Summary and Findings of the EPA and CDC Symposium on Air Pollution Exposure and Health

HALÛK ÖZKAYNAK[a], BARBARA GLENN[b], JUDITH R. QUALTERS[c],
HEATHER STROSNIDER[c], MICHAEL A. MCGEEHIN[C], AND HAROLD ZENICK[d]

Authors' Affiliations:

[a] U.S. Environmental Protection Agency, National Exposure Research Laboratory,
RTP, NC, USA

[b]U.S. Environmental Protection Agency, National Center for Environmental Research, Washington, DC, USA

[c]U.S. Center for Disease Control and Prevention, Division of Environmental Hazards and Health Effects, Atlanta, GA, USA

[d] U.S. Environmental Protection Agency, National Health and Environmental Effects Research Laboratory, RTP, NC, USA

Corresponding Author:

Dr. Halûk Özkaynak

U.S.EPA National Exposure Research Laboratory (E205-01),
Research Triangle Park, NC 27711, USA
Tel: + 1 919 541-5172, Fax: +1 919 541-0239.

E-mail: ozkaynak.haluk@epa.gov

Running Title: Symposium on air pollution exposure and health

Key Words: air pollution, exposure, health information, surveillance, tracking, accountability

Abstract

The U.S. Environmental Protection Agency (EPA) and the U.S. Centers for Disease Control (CDC) co-organized a symposium on "Air Pollution Exposure and Health" at Research Triangle Park, North Carolina on September 19-20, 2006. The symposium brought together health and environmental scientists to discuss the state of the science and the cross-jurisdictional and methodological challenges in conducting air pollution epidemiology, environmental public health tracking, and accountability research. The symposium was held over two days and consisted of keynote and technical presentations on each of the three principal themes of this meeting: 1) monitoring and exposure modeling information, 2) health effects data, and 3) linkage of air quality and health data for research, tracking and accountability. After these technical presentations the participants were split into four break-out groups, to identify short-and long-term priorities for improving monitoring, exposure and health information and their linkages, for future air pollution health effects assessments. Afterwards, the participants engaged in a facilitated discussion of priorities, and suggested recommendations for federal and state agencies and health care providers. This paper summarizes the symposium presentations and the conclusions and recommendations developed during the meeting. The accompanying two papers which appear in this issue of the Journal provide more in-depth discussion of issues pertinent to obtaining and analyzing air pollution exposure and health information. The symposium succeeded in identifying areas where there are critical gaps of knowledge in existing air pollution exposure and health information and in discovering institutional or programmatic barriers, which impede accessing and linking disparate data sets. Several suggestions and recommendations emerged from this meeting, directed towards:1) improving the utility of air monitoring data for exposure quantification, 2) improving access to and the quality of health data, 3) studying emerging air quality and health issues, 4) exploring improved or novel methods for linking data, and 5) developing partnerships, building capacity and facilitating interdisciplinary communication. The meeting was successful in promoting an interdisciplinary dialogue around these issues and in formulating strategies to support these recommended activities. Finally, this symposium subsequently led to strengthening and initiating new partnerships or interactions between the EPA, CDC, States, academia and the research community at-large.

Introduction

The U.S. Environmental Protection Agency (EPA) and the U.S. Centers for Disease Control (CDC) co-organized a symposium on "Air Pollution Exposure and Health" at Research Triangle Park, North Carolina on September 19-20, 2006. The symposium brought together health and environmental scientists to discuss the state of the science and the cross-agencies jurisdictional and methodological challenges in conducting air pollution epidemiology, accountability[1] research, and environmental public health tracking. The main goal of this symposium was to facilitate an interdisciplinary dialogue that would identify and prioritize actions to support these activities. At this symposium, air pollution-related exposure and health issues were examined since programs dealing with air pollution are relatively more established than for multimedia pollutants. To this extent, the symposium also provided a forum for interaction between traditional air researchers in toxicology, epidemiology and modelers and those scientists more focused on public health surveillance including the application of indicators that may used in such surveillance.

Adverse effects of air pollution on human health have been well documented. They include acute and chronic effects of particulate matter and various gaseous air pollutants on morbidity and mortality (Pope and Dockery 2006; Domenici et al. 2006; Burnett et al. 2000; Kinney and Özkaynak 1991; Ito et al. 2005; Levy et al. 2005; Ware et al. 1993; Woodruff et al 1998). Health outcomes associated with air pollution range from changes in respiratory function to exacerbation of symptoms of asthma to more serious cardiopulmonary events, increased hospitalizations and deaths (Dominici et al. 2006; Gauderman et al. 2007; Schwartz 1999). Since the historic London fog episode of 1952 (U.K. Ministry of Health 1954; Bell et al. 2004), public health and academic organizations in the US and abroad began investigating more closely the impact of environmental exposures on human health and disease. Epidemiologic studies (which include longitudinal cohort studies and time series studies of air pollution health effects), along with focused panel studies and toxicological evaluations have established the scientific foundation for development of national and state regulatory standards to protect public health.

As actions are taken to improve air quality and protect public health, there also is a need to evaluate the success of such efforts. Consequently, EPA and other research organizations have begun placing a greater priority on accountability research programs to evaluate the human health impacts of various pollution mitigation or intervention actions. Ultimately, focused examination and assessment of the relationships between emissions, concentrations, exposures and adverse health outcomes will help support the development of more targeted source reduction strategies and improve the ability of EPA to evaluate the public health gains achieved as a result of implementing risk management programs.

