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RESEARCH ARTICLE

Wood smoke risk assessment: Defining the questions

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Abstract
Risk assessment provides a framework for combining and evaluating scientific data on source-to-health effects for contaminants that could potentially affect the health of human populations. It utilizes an integrated approach to hazard identification, dose response, exposure assessment, and risk characterization. Since the range of potential exposure scenarios is considerable, given the complexity of wood-smoke sources and emissions, there is a need for defining the critical characteristics for the key parameters leading to adverse health outcomes. During the International Biomass Smoke and Health Effects (IBSHE) conference at the University of Montana (August 2007), the breakout group entitled "Risk Assessment: Defining the Questions" was tasked with evaluating the current state of the science in regard to risk assessment involving biomass smoke exposure. As a result of these discussions, important data gaps and future research questions were identified that are reported in this article.

Keywords: *Biomass; exposure; PM; risk assessment; wood smoke*

Introduction

The International Biomass Smoke and Health Effects (IBSHE) conference was held at the University of Montana on August 21 and 22, 2007. This article presents the findings of the breakout session entitled "Risk Assessment: Defining the Questions."

Background

Smoke from biomass burning has some unique components, but also shares many physical and chemical characteristics with emissions from other combustion sources (Fine et al., 2004; Hays et al., 2005; Clinton et al., 2006; Sinha et al., 2006; Dhammapala et al., 2007; Gustafson et al., 2007; Bergauff et al., 2008; Braun et al., 2008). Unlike the traditionally regulated fossil fuel combustion sources that burn specific fuel types under relatively well-controlled and efficient combustion conditions, biomass burning can involve multiple types of fuels (i.e., different woods, grasses, peat, crop residues, animal dung, etc., with varying composition and water content) burned under different conditions (i.e., smoldering versus flaming). Likewise, smoke can be generated from a wide variety of combusting modalities (woodstoves, cookstoves, uncontrolled forest fires, controlled open burning, etc.) over a very broad range of spatial (from an outdoor wood boiler to an uncontrolled forest fire) and temporal scales (from hours to weeks).

Consistent with the broad range of materials, conditions, and scales of origin and impact, both the gas- and particle-phase composition of emissions are complex and highly dynamic, so that these characteristics need to be considered when assessing the risk from exposure to biomass smoke (McKendry et al., 2004; Oanh et al., 2005; Buzcu et al., 2006; Gorin et al., 2006; Niemi et al., 2006; Zheng et al., 2006; Subramanian et al., 2007).

Exposure concentrations and chemical profiles are expected to vary significantly depending on specific scenarios and human receptors (Fine et al., 2004; Olsson et al., 2004; Hannigan et al., 2005; Kocbach et al., 2005; Molnar et al., 2005; Larson et al., 2007; Nopmongcol et al., 2007; Oliveira et al., 2007; Saksena et al., 2007; Ward et al., 2007; Barn et al., 2008; Gimbutaite and Venckus, 2008; Kim and

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Hopke, 2008a, 2008b; Kleeman et al., 2008; Ward et al., 2008; Zhang et al., 2008). These can range from the elevated, close-to-source inhalation of unvented emissions associated with biomass burning while cooking indoors (typical of many developing countries), to the lower concentration, repeated seasonal exposures encountered inside residences using low-emission, well-vented woodstoves for residential space heating. Low-level exposure to primarily emitted and secondarily formed air pollutants in ambient and indoor air can also occur due to long-range transport of wild or prescribed forest fire and agricultural residue burning plumes. These plumes can be transported over very long distances while undergoing chemico-physical transformations, resulting in exposures different than those found close to the source.

Exposure durations can also vary, including quasi-continuous (such as during indoor cooking or within homes using woodstoves) to episodic (multiple-day exposures that repeat seasonally and predictably over a lifetime, such as those associated with the common practice of burning agricultural residues prior to replanting). Exposures to communities located immediately downwind from wildland forest fires can be of low frequency and predictability, but can also result in episodes of highly elevated concentrations of smoke-related particulate matter (PM) over short and multiple-day time periods. High-intensity exposures can also be experienced in occupational scenarios such as during wildland forest fire fighting (Lewtas, 2007; Robinson et al., 2008; Swiston et al., 2008). This complexity of exposure duration impacts the ability to perform risk characterization in a systematic manner, as it may be difficult to extend estimates of risks across scenarios unless there are well-characterized, wood-smoke-specific, biologically relevant exposure metrics linked to equally well-defined health outcomes.

