates Nitrogen oxides
Combustion engines	Suspended particulates Polycyclic aromatic hydrocarbons Lead Carbon monoxide
Photochemical reactions involving oxygen and nitrogen oxides catalyzed by hydrocarbons	Photochemical smog (Ozone, nitrogen dioxide, peroxyacetyl nitrate)
Photochemical smog and fossil fuel combustion	Acid aerosols

[a]Based on Abramson and Voigt (1991) and OTA (1991)

multifactorial and interactive etiology of these diseases (NAS 1985). Further frustrating attempts to assign attributable risks is the observation that susceptibility to the effects of air pollution varies widely. Particularly sensitive subgroups include the young, the elderly, asthmatics, and those with particular pre-existing diseases. Nonetheless, air pollution might cause considerable burdens of respiratory disease, although cigarette smoking has a greater impact: even if the proportion of respiratory disease cases were low, the absolute number of cases in an exposed population would be high compared to other public health problems. In addition, because air pollution and cigarette smoking may have synergistic effects on the incidence of respiratory disease, action taken to reduce the impact of air pollution would have the concomitant effect of preventing some smoking-related illness (NAS 1985).

Thus, because of the multifactorial nature of respiratory disease etiology and the problems associated with assigning attributable risks to air pollution itself, much less to particular sources of air pollution, energy production-related or otherwise, evaluating the impact of energy production on human health is problematic. Nonetheless, disease related to air pollution is relatively amenable to primary prevention (NAS 1985) and reducing emissions related to energy production can be expected to have a positive impact on the health of exposed populations.

5. Role of Human Health Risk Assessment in Quantitatively Assessing the Impact of Energy Production on Human Health

In the absence of epidemiologic data that can be used to assign attributable risks to particular sources of energy production-related air pollution, health risk assessment methodologies can be used to generate estimates of the extent to which an air pollution source contributes to adverse health effects. Such health risk assessments could be used to set priorities for addressing emissions issues, to predict the impact that use of an alternative technology at a particular facility would have on human health, or to make human health risk-based decisions among technology alternatives. Health risk assessments estimate the extent to which a population is exposed to pollutants, assess the inherent toxicity of those pollutants, and predict the extent to which adverse health effects might be expected in the exposed population as a result. Performing health risk assessment is an uncertain process that relies on assumptions and to some extent, subjective judgment; as a result, they should not be used to determine *actual* risks, but to generate reasonable estimates that are useful for decision-making.

a. Monitoring/exposure assessment issues

The first step in a health risk assessment is to evaluate the extent to which a population is exposed to contaminants. In the case of air pollution related to energy production activities, this step would evaluate the levels of airborne contaminants in a particular city or region, and estimate the doses to which the population in that area is exposed. It is often impractical (due to cost) or impossible (due to the absence of suitable methods) to measure air pollution exposures directly for a particular person or population; it

is common, therefore, to estimate exposures using surrogate measures, such as emission estimates or mathematical models (Sexton et al. 1993). For example, measured ambient concentrations of ozone, nitrogen dioxide, carbon monoxide, sulfur dioxide, and particulate matter are often used to estimate exposures for the residents of a particular community. These estimates may be used as reasonable approximations of exposure for people who are outdoors near the monitoring stations. Accuracy is assumed to decrease with distance and with time spent indoors (Sexton et al. 1993).

Figure 3 shows that the certainty of exposure estimates depends on the surrogates being used. Some comparatively inexpensive exposure estimators, such as production volumes or emission estimates, are far removed from the point of contact between people and pollution. Their use to estimate human exposures requires assumptions, often heroic, about matters such as transport of a pollutant into the environment, its concentrations in both indoor and outdoor air, and contact between people and the pollutant. The resulting exposure estimates are very uncertain, although they can be useful in identifying areas where exposures are likely to be elevated (Sexton et al. 1993). More accurate and precise methods are needed to document actual exposures of people living in proximity to pollutant sources. Ambient air measurements, such as those recorded at central monitoring sites, provide better estimates, but can still be very inaccurate for members of a community who spend substantial time indoors (Sexton et al. 1993).

Estimating human exposures to air pollutants in developing countries for the purpose of assessing the health impact of energy production could best be accomplished through the use of ambient air concentrations or emissions measurements and simple atmospheric transport and dispersion models. This approach, while uncertain, would provide economical, upper-bound estimates of exposure that would be useful for making decisions and risk comparisons in the policy context sought by the Office of Energy and Infrastructure.

b. Dose-response assessment issues

The second step in a health risk assessment is characterizing the relationship between dose and effect for the contaminants of concern. Under the Clean Air Act, the U.S. Environmental Protection Agency has promulgated air quality criteria for pollutants that may be reasonably anticipated to endanger public health. These primary National Ambient Air Quality Standards represent levels of air quality that are, with an adequate margin of safety, considered requisite to protect public health. These standards are health-based standards derived from a quantitative evaluation of the relationship between exposure and effect for pollutants of concern. They do not consider economic or technical feasibility. Ambient Air Quality Standards have been promulgated for nitrogen dioxide, sulfur dioxide, ozone, lead, carbon monoxide, and particulate matter. These are summarized in Table 2. Polycyclic aromatic hydrocarbons are not regulated under the Clean Air Act, but the EPA Environmental Criteria and Assessment Office has issued inhalation exposure criteria for individual hydrocarbons, depending on whether they are considered carcinogens or noncarcinogens.

