21. Pinto JP, Pleasant M, Kellogg R, *et al.* Chemical characterization of the ambient aerosol in Philadelphia. Presented at: Particulate Matter: Health and Regulatory Issues: an A&WMA International Specialty Conference, April, Pittsburgh, PA. Air & Waste Management Association; submitted abstract 1995.

22. Stevens RK, Hoffman AJ, Baugh JD, *et al.* A comparison of air quality measurements in Roanoke, VA, and other integrated air cancer project monitoring locations. In: Measurement of Toxic and Related Air Pollutants: Proceedings of the 1993 USEPA/A&WMA International Symposium, May, Durham, NC, Pittsburgh, PA. Air & Waste Management Association 1993;185-9.

23. Grosjean D. Polycyclic aromatic hydrocarbons in Los Angeles from samples collected on Teflon, glass and quartz filters. Atmos Environ 1983;17: 2565-73.

24. Tong SL. Personal communication, 1998.

25. Menichini E. Urban air pollution by polycyclic aromatic hydrocarbons: levels and sources of variability. Sci Total Environ 1992;116: 109-35.

26. World Health Organization. Air quality guidelines for Europe. 2nd ed. Copenhagen, Denmark, Regional Office for Europe, 1999 (in press).

27. US Environmental Protection Agency. Integrated risk information system (IRIS) [on-line]. Cincinnati OH, National Centre for Environmental Assessment, 1994. Available online: *www.epa.gov/iris/.*

28. US Environmental Protection Agency. Health effects summary tables, FY1995. Cincinnati, OH, US Environmental Protection Agency, Report No. EPA/540/R-94/036, 1994.

29. GEMS/AIR Methodology review handbook series, Vol 1: quality assurance in air pollutant monitoring. World Health Organization, Geneva, 1994.

Table 1
US national ambient air quality standards

Pollutant	Standard value		Standard type
Carbon monoxide (CO)			
8-hour average	9 ppm	(10 mg/m^3)**	Primary
1-hour average	35 ppm	(40 mg/m^3)**	Primary
Nitrogen dioxide (NO_2)			
Annual arithmetic mean	0.053 ppm	(100 $\mu g/m^3$)**	Primary & secondary
Ozone (O_3)			
1-hour average*	0.12 ppm	(235 $\mu g/m^3$)**	Primary & secondary
8-hour average	0.08 ppm	(157 $\mu g/m^3$)**	Primary & secondary
Lead (Pb)			
Quarterly average		1.5 $\mu g/m^3$	Primary & secondary
Particulate matter < 10 micrometres (PM_{10})		50 $\mu g/m^3$	Primary & secondary
Annual arithmetic mean		150 $\mu g/m^3$	Primary & secondary
24-hour average			
Particulate matter < 2.5 micrometres ($PM_{2.5}$)			
Annual arithmetic mean		15 $\mu g/m^3$	Primary & secondary
24-hour average		65 $\mu g/m^3$	Primary & secondary
Sulfur dioxide (SO_2)			
Annual arithmetic mean	0.03 ppm	(80 $\mu g/m^3$)**	Primary
24-hour average	0.14 ppm	(365 $\mu g/m^3$)**	Primary
3-hour average	0.50 ppm	(1300 $\mu g/m^3$)**	Secondary

* The ozone 1-hour standard applies only to areas that were designated nonattainment when the ozone 8-hour standard was adopted in July 1997. This provision allows a smooth, legal, and practical transition to the 8-hour standard.

** Parenthetical value is an approximately equivalent concentration.

Source: EPA Website: *www.epa.gov/criteria.html.*

Table 2
Comparison of PSI values with pollutant concentrations, descriptor words, generalized health effects, and cautionary statements