The building blocks for understanding the public health impact of air pollution include good health surveillance and environmental monitoring data and appropriate methods and tools that relate these data to human exposures and health risks. In 2002, CDC launched the National Environmental Public Health Tracking Program (Tracking Program) with broad state and local

[1] Accountability is defined as the evaluation of the extent to which air quality regulations improve public health (HEI, 2003).

partnerships to integrate environmental, exposure and health information data into a nationwide, standardized, web-based data network (McGeehin et al. 2004). The Tracking Network is a public health surveillance system that will serve as a "one-stop shop" for data and information on environmental exposures, health effects, and, by linking these data, the possible spatial and/or temporal relation between them. These linkages can be used to develop and evaluate policy and interventions to reduce the burden of environmentally related health effects in communities and to generate hypotheses that will stimulate more in depth research into the air pollution-health relationship. Complimentary to CDC's efforts has been the concurrent development in EPA of the Environmental Information Exchange Network (EIEN) which is an Internet-based system used to securely exchange environmental and health data among EPA, states, tribes and territories, and other partners. Considerable effort is underway to allow for smooth data exchange between the Tracking and EIEN networks).

The connections between environmental public health tracking, etiologic research and risk management decisions or health promotion activities are illustrated in Figure 1. While each component in this diagram uses inputs from a variety of sources, the data and analyses produced in each area can contribute to success in the others. The successes of research, tracking and accountability programs critically depend on our ability to work across disciplines and institutions to: 1) reliably estimate pollutant-specific exposures; 2) ascertain cases or health outcomes of concern, and; 3) link exposures with health effects/diseases by appropriate quantitative techniques or models. Table 1 presents various institutional roles and responsibilities for assessing environmental concentrations, exposure, and health data at the local, state, and federal level. EPA and CDC are among the key federal organizations involved in addressing the problems of air pollution. However, state, local, academic, private and non-profit organizations also play a critical role in contributing to information gathering, synthesizing or processing and data analysis activities. It is obvious that the separation of responsibilities for environmental, exposure and health data in the states and at the federal level pose challenges for linking these data. Furthermore, the freedom to disseminate health data is restricted by state and federal laws designed to protect the privacy of individuals. Yet the success of these programs depends on the development of satisfactory mechanisms to provide researchers with access to health data across multiple state jurisdictions. In addition, differences in the degree of statutory authority to issue mandates for data reporting, coupled with the allocation of minimal resources for this purpose, have led to variable standardization and completeness in environmental and health datasets across local and state jurisdictions. The EIEN and the Tracking Program has spurred the development of new and strengthened federal-state partnerships and facilitated progress toward an integrated program linking environmental and health information to support health promotion and risk management initiatives (McGeehin et al., 2004; Litt et al., 2004). However, this endeavor continues to face significant challenges.

The symposium provided a forum for a systematic evaluation of these issues. The symposium presenters and participants discussed many of the key problems that limit the ability of research, accountability, and tracking programs to develop and link environmental, exposure and health measures. Some of the topics discussed include, the variability in spatial and temporal coverage of pollutant monitoring data, relevance of ambient monitoring or modeling information for estimating personal exposures; data requirements for empirical as well as physical

microenvironmental personal exposure modeling methods; the format, content, and validity of vital statistics and medical records; restricted access to health data and compliance with privacy protections; the absence of additional information about individuals that would improve the validity of effect estimates; barriers to the sharing of exposure and health information between institutions and jurisdictions, and; the need for complex analytical methodology. Recommendations were developed in issue-specific workgroups to address the limitations and accomplish the stated goals of these programs. The meeting was successful in promoting an interdisciplinary dialogue around these issues and in formulating strategies to support these recommended activities. Finally, this symposium subsequently led to strengthening and initiating new partnerships or interactions between the EPA, CDC, States, academia and the research community at-large.

.

Methods

Organization of the Symposium

The format of the two-day symposium consisted of introductory keynote presentations followed by moderated presentations on each of the three principal themes of this symposium. These sessions focused on: 1) monitoring and exposure modeling, 2) health effects data, and 3) linkage of air quality and health data for research, tracking and accountability. After the technical presentations on the second day, the participants were split into four break-out groups, to address the following topics:

- Ozone, PM and air toxics ambient monitoring and exposure modeling information,
- health effects data,
- exposure and health effects data for emerging health and air quality issues, and
- linkage and analysis of air quality and associated health effects.

The break-out groups also were tasked to identify short-and long-term priorities for future air pollution health effects research, tracking and accountability assessments. After a brief report-out from each of the break-out groups, the symposium participants engaged in a facilitated discussion of priorities, and suggested recommendations for federal and state agencies and health care providers.

Results

In the following, we summarize the symposium presentations and the conclusions and recommendations developed during the breakout groups and overall group discussions. Complete copies of symposium presentations and the break-out group reports are also available through the symposium website: http://www.epa.gov/nerl/symposium/.