Risk assessment provides a framework for combining and evaluating scientific data on source-to-health effects for contaminants that have the potential to harm human populations. Proper risk assessment plays an important role in helping to inform policy decisions in protecting public health. Specifically, this framework provides for a systematic evolution of the scientific data relevant to (1) hazard identification, (2) dose response, (3) exposure assessment, and (4) risk characterization. When assessing the potential for exposure when dealing with biomass smoke, there are still many data gaps and research questions that need to be addressed in the effort to adequately protect specific populations under a variety of exposure scenarios.

Panel discussion

The International Biomass Smoke and Health Effects (IBSHE) conference was held August 21 and 22, 2007 at the University of Montana in Missoula. In addition to presentations throughout the conference, breakout sessions were held to identify and discuss gaps of knowledge in the field of smoke-related health effects. One of the breakout sessions—"Risk Assessment: Defining the Questions"—was tasked with identifying the current state of the science in regard to risk assessment involving biomass smoke exposure. Specifically, discussions in this breakout session considered: (1) whether the $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS), largely based on studies in urban areas with ambient aerosols dominated by conventional fossil fuel combustion emissions, are protective of human health when wood smoke is the major contributor to the atmospheric PM load, and (2) whether, to what extent, where, and under which exposure scenarios wood smoke may be a significant and discernable contributor to the air pollutant mix such that the attributable risk could be estimated.

Hazard identification

As summarized in several review articles (Ezzati and Kammen, 2002; Zelikoff et al., 2002; Naeher et al., 2007; Lewtas, 2007), there is a growing body of evidence from human and animal studies that exposure to wood smoke poses a risk to human health at environmentally relevant concentrations. These adverse health effects range from irritancy to serious respiratory diseases, including chronic obstructive airway disease and lung cancer. Some types of effects reported to be associated with wood smoke are not unlike those of mixed, urban ambient PM for both cancer and non-cancer endpoints (Mishra et al., 2004; LeVan et al., 2006; Gerlofs-Nijland et al., 2007). The Risk Assessment breakout session considered three important future research questions: (1) Are there effects (perhaps irritancy under certain exposure conditions?) more intrinsically and specifically associated with exposure to wood smoke compared to emissions from traditional urban sources such as industrial and vehicular emissions? (2) Is there a characteristic(s) common and unique to all wood smoke that is critical for assessing risk, or are there important differences in composition among different types of smoke (i.e., wildland vs. agricultural vs. woodstoves, etc.)? (3) Are specific gas-phase components important for effects such as irritancy?

Dose response

The preponderance of characterization and health studies have focused on the particle-bound phase of wood smoke using the U.S. Environmental Protection Agency (EPA)-sanctioned National Ambient Air Quality Standards (NAAQS) for particulate matter as a referent metric. While there is a large body of data available to establish dose response for the gas-phase NAAQS pollutants that are also components of biomass burning emissions, such information is far less than complete for the particle-bound and air toxics fraction of biomass burning emissions. Wood-smoke exposure concentrations in the United States and other developed countries are typically lower than those that have been associated with severe lung disease. However, existing evidence suggests that short-term exposures can lead to irritancy and transient changes in inflammatory markers—with chronic endpoints yet to be characterized. Low-level chronic exposures can impact susceptible individuals, such as those with preexisting respiratory or cardiopulmonary disease, and thus may affect a considerable fraction of the population in the developed countries where wood is used for space and water heating, or where exposures occur during controlled and uncontrolled fires. While the available evidence suggests that health endpoints associated with wood-smoke exposure under the conditions prevalent in the developed world are similar to those reported for urban PM, the relative potency in dose response for cancer and non-cancer endpoints remains uncertain. Specific dose-response research questions identified from the risk assessment breakout session include: (1) Given well-defined endpoints, is the potency of wood smoke particles similar to that of mixed ambient PM? (2) Are there differences in the toxic potency between wood smoke particles generated by different combustors? (3) Are there differences in the toxic potency of freshly generated versus aged wood smoke aerosols? (4) Are there specific wood-smoke components that can be quantitatively linked to specific responses, and are these components unique to wood smoke?