Index value	Air quality level	Pollutant levels					Health effect descriptor	General health effects	Cautionary statements
		PM_{10} (24-h) $\mu g/m^3$	SO_2 (24-h) $\mu g/m^3$	CO (8-h) ppm	O_3 (1-h) ppm	NO_2 (1-h) ppm			
								Acutely incapacitating symptoms experienced by significant portion of the population especially by persons undergoing light exercise; health status of particular vulnerable cardiopulmonary subjects may be compromised	Same recommendations as for Emergency level
500	SIGNIFICANT HARM	600	2,620	50	0.6	2.0	HAZARDOUS	Premature death of ill and elderly. Healthy people will experience adverse symptoms that affect their normal activity	All persons should remain indoors, keep windows and doors closed, minimize physical exertion, and avoid traffic.
400	EMERGENCY	500	2,100	40	0.5	1.6	HAZARDOUS	Premature onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons.	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. General population should avoid outdoor activity
300	WARNING	420	1,600	30	0.4	1.2	VERY UNHEALTHFUL	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population.	Elderly and persons with existing diseases should stay indoors and reduce physical activity.
200	ALERT	350	800	15	0.2	0 6	UNHEALTHFUL	Mild aggravation of symptoms in susceptible persons, with irritation symptoms in the healthy population.	Persons with heart or respiratory ailments should stay indoors and reduce physical activity.
100	NAAQS	150	365	9	0 12	a	MODERATE		
50	50% OF NAAQS	75	80[b]	4.5	0.06	a	GOOD		
0	-	0	0	0	0	a			

a No index values reported at concentrations level below those specified by "Alert level" criteria
b Annual primary NAAQS

Source: *www epa.gov/oar/oaqps/psi.html*

Table 3
US Environmental protection agency-designated reference and equivalent methods for PM_{10} (6)

Method No.	Identification	Description	Type	Date
RFPS-1087-062	Wedding & Associates PM_{10} Critical Flow High-Volume Sampler	High-volume (1.13 m^3/min) sampler with cyclone-type PM_{10} inlet, 203 x 254 cm (8 x 10 in) filter.	Manual reference method	10/06/87
RFPS-1287-063	Sierra-Andersen or General Metal Works Model 1200 PM_{10} High-Volume Air Sampler System	High-volume (1.13 m^3/min) sampler with impaction-type PM_{10} inlet, 203 x 254 cm (8 x 10 in) filter	Manual reference method	12/01/87
RFPS-1287-064	Sierra-Andersen or General Metal Works Model 321-B PM_{10} High-Volume Air Sampler System	High-volume (1.13 m^3/min) sampler with impaction-type PM_{10} inlet, 203 x 254 cm (8 x 10 in) filter. (No longer available.)	Manual reference method	12/01/87
RFPS-1287-065	Sierra-Andersen or General Metal Works Model 321-C PM_{10} High-Volume Air Sampler System	High-volume (1.13 m^3/min) sampler with impaction-type PM_{10} inlet; 203 x 254 cm (8 x 10 in) filter. (No longer available.)	Manual reference method	12/01/87
RFPS-0389-071	Oregon DEQ Medium Volume PM_{10} Sampler	Non-commercial medium-volume (110 L/min) sampler with impaction-type inlet and automatic filter change; two 47-mm diameter filters	Manual reference method	3/24/89
RFPS-0789-073	Sierra-Andersen Models SA241 or SA241M or General Metal Works Models G241 and G241M PM_{10} Dichotomous Samplers	Low-volume (16.7 L/min) sampler with impaction-type PM_{10} inlet; additional particle size separation at 2.5 micron, collected on two 37-mm diameter filters.	Manual reference method	7/27/89
EQPM-0990-076	Andersen Instruments Model FH62I-N PM_{10} Beta Attenuation Monitor	Low-volume (16.7 L/min) PM_{10} analyzers using impaction-type PM_{10} inlet, 40 mm filter tape, and beta attenuation analysis.	Automated equivalent method	9/18/90
EQPM-1090-079	Rupprecht & Patashnick TEOM Series 1400 and Series 1400a PM_{10} Monitors	Low-volume (16 7 L/min) PM_{10} analyzers using impaction-type PM_{10} inlet, 12.7 mm diameter filter, and tapered element oscillating microbalance analysis.	Automated equivalent method	10/29/90
EQPM-0391-081	Wedding & Associates PM_{10} Beta Gauge Automated Particle Sampler	Low-volume (16.7 L/min) PM_{10} analyzer using cyclone-type PM_{10} inlet, 32 mm filter tape, and beta attenuation analysis.	Automated equivalent method	3/5/91
RFPS-0694-098	Rupprecht & Patashnick Partisol Model 2000 Air Sampler	Low-volume (16 7 L/min) PM_{10} sampler with impaction-type inlet and 47 mm diameter filter.	Manual reference method	7/11/94

Table 4
Sampling and analysis methods for data collected in Malaysia and Indonesia.