Presentations

Keynote Presentations

Dr. Harold Zenick, Director of the National Health and Environmental Effects Research Laboratory (NHEERL) at U.S. EPA's Office and Research and Development (ORD) observed that the motivation for this symposium stemmed from many concurrent activities conducted by CDC and EPA over the last several years. While CDC is moving forward in environmental public health tracking, EPA has produced its first "Report on the Environment" (www.epa.gov/roe) and recently ORD launched its accountability research program, which is addressing whether links between agency actions and outcomes can be more directly documented. As part of this recent Program, ORD is developing a strategic framework to understand how to link environmental measures and health outcomes and define a research agenda for ORD. Clearly, the EPA's EIEN network and accountability research programs are closely related to CDC's surveillance and tracking activities. For example, EPA scientists are developing exposure models which can be used by CDC epidemiologists in studies of environmentally-related health outcomes. In some cases, connections between the efforts of the two Agencies are in place, whereas in other cases additional collaborations is being pursued. The hope is that the two Agencies can forge a new generation of research that combines both of these disciplines in an iterative fashion. Dr. Zenick concluded by stating that relying upon modeling tools may be the most promising way to address many environmental-health interactions in the future.

Dr. Michael McGeehin, Director of the Division of Environmental Hazards and Health Effects in CDC's National Center for Environmental Health discussed the role of surveillance in public health and the need to improve both health and environmental data for public health purposes. Currently, health and environmental data are fragmented and incompatible. To fill data gaps and integrate data systems, CDC's Environmental Public Health Tracking Program is developing a nationwide environmental public health tracking network. Tracking is synonymous with public health surveillance; it involves the ongoing collection, analysis, integration of data and dissemination of information to those who can use it to take action. For Tracking, three main types of data are pulled together: hazard, exposure, and health effects data. Tracking data will be used to track temporal and spatial trends, identify populations at risk, plan and evaluate public health interventions and stimulate research. To address these functions, the Tracking Program is also building capacity in environmental health at state and local health departments

Dr. Richard Scheffe, Senior Science Advisor with EPA's Office of Air Quality Planning and Standards (OAQPS), discussed the air accountability and monitoring programs at EPA and the current and emerging air quality management challenges. He discussed the likely implications of the revised particulate matter (PM) National Ambient Air Quality Standards (NAAQS) on monitoring, exposure, health effects and accountability assessments. As EPA moves to a lower standard for PM, it will be more challenging to monitor environmental conditions for health research and accountability. Within the Multi-Pollutant Analytical Framework of EPA, the Agency is evaluating how to harmonize across its current air programs, including criteria air pollutants (CAPs), mercury, and hazardous air pollutants (HAPs). The Agency is reorganizing its monitoring networks to reflect its multi-pollutant focus. In addition to

its accountability studies, EPA has embraced other issues, such as climate change, the ozone hole, and acid rain, in a more comprehensive manner.

Presentations from Session 1: Air Quality Monitoring and Exposure Modeling information

Dr. P. Barry Ryan of Emory University moderated the session, which addressed the current configuration of monitoring networks in the United States and availability of air quality data for modeling human exposure to ambient air pollution. The directive for the four speakers was to evaluate the status of the air monitoring program in order to recommend future directions.

Tim Hanley, of EPA OAQPS, described the monitoring networks for particulate matter (PM) and ozone, which are operated by states, cities, and local agencies using grant support from the EPA. EPA supports large robust networks for monitoring 24-hr average $PM_{2.5}$, PM_{10}, and hourly average ozone. These monitors are sited for specific purposes including the ascertainment of high pollution areas, general population exposure levels, and concentrations near specific sources, for example, next to roads. The $PM_{2.5}$ measurements are collected at about 600 sites in the U.S. every third day and at 100 sites every sixth day. The PM_{10} measurements are collected either every 6^{th} or 3^{rd} day around 1000 locations in the U.S. In contrast, continuous ozone monitors are deployed at approximately 1,200 sites by cities and states in areas downwind of cities and operate mostly during the ozone season. There are also 216 chemical speciation sites, where data are collected every third day on PM components including organic carbon, elemental carbon, sulfates, nitrates, carbon monoxide, and a host of metals. Speciation is not conducted for near-roadway or source-oriented monitors. In addition, 35 states collect speciated data on $PM_{2.5}$ every sixth day at 110 rural sites in a network called the Interagency Monitoring of Protected Visual Environments (IMPROVE), designed to monitor air quality in the nation's national parks. On the other hand, no speciation data are collected for PM_{10}, but EPA hopes to improve characterization on coarse PM ($PM_{10-2.5}$) as part of the planned National Core (NCore) Monitoring Network by July 2009. EPA is working on improving access to its monitoring data and is organizing a new AirNOW data management center (www.airnowtech.org).

Michael Jones, of EPA OAQPS, described the National Air Toxics Trends Stations (NATTS) monitoring sites, established in 2003 - 2004. The principal objectives of this monitoring program are to address hot spots, environmental justice, and public complaint issues. The 23 NATTS (17 urban and 6 rural) are co-located with $PM_{2.5}$ speciation samplers. Some sites also are co-located with Photochemical Assessment Monitoring Stations (PAMS). Samples are analyzed for volatile organic compounds (VOCs), carbonyls, PM_{10}, HAPs metals, and total suspended particulate (TSP) hexavalent chromium. Additional sites and analyses (e.g., semi-volatile organic compounds) may be added in 2008. Coordination has begun on local exposure and health studies through community-scale monitoring (www.epa.gov/ttn/amtic/aiartoxqa.html).