Figure 3
Comparison of the Utility of Different Exposure Estimators[a]

SEXTON et al., 1992		NATIONAL RESEARCH COUNCIL, 1991b	
EXPOSURE ESTIMATORS	COSTS AND ABILITY TO PREDICT/CLASSIFY EXPOSURES	EXPOSURE ESTIMATORS	APPROXIMATION TO ACTUAL EXPOSURE
• Production Volumes	Generally Lower Costs and Limited Accuracy	• Residence or Employment in Defined Geographic Area (e.g., county of the emission source/site)	Poorest
• Emission Inventories		• Residence or Employment in Geographic Area in Reasonable Proximity to the Emission Source/Site	
• Environmental Concentrations - Models - Measurements		• Distance from Emission Source/Site or Duration of Residence	
• Microenvironmental Concentrations - Models - Measurements		• Distance from Emission Source/Site and Duration of Residence	
• Human Contact - Models - Measurements		• Quantified Surrogates of Exposure (e.g., estimates of drinking water use)	
		• Quantified Area or Ambient Measurements in the Vicinity of Residence or Location of Other Significant Activities	
• Internal Dose - Models - Measurements	Generally Higher Costs and Better Accuracy	• Quantified Personal Measurements	Best

[a]From Sexton et al. (1993)

Table 2
Summary of National Ambient Air Quality Standards[a]

Pollutant	Standard	Averaging Time
Carbon Monoxide	9 ppm 35 ppm	8-hour[b] 1-hour
Lead	1.5 g/m^3	quarterly
Nitrogen dioxide	0.053 ppm	annual (arithmetic mean)
Particulate Matter (PM_{10})[c]	50 g/m^3 150 g/m^3	annual (arithmetic mean)[d] 24-hour[e]
Ozone	0.12 ppm	1-hour
Sulfur dioxide	0.03 ppm 0.14 ppm	annual (arithmetic mean) 24-hour

[a]Based on EPA (1992) and IRIS (1993)
[b]Not to be exceeded more than once in any consecutive 8-hour period per year
[c]PM_{10} is the designation for particulate matter in the atmosphere that has an aerodynamic diameter of 10 μm or less.
[d]The standard is attained when a 24-hour average concentration above 150 g/m^3 occurs no more than one day per calendar year.
[e]The standard is attained when a maximum hourly average concentration above 0.12 ppm occurs no more than one day per calendar year.

While the criteria and standards for air pollutants promulgated by EPA are based on dose-response relationships, they are not suitable for determining population risks because they are standards not to be exceeded, not exposure levels associated with a certain level of adverse health risk. They often incorporate safety factors intended to protect the most sensitive members of a population from the most sensitive adverse effect (i.e., that which occurs at the lowest dose). The documentation for the criteria and standards, however, is extensive, and integrates many types of adverse health effect data to be used as the basis for standard-setting. These documents, most of which have been updated very recently, include information on a variety of effects that occur at a variety of pollutant exposure levels and could be relied on for dose-response information for the purpose of performing risk assessments of energy production-related activities in developing countries.

c. Risk characterization issues

The final step in health risk assessment, risk characterization, combines information from the exposure and dose-response assessments to obtain estimates of the extent to which adverse health effects might occur in a population as a result of a particular exposure. In the case of energy production-related activities in developing countries, the outcome of a risk characterization might be the conclusion that 10% of the population downwind of a certain coal-fired electric plant is experiencing a 20% deficit in lung function and a 5% increase in mortality rate as a result of exposure to the nitrogen oxides, sulfur oxides, and particulate matter produced by the plant. Another risk characterization might conclude that in a certain city in a developing country, exposure to mobile sources is contributing to a 10-point IQ deficit among children, a 10% deficit in lung function, an increased risk of lung cancer of 10 new cases per 10,000 people, and a 5% increase in mortality rate due to the lead, carbon monoxide, polycyclic aromatic hydrocarbons, and particulate matter produced. These estimates of the human health impact of energy production could then be used to make risk management decisions about appropriate remedial or technology innovation alternatives.

d. Risk assessment versus risk management

Risk assessment is the characterization of the potential adverse health effects of human exposures to environmental hazards: risk assessment asks, "Is there a problem?" In contrast, risk management asks, "What can be done about it?" Risk management is the process of evaluating alternative actions and selecting among them. Risk management takes into account issues in addition to concerns about health, such as economic and technical feasibility, and public perception.