Sample collected	**Method**
$PM_{2.5}$, PM_{10}	Modified virtual impactor containing 47mm Teflon filters.
Organic carbon, elemental carbon	Samples collected on 47mm quartz filters mounted in same virtual impactor.
PAHs	Samples collected on 47mm Quartz filter for particulate bound PAHs followed by polyurethane foam (PUF) trap for gas phase PAHs.
Trace elements (Na-Pb)	Samples collected on 47mm Teflon filters.
Sample Analysis	**Method**
$PM_{2.5}$, PM_{10}	Gravimetric analysis of deposit on Teflon filters.
Organic carbon, elemental carbon	Thermo-optical analysis of deposit on quartz filters.
PAHs	Gas chromatography using FID/MS detection for analysis of extracts from quartz filters and polyurethane foam traps.
Trace elements (Na-Pb)	X-ray fluorescence analysis of particles collected on Teflon filters.

Table 5

Mean aerosol composition measured in Petaling Jaya, Malaysia; Palembang, Sumatra, Indonesia; and the campus of Sriwijaya University, Sumatra, Indonesia in November 1997.

Species	Petaling Jaya		Palembang		Sriwijaya University
Particulate matter ($\mu g/m^3$)					
	Fine ($PM_{2.5}$)	Coarse ($PM_{10-2.5}$)	Fine ($PM_{2.5}$)	Coarse ($PM_{10-2.5}$)	Fine ($PM_{2.5}$)
No. of samples	9	9	5	5	5
Total mass	62.1	11.9	341	61	264
Organic carbon	26.1	no	282	no[1]	200
Elemental carbon	1.9	no	5.4	no[1]	3.2
Metal oxides	10.0	1.0	15	—	13
Sulfate	10.0	1.0	44	4.4	29
Trace elements (ng/m^3)					
Al	Bd[2]	630	bd[2]	1300	bd[1]
Si	160	1270	200	3700	115
S	2400	235	11000	1100	6900
Cl	70	83	4500	1200	4600
K	280	160	1400	420	1500
Ca	98	580	79	1400	47
Ti	27	55	11	100	6.5
V	9.3	1.5	bd[2]	3.0	bd[2]
Cr	0.2	2.4	bd[2]	1.3	bd[2]
Mn	4.5	3.9	1.7	17	bd[2]

[1]no = not obtained.
[2]bd = beneath detection limit.

Table 5 (Cont'd)

Mean aerosol composition measured in Petaling Jaya, Malaysia; Palembang, Sumatra, Indonesia; and the campus of Sriwijaya University, Sumatra, Indonesia in November 1997.

Species	Petaling Jaya		Palembang		Sriwijaya University
Particulate matter ($\mu g/m^3$)					
Fe	120	310	83	1000	71
Ni	2.2	1.0	3.8	0.4	<0.1
Cu	9.3	10.2	2.1	2.1	3.9
Zn	34.3	13	13	20	6.4
As	2.3	0.5	1.2	0.5	1.3
Se	0.7	bd[2]	3.9	<0.1	1 4
Br	9.8	1.0	95	11	72
Pb	39	19	64	15	7.7

Table 6
Mean aerosol composition measured in Los Angeles, CA; Philadelphia, PA; Roanoke, VA; and Teplice Czech Republic.

	Los Angeles,[20] CA (1987)	Philadelphia,[21] PA (1994)		Roanoke,[22] VA (1988)	Teplice,[13] CR (1993)	
Particulate matter ($\mu g/m^3$)						
	Fine ($PM_{2.5}$)	Fine ($PM_{2.5}$)	Coarse ($PM_{10-2.5}$)	Fine ($PM_{2.5}$)	Fine ($PM_{2.5}$)	Coarse ($PM_{10-2.5}$)
No. of samples	11	21	21	—	66	62
Total mass	41	32	8	20	122	18.5
Organic carbon	8.3	4.5	no[1]	7.3	33.8	no[1]
Elemental carbon	2.4	0.8	no[1]	1.5	2.3	no[1]
Metal oxides					6.5	14.0
Sulfate	11.8	13.8	bd[2]	4.9	41.3	1.5[3]
Trace elements (ng/m^3)						
Al	35	114	325	18	510	1900
Si	52	165	933	77	930	3100
S	2830	3300	bd[2]	1180	10000	370[3]
Cl	93	26	47	53	410	100
K	41	60	100	177	300	210
Ca	22	58	421	47	140	600
Ti	5	<42	30	bd[2]	51	140
V	6	<13	bd[2]	1.7	7.7	-0.2[3]

[1]no = not obtained
[2]bd = beneath detection limit
[3]Detected at the analytical uncertainty in fewer than half the samples.
[4]Detected at 3 times the analytical uncertainty in fewer than half the samples.