EPA integrates concentration measurements, emissions information, meteorological and other data in air quality models to predict pollutant concentrations on a national, regional and local geographic scale. Tyler Fox, EPA OAQPS, described the National Air Toxics Assessment (NATA) program, which emphasizes inhalation exposures from facility/pollutant-specific assessments. National-level risk estimates are generated by using census track-level risks by

pollutant, generated by dispersion modeling and available emissions. EPA recently released 1999 NATA data. The emerging focus for the NATA program is the integration of HAPs and CAPs through the Community Multiscale Air Quality (CMAQ) modeling framework.

Fred Dimmick, with the National Exposure Research Laboratory (NERL) of EPA ORD, outlined the application of EPA air quality models in a collaborative pilot project called Public Health Surveillance of Air Pollution Related Morbidity and Mortality (PHASE) which involves CDC's Tracking Program, EPA, and Tracking Programs in Maine, Wisconsin, and New York. The air quality model, CMAQ, is characterized by: 1) reliance on complete emissions inventories (updated every 3 years) and projections in other years, 2) complex atmospheric chemistry and fine particle chemistry, 3) fusion of CMAQ modeling outputs with monitoring data using statistical hierarchical Bayesian (HB) methods, 4) limitation of model outputs to 2001 and 2002, with a 2005 model anticipated. CMAQ models air concentrations using square grids that are at 36 km^2, 12 km^2, and/or 4 km^2 spatial resolutions. Comparisons to air quality measurements indicate that, except for modeled organic carbon (OC), the model performs fairly well over space and time. An important issue for air quality model applications in health and accountability studies is the determination of the right resolution needed for matching the model results with different health data. EPA is planning to build a tool for the environmental health tracking program, and will add a dataset that can inform concentration-exposure-health linkages. EPA is seeking input concerning the right metadata that health professionals need.

Drs. Lucas Neas (EPA ORD/NHEERL) and Halûk Özkaynak (EPA ORD/NERL) discussed alternative approaches to model exposure in air pollution health studies. Different approaches may be appropriate depending on the particular detail and scale of the health data used in an epidemiological study (e.g., county-level daily mortality counts or individual-level health status followed over a period of years). Current approaches range from area-wide assignment of ambient concentration measurements, use of GIS-based modeling methods to more sophisticated physical or mechanistic exposure modeling techniques. Dr. Neas described how GIS-based Land Use Regression (LUR) methods can be used with landscape information (e.g., proximity to roadways, traffic density, distance to nearby pollution sources, etc.) and limited monitoring data to estimate ambient pollutant concentrations at study subjects' geocoded home locations. Dr. Neas presented an example of a study conducted on the exposure of 6,000 children in El Paso, Texas that successfully employed the LUR modeling technique. Applications must address several issues, including, how to standardize the traffic metrics across all studies, the applicability of models developed for one location to other geographic areas, and whether a comparison can be made with diffusion models. Dr. Özkaynak explored how one can go beyond outdoor concentrations to actually predicting personal exposures using physical models. He described the key features of EPA's population exposure models, such as the Stochastic Human Exposure and Dose Simulation (SHEDS) model, Air Pollutant Exposure (APEX) model, and the Hazardous Air Pollutant Exposure Model (HAPEM). These models can provide spatially and temporally resolved exposure profiles for representative populations (cf. Burke et al. 2001, Özkaynak et al. 2008), which differ considerably from the corresponding ambient air quality concentrations. Atmospheric fate and transport models coupled with exposure models (i.e., CMAQ with SHEDS, APEX or HAPEM) are now being employed in various epidemiologic and accountability studies at EPA (cf. Isakov et al. 2006, Isakov and Özkaynak 2007).

Presentations from Session 2: Health Effects Data for Air Pollution Research, Tracking, & Accountability

Session 2, titled, "Health Effects Data for Air Pollution Research, Surveillance, and Accountability," was moderated by Dr. Mark Utell of the University of Rochester. Dr. Utell raised the question: does our health research and surveillance lead to making good decisions? It is important to examine whether regulatory actions to change emission levels result in improved human health. Dr. Utell challenged the session's presenters to consider this research application when addressing sources of data for human health outcomes and links to air pollution.

Tom Sinks, Deputy Director of the National Center for Environmental Health at the CDC, gave an overview of sources of health data available for research and surveillance. Public health promotion depends on surveillance systems. The purpose of surveillance is not regulatory in nature. It provides information to assess public health status, define public health priorities, evaluate programs, develop and target interventions, and disseminate information. Health data includes reportable conditions, health care services data, vital statistics, disease registries (special collections), and surveys including the National Health Interview Survey (NHIS), National Health and Nutrition Examination Survey (NHANES), and Behavioral Risk Factor Surveillance System (BRFSS). The CDC has identified asthma, chronic obstructive pulmonary disease, cardiovascular disease, and mortality to be related to air pollution exposure. Dr. Sinks stressed that information on a smaller geographic scale (county/zip code or smaller) is necessary to track or assess the impact of air pollution on health. Hospital discharge and emergency department visit data, vital statistics, and cancer and birth defects registry data can be obtained from state officials, but researchers must obtain study approval from an institutional review board to gain access to data associated with geographic location. Finally, Dr. Sinks discussed some barriers to gaining access to health data including confidentiality restrictions and data sharing prohibitions imposed by such statutes as the Health Insurance Portability and Accountability Act (HIPAA) and Family Educational Rights and Privacy Act (FERPA) developed to assure privacy.