Exposure assessment

As indicated earlier, scenarios for assessing wood smoke exposure can vary widely with respect to concentration, composition, and duration. Given this complexity, identification of specific qualitative and quantitative tracers that can be used for source identification and exposure assessment is a critical need. Evidence to date suggests that organic tracers such as levoglucosan and methoxyphenols are promising candidates as unique tracers, but there is significant variability in the relative quantitative composition of these tracers due to type of fuel combusted, burning conditions, and time course during the burning event (Conde et al., 2004; Garcia et al., 2005; Simpson et al., 2005; Engling et al., 2006; Jordan et al., 2006; Kleeman et al., 2008). Composite vectors of organic tracers rather than unique compounds or compound classes appear more amenable for use in exposure assessment. Unlike other sources, characterization of emission profiles may be insufficient because of the dynamic nature of the organic tracers. The use of biomarkers to assess wood smoke exposure is promising, yet there are apparent limitations as quantitative indicators of exposures (Dills et al., 2006; Clark et al., 2007; Hinwood et al., 2008; Migliaccio et al., 2009). Important future research questions identified by the risk assessment group for exposure assessment include: (1) What are the most prevalent exposure scenarios (i.e., source, concentration, duration) and pathways of exposure? (2) What are the most effective source apportionment techniques for resolving and quantifying wood-smoke exposure? (3) Are there specific components that can be used as external markers for wood-smoke exposure? (4) If so, are they applicable across all scenarios, or only some scenarios? (5) Are there other potential chemical markers of wood smoke we need to focus on (i.e., gas and/or particle phases) when assessing exposures? (6) Which chemical markers of wood smoke can be used to aid source apportionment techniques?

Risk characterization

The objective of risk characterization is to determine the probability of adverse effects on human populations, and derives from the first three phases of the risk assessment process. Key risk characterization research questions identified by the risk assessment group include: (1) What is the fraction of the population exposed to wood smoke? (2) Are there susceptible population subgroups at risk from exposure? (3) Which is the critical endpoint(s)? (4) How many excess outcomes for each critical endpoint are in the identified scenarios?

Conclusions

There is compelling evidence that emissions from biomass burning are linked to adverse health outcomes and to indicators of early biological effects. However, from the risk management standpoint, it is uncertain whether policies and regulations (such as the U.S. EPA NAAQS) directed at controlling concentrations of air pollutants are sufficiently protective for exposures to biomass burning, or whether more source(s)-specific public health protection measures are needed. Although health assessments of wood burning emissions have been done for specific scenarios (see Ezzati and Kammen, 2002, for example), only one report of formal risk assessment from a biomass source (outdoor wood boilers) was found in the peer-reviewed literature (Brown et al., 2007). This assessment demonstrated some of the limitations inherent in estimating risk for just one specific type of biomass combustor (Long and Valberg, 2007).

While exposure to the same stressor can be associated with different effects, in the case of wood burning different components could be associated uniquely with specific endpoints (i.e., irritancy or increases in inflammatory markers). Moreover, the relative contribution from the biologically relevant components of wood smoke could vary depending on the specific wood, burning condition, age of the emissions, and/or other factors. This complexity in characterizing the biomass smoke exposure impacts the ability to perform risk characterization in a systematic manner, as it may be difficult to extend estimates of risks across scenarios unless there are well-characterized, wood-smoke-specific, biologically relevant exposure metrics linked to equally well-defined health outcomes. Consequently, future research efforts need to be directed at resolving the exposure–effect relationships that are unique to biomass burning emissions and characterizing the critical exposure scenarios leading to those effects.

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