# The Workshop on the Source Apportionment of PM Health Effects: Inter-Comparison of Results and Implications

George D. Thurston[1], Kazuhiko Ito[1], Therese Mar[2], William F. Christensen[3], Delbert J. Eatough[3], Ronald C. Henry[4], Eugene Kim[5], Francine Laden[6], Ramona Lall[1], Timothy V. Larson[2], Hao Liu[2], Lucas Neas[7], Joseph Pinto[7], Matthias Stölzel[8], Helen Suh[6], Pentti Paatero[9] and Philip K. Hopke[5]

1. New York University School of Medicine, 2. University of Washington, 3. Brigham Young University, 4. University of Southern California, 5. Clarkson University, 6. Harvard School of Public Health, 7. U.S. Environmental Protection Agency, 8. GSF National Research Center for Environment and Health, Germany, 8. University of Helsinki, Finland

## INTRODUCTION

While the association between exposure to ambient fine particulate matter mass (PM2.5) and human mortality is well established, the most responsible particle types/sources are not yet certain. In May 2003, the U.S. Environmental Protection Agency's Particulate Matter Centers Program sponsored the "Workshop on the Source Apportionment of PM Health Effects". The goal was to evaluate the consistency of the various source apportionment methods in assessing source contributions to daily PM2.5 mass-mortality associations. Nine research institutions, using varying methods, participated in the estimation of source apportionments of PM2.5 mass samples collected in Washington, DC and Phoenix, AZ. Apportionments were evaluated for their respective associations with mortality using Poisson regressions, allowing a comparative assessment of the extent to which variations in the apportionments contributed to variability in the source-specific mortality results. Ther results of this workshop have been summarized in a series of papers[1-4]

## SOURCE APPORTIONMENT

Multiple groups (Table 1) have analyzed particulate composition data sets from Washington, DC and Phoenix, AZ[2]. Similar source profiles were extracted from these data sets by the investigators using different factor analysis methods. There was good agreement among the major resolved source types. Crustal (soil), sulfate, oil, and salt were the sources that were most unambiguously identified (generally highest correlation across the sites). Traffic and vegetative burning showed considerable variability among the results with variability in the ability of the methods to partition the motor vehicle contributions between gasoline and diesel vehicles. However, if the total motor vehicle contributions are estimated, good correspondence was obtained among the results. The source impacts were especially similar across various analyses for the larger mass contributors (e.g., in Washington, secondary sulfate SE =7%, and 11% for traffic; in Phoenix, secondary sulfate SE=17%, and 7% for traffic)). Especially important for time-series health effects assessment, the source-specific impacts were found to be highly correlated across analysis methods/researchers for the major components (e.g., mean analysis to analysis correlation, r > 0.9 for traffic and secondary sulfates in Phoenix and for traffic and secondary nitrates in Washington. The sulfate mean r value is > 0.75 in Washington.). An ANOVA analysis was performed on the mean source contributions to examine the between-source as compared to the between-group variance. Figure 1 presents the central estimate of the source contributions and the 95% confidence intervals for Washington, DC and Figure 2 presents analogous results for . The results show that between-source variance is greater than between-group variance with p <0.001.

Table 1. Summary of the data analyses performed by the various participating groups.

| Group | | Phoenix, AZ data | Washington, DC data |
|---|---|---|---|
| BYU | Eatough | UNMIX | UNMIX |
| | Christensen | | Iterated Confirmatory FA |
| Clarkson (CU) | Hopke/Kim | PMF2 | PMF2 |
| | | ME | |
| | | Expanded Model (ME) | |
| GSF | Stölzel | APCA | |
| Harvard (EPA) | Laden/Neas | Target Rotated APCA | Target Rotated PCA |
| NYU | Thurston/Ito/Lall | PMF2 and APCA | PMF2, APCA, and Single element multiple regression |
| USC | Henry | UNMIX | UNMIX |
| U. Washington | Larson | PMF2 | |

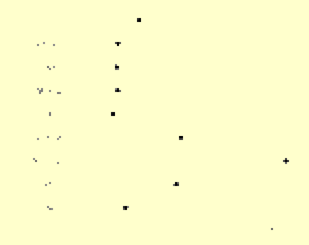

Figure 1. ANOVA results for the source apportionments from the IMPROVE site in Washington, DC

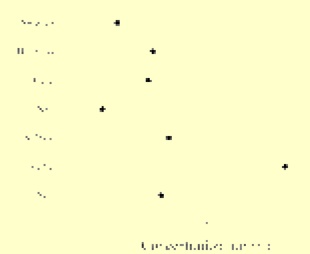

Figure 2. ANOVA results for the source apportionments from the site in Phoenix, AZ

Overall, although these intercomparisons suggest areas where further research is needed (e.g., better division of traffic emissions between diesel and gasoline vehicles), they provide support the contention that $PM_{2.5}$ mass source apportionment results are consistent across users and methods

## HELATH EFFECT MODELING

The relationships between source apportionment and health effects analyses was investigated by examining the associations between daily mortality and the estimated source-apportioned $PM_{2.5}$. For Washington, DC, a Poisson Generalized Linear Model (GLM) was used to estimate source-specific relative risks at lags 0-4 days for total non-accidental, cardiovascular, And cardio-respiratory mortality adjusting for weather, seasonal/temporal trends, and day-of-week. Source-related effect estimates, and their lagged association patterns were similar across investigators/methods. The varying lag structure of associations across source types, combined with the Wednesday/Saturday sampling frequency made it difficult to compare the source-specific effect sizes. The largest (and most significant) percent excess deaths per 5th-to-95th percentile increment of apportioned $PM_{2.5}$ for total mortality was for secondary sulfate (variance-weighted mean percent excess mortality = 6.7% [95%CI: 1.7, 11.7]), but with a peculiar lag structure (lag 3 day). Primary coal-related $PM_{2.5}$ (only three teams) was also significantly associated with total mortality with a 3-day lag. Risk estimates for traffic-related $PM_{2.5}$, while significant in some cases, were more variable. Soil-related PM showed smaller effect size estimates, but they were more consistently positive at multiple lags. The cardiovascular and cardio-respiratory mortality associations were generally similar to those for total mortality. Alternative weather models generally gave similar patterns, but sometimes affected the lag structure.