Dr. George Thurston and Dr. Kazuhiko Ito, New York University School of Medicine, discussed the "State of Science" for acute health effects research. Dr. Thurston asserted that while there is no doubt that acute exposure to air pollution is associated with excess mortality, the size of the effect is uncertain. Studies examining air pollution effects in multiple cities using a standardized format have been largely consistent, but differences have been reported between studies examining specific particle components. Some sources of uncertainty may include publication bias, adjustments due to weather, and methodological issues. Spatial and temporal correlation of PM components has been found to vary across PM species and across cities. There are few monitoring locations collecting daily ambient pollution concentrations and the missing data contributes to a large degree of variability in exposure estimates. Drs. Thurston and Ito proposed future directions, including, resolution of modeling uncertainties (weather effects, lag structure choices), improvement of source-specific effect estimates (expand daily speciation data), and improvement of epidemiologic population exposure estimates (time-activity, outdoor-indoor contributions).

The "State of the Science" for air pollution-related chronic health effects research was reviewed by Dr. Arden Pope of Brigham Young University. Most air pollution studies have

focused on fine particles and the sulfate mortality effect. The literature reporting associations of long term PM exposure with cardiopulmonary and vascular mortality has grown. Some studies have evaluated respiratory disease and lung function change, heart disease and atherosclerosis, and inflammation/oxidative stress. The relevant time scale for exposure is a key question for research. Risk estimates increase when progressively longer time-scales are evaluated ranging from days, to months, to years. The size of the predicted risk also depends on the precision of the exposure estimate. There are research opportunities using existing cohorts to improve concentration and exposure metric assignments and he cited the American Cancer Society and Harvard study cohorts.

Dr. Marni Bekkedal, Wisconsin Department of Health and Family Services, discussed emerging issues in health effects and air pollution. Dr. Bekkedal noted that, while awareness is increasing, there is limited evidence that multiple sclerosis, amyotrophic lateral sclerosis, autism and other diseases are related to air pollution. She emphasized the need for improvements in case ascertainment, improvements in exposure assignments, and the development of evidence of biological plausibility. Currently these diseases do not have a clear consistent definition that is necessary for surveillance and research. The relevant period of exposure prior to disease incidence is believed to be between a few to many years, depending on the disease. These issues highlight the need for consistent, good quality long-term environmental monitoring and health surveillance. Finally, the animal models to establish biological plausibility for these endpoints are lacking. Development of toxicological assays to establish links with air pollution exposure will be important to guide surveillance and accountability studies.

Presentations from Session 3: Linking Air Quality & Health Data for Accountability and Tracking

Dr. Suzanne Condon, Massachusetts Department of Public Health, served as moderator for "Session 3: Linking Air Quality & Health Data for Accountability and Tracking". Dr. Condon discussed the importance of cross discipline collaboration and the ability of meetings such as this one to initiate cross discipline dialog.

Dr. Carol Gotway Crawford from CDC provided an overview of methodological and inferential considerations of the analysis of health and environmental data. These data are collected for different purposes, are rarely recorded at the same time and place, and are aggregated at different spatial units. Linking health and environmental data involve harmonizing geographic and temporal units, evaluating spatial support, and uncertainty. The statistical analyses must account for the uncertainties that arise from prediction during linkage as well as any uncertainties in the initial data. Linking, analyzing, and assessing the uncertainty are often performed as three separate steps, but methods such as Bayesian Hierarchical Models with Kalman Filtering can theoretically perform all three steps simultaneously. While methods may be developed to compensate for statistical and inferential issues, consideration must always be given to the fact that these data are collected for different purposes.

Dr. Andrew Smith from the Maine Centers for Disease Control and Prevention discussed the states' involvement in the PHASE project. PHASE was designed to enable health departments to link and analyze data on asthma related emergency department visits and hospitalizations with ozone data. Analysis of asthma and ozone in Maine is hindered by both

small numbers of health events and limited ozone monitoring. PHASE provided the means to extend the population under study to three states and to develop new techniques. Ozone monitoring data was combined with modeling data. Hierarchical Bayesian models and case crossover methods were used to evaluate the contribution of ozone to asthma morbidity. Important uncertainties in both the environmental and health data remain and will need to be addressed.

Dr. Eric Roberts of the California Department of Health Services discussed the spatial linkage and analysis of health outcome point data and environmental data. He used the linkage of traffic counts to birth outcome and asthma data in Alameda County to illustrate the benefits and challenges associated with such linkages. For the Alameda County linkage project, available traffic count data was used to create multiple metrics of traffic exposure. While these metrics were validated using NO_2 measurements taken throughout the county, further refinement is possible if data is available for factors such as the vehicular composition of traffic, temporal variations in traffic counts, and personal activity patterns. In addition to validation and improvements in hazard and exposure metrics, further development of spatial analytic methods designed for point data is needed. This linkage project used locally weighted estimation (loess) to account for spatial structure of residuals in the regression model.