In the case of evaluating adverse health effects associated with energy production-related activities in developing countries, risk management would be performed following a health risk assessment, for example, to select among several innovative technologies an alternative that would produce the greatest reduction in health risk for the least cost.

6. Related, On-Going Activities

USAID has few, if any, projects in which a human health risk component has been incorporated into an energy technology project. Review of the on-line data base in the USAID library and discussions with Ronald Greenberg, Division Chief, Environment and Natural Resources, Europe Bureau (ENI/EUR/DR/ENR); Robert F. Ichord, Division Chief, Energy and Infrastructure, Europe Bureau (ENI/EUR/DR/EI); and, Dennis Carroll, Bureau for Global Programs, Field Support and Research, Office of Health (G/R&D/H/CD) identified only the following:

- The Department of Energy-sponsored, USAID-funded, Low-Level Emissions project in Kraków, Poland. This project is evaluating the emissions from small boilers and other small generators that provide heat and energy using low-quality fuels. There is no formal health risk component, however; qualitative consideration of human health risks is implicit, but quantitative evaluation is not being performed.

7. Proposed Activities

Human health risk assessment could conceivably play a role in any Office of Energy and Infrastructure project involving the implementation of cleaner alternative energy technologies. This role would be complementary to the primary activity and could be as extensive or as limited as interest and resources permit. Rough estimates of health risks can be made on the basis of whatever limited data are available in the country of interest as well as from comparisons to similar situations about which more may be known in other countries. More precise estimates of health risks can be made if ambient air quality and emissions monitoring programs are instituted and complex exposure models developed in the country of interest.

As there are no current models of human health risk assessment/energy production-related activities projects at USAID to follow, the first step in integrating health risk assessment into energy technology projects is to design pilot projects. The pilot projects could be add-ons to technical assistance programs in USAID-assisted countries that are currently or about to be underway involving, for example, implementation of cleaner alternative energy technologies. Health risks associated with current energy production practices would be estimated, and the extent to which each of several alternative technologies reduced those risks would be compared. This comparison could then serve as one of the bases for the choice among the technology alternatives. In addition, the extent to which a USAID project is expected to reduce a country's health risks is newsworthy and could serve as attractive publicity for USAID.

If several pilot projects indicate that including a health risk assessment component in innovative energy technology projects is feasible and useful, health risk assessment could become an integral part of future Office of Energy and Infrastructure activities.

References

Abramson, M. and Voigt, T. 1991. Ambient air pollution and respiratory disease. Med. J. Austr. 154:543-553

Agency for Toxic Substances and Disease Registry (ATSDR). 1992. Toxicological Profile for Lead. U.S. Dept. of Health and Human Services

Amdur, M.O. 1991. Air pollution. In: M.O. Amdur, J. Doull, and C.D. Klaassen, eds. Casarett and Doull's Toxicology. The Basic Science of Poisons. Fourth Edition. Pergamon Press: New York

Environmental Protection Agency (EPA). 1992. ARARs Fact Sheet. Compliance with the Clean Air Act and Associated Air Quality Requirements. Publ. No. 9234.2-22FS. Office of Solid Waste and Emergency Response. Washington, DC

Environmental Protection Agency (EPA). 1982. Air Quality Criteria for Particulate Matter and Sulfur Oxides. EPA 600/8-82-029a. Environmental Criteria and Assessment Office. Research Triangle Park, NC

Integrated Risk Information Service (IRIS). 1993. On-line data base

National Academy of Sciences (NAS). 1985. Epidemiology and Air Pollution. National Academy Press: Washington, DC

National Research Council (NRC). 1991. Environmental Epidemiology: Public Health and Hazardous Wastes. National Academy Press: Washington, DC

Office of Technology Assessment (OTA). 1991. Energy in Developing Countries. OTA-E-486. U.S. Congress. U.S. Government Printing Office: Washington, DC

Ostro, B. 1993. The association of air pollution and mortality: examining the case for inference. Arch. Environ. Health 48:336-342

Sexton, K., Selevan, S.G., Wagener, D.K., and Sybarger, J.A. 1992. Estimating human exposures to environmental pollutants: availability and utility of existing data bases. Arch. Environ. Health 47:398-407

Sexton, K., Gong, H., Bailar, J.C., Ford, J.G., Gold, D.R., Lambert, W.E., and Utell, M.J. 1993. Air pollution health risks: do class and race matter? Toxicol. Indus. Health 9:843-878

Sheppard, D. 1986. Mechanisms of bronchoconstriction from non-immunologic environmental stimuli. Chest 90:584-587

Wilson, R., Colome, S.D., Spengler, J.D., and Wilson, D.G. 1980. Health Effects of Fossil Fuel Burning. Assessment and Mitigation. Ballinger Publishing Company: Cambridge, MA