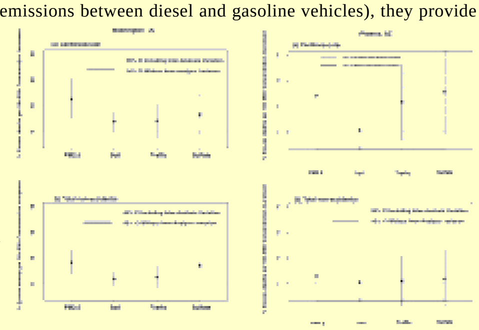

Figure 3. Mean Relative Risks (RR) Estimates and 95% Confidence Intervals of Cardio-vascular and Total Daily Mortality, for each Major Source Category in Washington, DC and Phoenix, AZ

The associations between the participant's estimated source contributions of PM2.5 for Phoenix, AZ for the period from 1995-1997 and cardiovascular and total non-accidental mortality were analyzed using Poisson generalized linear models (GLM). The base model controlled for extreme temperatures, relative humidity, day of week, and time trends using natural spline smoothers. The same mortality model was applied to all of the apportionment results to provide a consistent comparison acrosssource components and investigators/methods. Of the apportioned anthropogenic PM2.5 source categories, secondary sulfate, traffic, and copper smelter-derived particles were most consistently associated with cardiovascular mortality. The sources with the largest cardiovascular mortality effect size were secondary sulfate (median estimate = 16.0% per 5th-to-95th percentile increment at lag 0 day among eight investigators/methods) and traffic (median estimate = 13.2% per 5th-to-95th percentile increment at lag 1 day among nine investigators/methods). For total mortality, the associations were weaker. Sea salt was also found to be associated with both total and cardiovascular mortality, but at 5 day lag. Fine particle soil and biomass burning factors were not associated with increased risks. Variations in the maximum effect lag varied by source category suggesting that past analyses considering only single lags of PM2.5 may have underestimated health impact contributions at different lags. Further research is needed on the possibility that different PM2.5 source components may have different effect lag structure. There was considerable consistency in the health effects results across source apportionments in their effect estimates and their lag structures. Variations in results across investigators/methods were small compared to the variations across source categories.

## REFERENCES

1 The Workshop on the Source Apportionment of PM Health Effects: Inter-Comparison of Results and Implications, G.D. Thurston, K. Ito, T. Mar, W.F. Christensen, D.J. Eatough, R.C. Henry, E.Kim, F. Laden, R. Lall, T.V. Larson, H. Liu, L. Neas, J. Pinto, M. Stölzel, H. Suh, and P.K. Hopke, *Environmental Health Perspectives* (in press, 2005).

2 PM Source Apportionment and Health Effects: 1. Intercomparison of Source Apportionment Results, Hopke, P.K., Ito, K., Mar, T., Christensen, W.F., Eatough, D.J., Henry, R.C., Kim, E., Laden, F., Lall, R., Larson, T.V., Liu, H., Neas, L., Pinto, J., Stölzel, M. Suh, H., Paatero, P. and Thurston, G.D., J. Exposure Analysis Environmental Epi. (in press, 2006).

3 PM Source Apportionment and Health Effects: 2. An Investigation of Inter-method Variability in Associations between Source-Apportioned Fine Particle Mass and Daily Mortality in Washington, DC, Ito, K., Christensen, W.F., Eatough, D.J., Henry, R.C., Kim, E., Laden, F., Lall, R., Larson, T.V., Naes, L., Hopke, P.K., Thurston, G.D., J. Exposure Analysis Environmental Epi. (in press, 2006).

4 PM Source Apportionment and Health Effects. 3. Investigation of Inter-method Variations in Associations between Estimated Source Contributions of PM2.5 and Daily Mortality in Phoenix, AZ, Mar, T.F., Ito,K., Koenig, J.Q., Larson, T.V., Eatough, D.J., Henry, R.C., Kim, E., Laden, F., Lall, R., Naes, L., Stölzel, M., Paatero, P., Hopke, P.K., Thurston, G.D., J. Exposure Analysis Environmental Epi. (in press, 2006).

## ACKNOWLEDGMENTS

The Workshop was organized under the auspices of the participating U.S. EPA PM Health Effects Research Centers (grant R827351 at NYU, R827351 at the University of Washington, R827353 at Harvard University, and R927354 at the University of Rochester). We thank the individual researchers who undertook participation in this workshop, often on their own time and resources. The information in this poster has been subjected to review by EPA's National Health and Environmental Effects Research Laboratory and approved for publication. Approval does not signify that the contents reflect the views of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. Support for the organization and administration of the workshop was also provided by the New York State Energy Research and Development Authority (NYSERDA grant 375-34215).