Dr. Jerald Fagliano (New Jersey Department of Health and Senior Services) discussed the results and observations of an ecological analysis, linking incident cancers and air toxics at the census tract level. Data for cases of leukemia, brain cancer, and angiosarcoma occurring between 1979 and 2002 were obtained from New Jersey State Cancer Registry. Air toxics exposures were estimated for census tracts using data from the National Air Toxics Assessment (NATA), a national scale, multi-source model of estimated concentrations of 32 air toxics by EPA. Poisson regression models, adjusted for age, race, and poverty level, were generated for leukemia and benzene, brain cancer and vinyl chloride, and angiosarcoma and vinyl chloride. Such ecological analyses present many epidemiologic challenges. In addition to confounding due to unaccounted risk factors and exposure misclassification, these analyses were limited by possible selection bias due to incomplete geocoding. Cancer cases occurring in rural areas were more likely to be dropped from the analysis. Incompleteness in geocoding is a potential problem for ecologic analyses if lost cases are associated with exposure.

A presentation on EPA's accountability program prepared by Dr. Danelle Lobdell (ORD) and Susan Stone (OAQPS) was provided by Dr. Danelle Lobdell. The Clean Air Advisory Committee recommended that EPA work with health effects experts to develop measures to define and assess the human health impacts of air pollution and evaluate progress in reducing those impacts. Traditional evaluation of regulatory decisions and actions involve process indicators such as decreases in emissions, discharges, and pollutant levels in environmental media. EPA is currently developing and validating environmental public health indicators. There are several accountability activities within EPA including the OAR/ORD Air Accountability Team, OAQPS Health Indicators, ORD Accountability Initiative, and ORD/OEI Report on the Environment. Accountability requires a cross-disciplinary approach and collaboration with multiple stakeholders.

Findings and Recommendations

The meeting participants were next divided into four working groups to address issues related to environmental or health information or establishing linkages between them. The groups were moderated by participants with specific expertise who were tasked to determine short-term and long-term goals to overcome limitations, barriers, and challenges associated with relevant (e.g., monitoring, exposure, health or methodological) information applicable for each break-out group. They developed specific recommendations (*provided in more detail in the on-line supplement*) regarding the types of exposure and health information needed; the methodologies necessary to link them, and suggested approaches to promote better informational exchange between the practitioners of air pollution epidemiology research, tracking and accountability analyses. These findings were then discussed in the closing facilitated large-group discussions to identify commonalities and other cross-cutting issues. However, within the time and logistical constraints of this symposium, it was not possible to prioritize these recommendations. Overall, several common themes and recommendations emerged that apply to the entire main symposium themes (i.e., air pollution epidemiology, tracking and accountability). The recommendations were grouped under six categories: 1) Improve the utility of air monitoring data for exposure quantification, 2) Improve access to and the quality of health data, 3) Improve access to and the quality of health data, 4) Study emerging air quality and health issues, 5) Explore improved or novel methods for linking data, and 6) Develop partnerships, build capacity and facilitate interdisciplinary communication. A number of these issues are also covered in the accompanying papers by McKone et.al. (2008) and Thurston et al. (2008).

Conclusions

The symposium succeeded in identifying areas where there are critical gaps of knowledge in existing air pollution exposure and health information and in discovering institutional or programmatic barriers, which impede accessing and linking disparate data sets. Various strategies for enhancing the exiting monitoring networks, in order to meet the specialized needs of human exposure and health researchers, were proposed. Limitations of available monitoring and health data collection systems, and the means to be able to link them, in order to address emerging air quality and health issues (such as, long latency health outcomes, MS, autism, cancers) were addressed. A number of improved or novel approaches for linking environmental, exposure and health data were suggested. Perhaps the most significant problem raised during the meeting was the clear need to improve access to and the quality of existing health data. A number of considerations for standardization of health data collection, compilation and sharing were proposed, and some are now being considered. Participants acknowledged that no single institution can provide all of the expertise nor the resources required to generate the information or the analyses needed to link the various hazard, exposure and health data sets. The symposium participants also recognized that in order to improve our current capabilities in the area of air pollution and health evaluations, we will need to develop: new or stronger collaborations; leverage resources; build capacity, and; facilitate interdisciplinary communications through future meetings similar to this one.

The symposium has already helped catalyze a number of partnerships or interactions between the EPA, CDC, States and the academia. EPA and CDC have recently extended their memorandum of understanding and instituted and Interagency Agreement focusing further on the EPA-CDC PHASE program. Both EPA and CDC have new and on-going collaboration with various States that focus on developing and linking enhanced air pollution exposure indicators with available health information. Both Agencies are also pursuing new opportunities for establishing expanded collaborations with academia and research community. Finally, EPA and CDC are actively engaged in promoting and facilitating an interdisciplinary dialogue with the exposure and health community through upcoming workshops and conferences. We hope to evaluate the successes and results of these efforts at a follow-up symposium or a suitable meeting in the near future.

Acknowledgements

We thank the symposium Steering Committee members: V. Boothe (CDC), G. Foley (EPA), P. Meyer (CDC), L. Reiter (EPA), and L. Neas (EPA) for their valuable assistance with the organization of this meeting. We are also grateful to many presenters and attendees from federal, state and local agencies, academia and private sector organizations for their important contributions during the meeting and the break-out group discussions.

Disclaimer

The United States Environmental Protection Agency through its Office of Research and Development and the United States Centers for Disease Control through its Division of Environmental Hazards and Health Effects have partially funded and collaborated in the research described here under EPA contract No. EPA-C-05-015 to SCG, Inc. and under CDC contract No. xxx-CDC to provide to Nancy Tosta (Ross Associates). This manuscript has been subjected to both EPA and CDC Agency reviews and approved for publication. [Need to insert here the standard CDC disclaimer statement that this does not represent the opinion of the Agency]

References

Bell, M.L., Davis, D.L and Fletcher, T.A retrospective assessment of mortality from the London Smog Episodes of 19542: the role of influenza and pollution. *Environ Health Perspect.* 2004: 112:6-8.