Table 6 (Cont'd)
Mean aerosol composition measured in Los Angeles, CA; Philadelphia, PA; Roanoke, VA; and Teplice Czech Republic.

	Los Angeles,[20] CA (1987)	Philadelphia,[21] PA (1994)		Roanoke,[22] VA (1988)	Teplice,[13] CR (1993)	
Particulate matter ($\mu g/m^3$)						
Cr	22	bd[2]	bd[2]	1	4.7	-0.3[3]
Mn	16	3	6	12	17	12
Fe	99	127	352	114	390	840
Ni	5	7	2	bd[2]	3.6[4]	0.8[3]
Cu	63	7	bd[2]	7	12	7.8
Zn	90	41	5	83	160	20
As	22	bd[2]	bd[2]	2	34	3.6[3]
Se	13	<2	bd[2]	2	6.7	0.3[3]
Br	13	9	3	5	18	3.5
Pb	38	19	13	27	110	6.5

Table 7
Concentrations of benzo[*a*]pyrene (BAP) in selected areas of the world

Location	BaP concentration (ng/m^3)	Source
Los Angeles, CA		(23)
- summer	0.2	
- winter	0.6	
Teplice, Czech Republic		(13)
- summer	0.5	
- winter	8.0	
Prachatice, Czech Republic		(13)
- summer	0.1	
- winter	0.5	
Kuala Lumpur, Malaysia		(24)
- Sept. 1997	0.6	
Palembang, Indonesia		(1)
- Nov. 1997	7.1	

Figure 1
Daily PM10 concentrations and API values in July-November 1997 in Kuala Lumpur

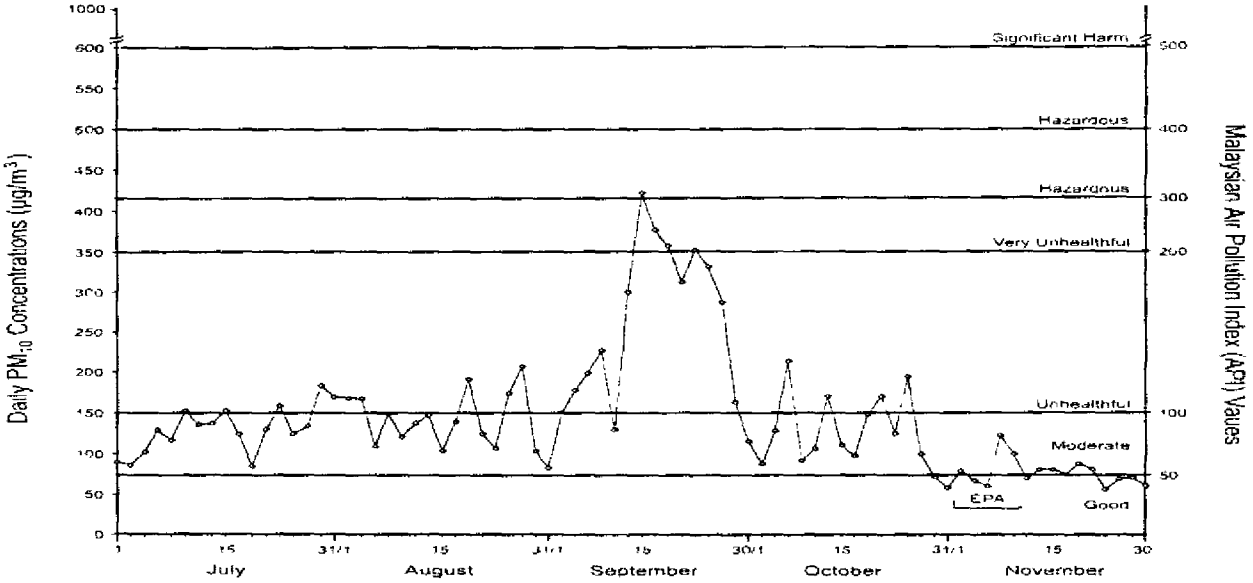


Figure 2
Location of sampling sites and general meteorological and haze conditions during sampling period