Burke, J.M., Zufall, M. J and Özkaynak, H. A population exposure model for particulate matter: case study results for PM2.5 in Philadelphia, PA. *J Exp Anal Environ Epidemiol* 2001: 11: 470-489.

Burnett, R.T., Brook, J., Dann, T., Delocla, C., Philips, O., Cakmak, S., Vincent, R., Goldberg, M.S., Krewski, D. Association between particulate- and gas-phase components of urban air pollution and daily mortality in eight Canadian cities. *Inhal Toxicol* 2000; 12 Suppl 4:15-39.

Dominici F, Peng R.D, Bell M.L, Pham L, McDermott A, Zeger S.L, and Samet J.M. Fine Particulate Air Pollution and Hospital Admission for Cardiovascular and Respiratory Disease; J. Am. Med. Assoc. 2006**;** 295:1127-1134.

Gauderman W. J, Vora H, McConnell R, Berhane K, Gilliland F, Thomas D, Lurmann F, Avol E, Kunzli N, Jerett M, Peters J. Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study. *Lancet* 2007; 369 (9561):571-7.

HEI Accountability Working Group. 2003. Assessing Health Impact of Air Quality Regulations: Concepts and Methods for Accountability Research. Communication 11. Health Effects Institute, Boston MA.

Isakov V., Graham S. Burke J. and Özkaynak H. Linking air quality and exposure models. *EM Magazine*, September 2006: 26-29.

Isakov, V. and Özkaynak, H. A modeling methodology to support evaluation of public health impacts of air pollution reduction programs. Proceedings of the 29th International Technical Meeting on Air Pollution Modeling, Aveiro, Portugal, Sept 24-28, 2007.

Ito, K., De Leon S.F., and Lippmann, M. Associations between ozone and daily mortality: analysis and meta-analysis. *Epidemiology* 2005; 16: 446-457.

Kinney, P.L., and Özkaynak, H. Associations of daily mortality and air pollution in Los Angeles County. *Environ. Res.* 1991; 54:99-120.

Kinney P.L, Chillrud S.N, Ramstrom S., Ross, J., and Spengler J.D. Exposure to multiple air toxics in New York City. *Environ Health Perspect* 2002: 110(suppl 4):539-546.

Levy, J.I., Chemerynski, S. M. and Sarnat, J. A. Ozone exposure and mortality: an empirical Bayes metaregression analysis. *Epidemiology* 2005; 16: 458-468.

Litt J, Wismann A, Resnick B, Dawson RS, Hano M and Burke TA. Advancing health and environmental disease tracking: a 5-year follow-up study. AJPH 2007; 97:456-463.

McGeehin M, Qualters J, Niskar A. 2004. National Environmental Public Health Tracking Program: Bridging the Information Gap. *Environ Health Perspect.* 112(14):1409-1413.

McKone, T.E., Ryan, P.B., and Özkaynak H. Exposure information in environmental health research; current opportunities and future direction for particulate matter, ozone and toxic air pollutants. *J Expos Sci Environ Epidemiol,* 2008 (Accepted).

Özkaynak H., Ryan P. B, Spengler J.D, and Laird, N.M. Bias due to misclassification of personal exposures in epidemiologic studies of indoor and outdoor air pollution. *Environment International*. 1986; 12:389-393.

Özkaynak H., Palma T., Touma J.S., and Thurman J. Modeling population exposures to outdoor sources of hazardous air pollutants. *J Expos Sci Environ Epidemiol*, 2008;18, (1):45-58. .

PEHC 2000a. America's Environmental Health gap: why the country needs a nationwide health tracking network-companion report, Baltimore, MD: Pew Environmental Health Commission, Johns Hopkins School of Public Health.

PEHC 2000b. Attack on asthma: why America needs a public health defense system to battle environmental threats. Baltimore, MD: Pew Environmental Health Commission, Johns Hopkins School of Public Health.

PEHC 2000c. Healthy from the start: why America needs a better system to track and understand birth defects and the environment. Baltimore, MD: Pew Environmental Health Commission, Johns Hopkins School of Public Health.

Pope, C. A III and Dockery, D. W Critical review: health effects of fine particulate air pollution: lines that connect. *J Air Waste Manage Assoc* 2006; 56: 709-742.

Schwartz J. Air pollution and hospital admissions for heart disease in eight U.S. counties. *Epidemiology* 1999; 10: 17-22.

Thurston, G.D., Bekkedal, M.Y.V., Roberts, E.R., Ito, K., Pope, C.A III, Glenn, B., Özkaynak H., and Utell, M.J. Emerging health and air quality issues for air pollution epidemiology, surveillance and accountability. *J Expos Sci Environ Epidemiol,* 2007 (Submitted).

U.K. Ministry of Health 1954. Mortality and morbidity during the London Fog of December 1952. Reports on Public Health and Medical Subjects No. 95. London Ministry of Health.

Ware J.H, Spengler J.D, Neas L.M, Samet J.M, Wagner G.R, Coultas D, Özkaynak H, Schwab M. Respiratory and irritant health effects of ambient volatile organic compounds: The Kanawha County Health Study. *Am J Epidemiol*, 1993; 137(12):1287-1301.

Woodruff, T.J., Axelrad, D.A., Caldwell, J., Morello-Frosch, R., and Rosenbaum, A. Public health implications of 1990 air toxics concentrations across the United States. *Environ Health Perspect*. 1998; 106 (5): 245-241.

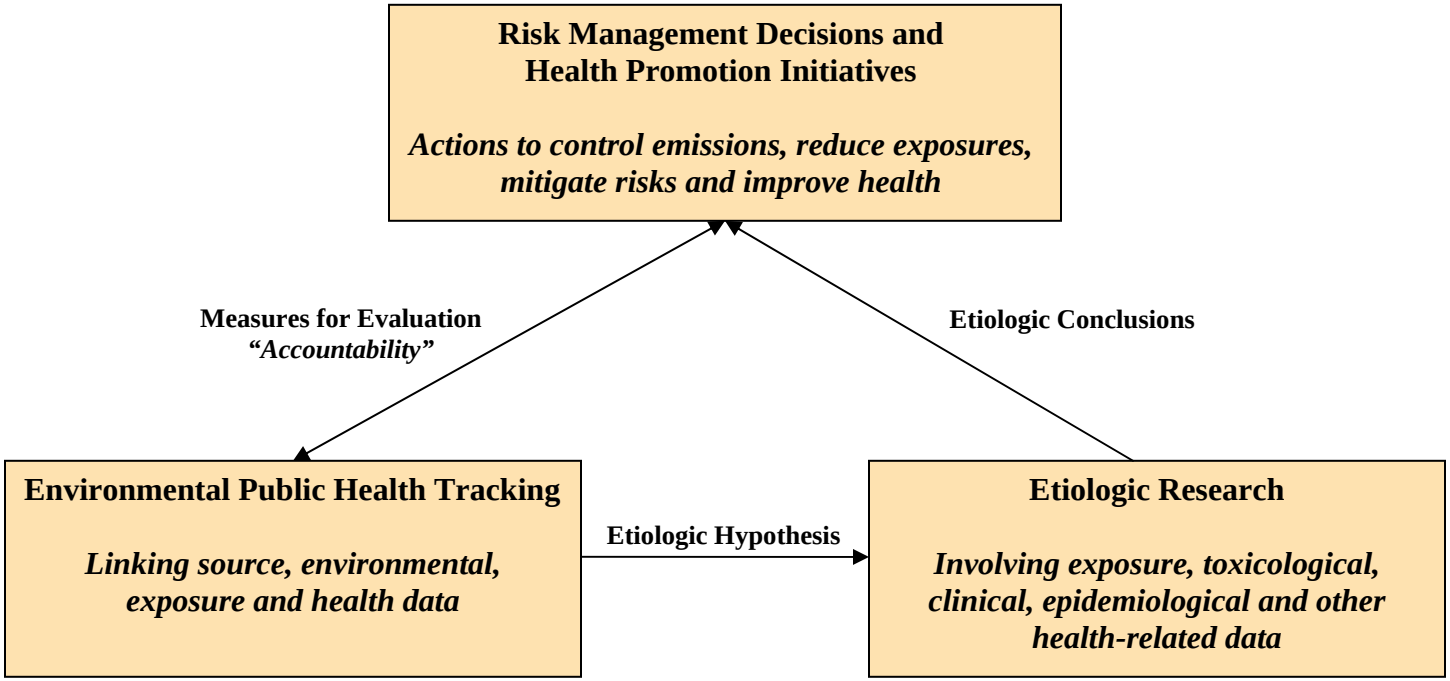

Figure1: Linkages between environmental public health tracking, etiologic research, risk management decisions and health promotion activities.

Table 1: Roles and Responsibilities of Different Environmental Public Health Organizations

Roles and Responsibilities of Different Environmental Public Health Organizations				
Data Types	Local organizations	State Institutions	Federal Institutions	Research Institutions
Hazard (e.g., industrial and motor-vehicle emissions, ambient concentrations, atmospheric models)	Private industry, air quality management agencies –Measurements, data collection, summarization, reporting to state/federal government	Environmental agencies – Data collection & compilation, reporting to EPA	EPA – Data compilation, dissemination, and analysis and regulatory support	Academic & private organizations – Data analysis & interpretation
Exposure (e.g., land use regression models, personal exposure monitoring, biomonitoring, mechanistic exposure models)		Health Departments – Data analysis for research, tracking & risk management	EPA, CDC – Data collection, data analysis for research, tracking & risk management	Academic & private/non-profit organizations (e.g., HEI, EPRI, ACC, etc.) – Data collection, data analysis & interpretation for research
Health (e.g., vital statistics, disease registries, health surveys, hospital discharge or billing records, school attendance records)	Private & public health care providers, individual & group medical practices, local public health agencies, schools – Data collection, summarization, reporting to state/federal government	Health Departments - Data collection & compilation, reporting to CDC, summarization and dissemination, data analysis for health promotion, linkage with environmental data for tracking & research	CDC – Data collection, compilation, analysis & dissemination for health promotion. CDC & EPA - Linkage with environmental data for tracking, research, risk management & “accountability” studies	Academic & private organizations – Data collection, Linkage with environmental data for research & “accountability” studies