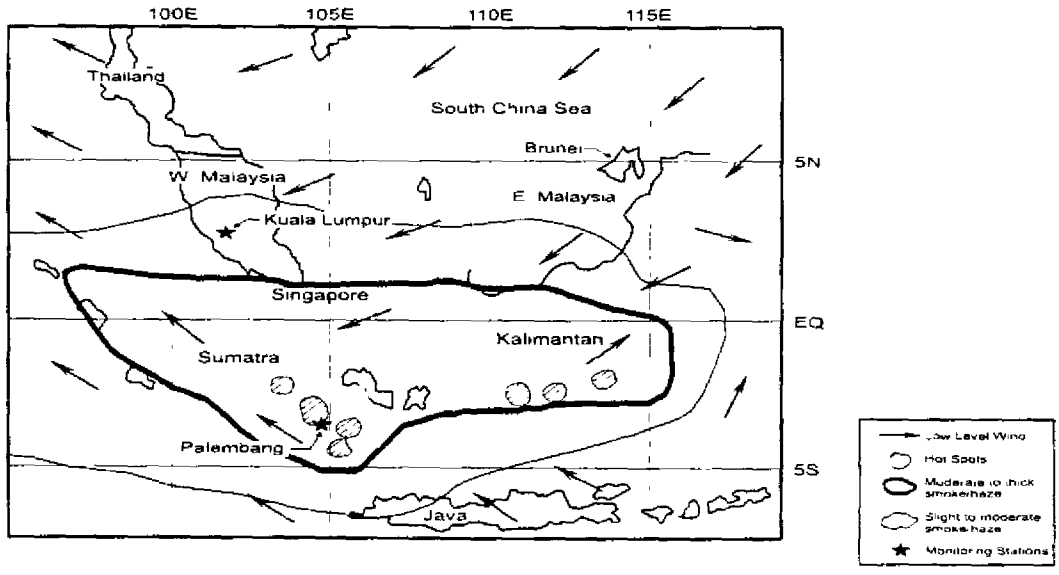


Figure 3
PM_{10} concentrations monitored by US EPA and ASMA, 3-11 November 1997

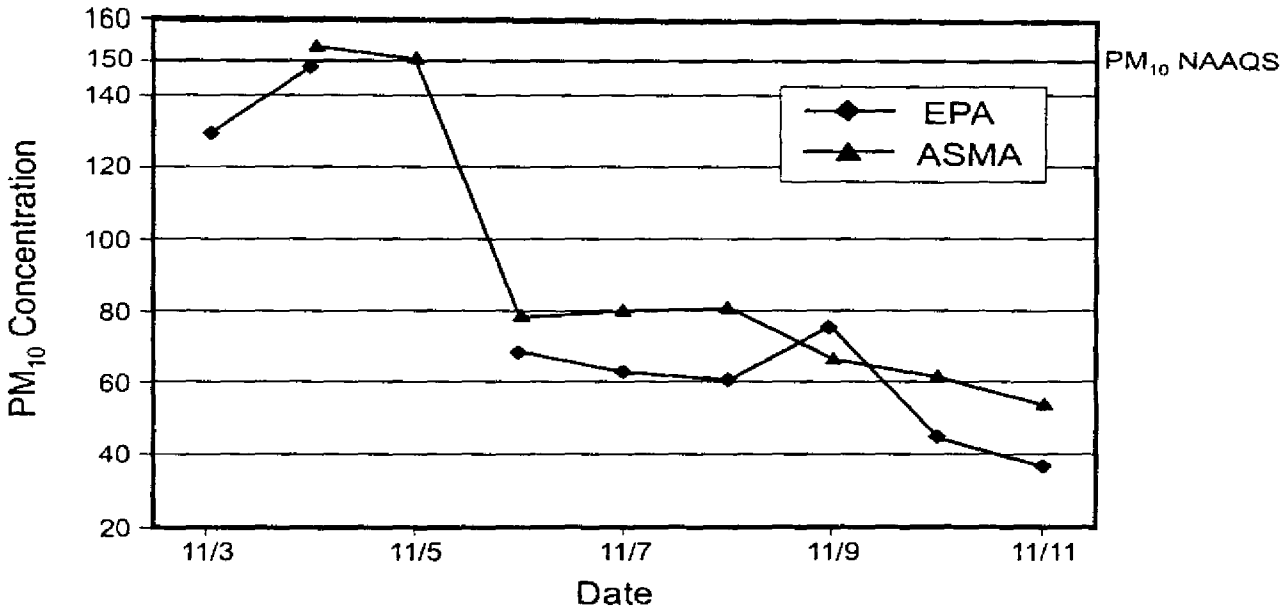
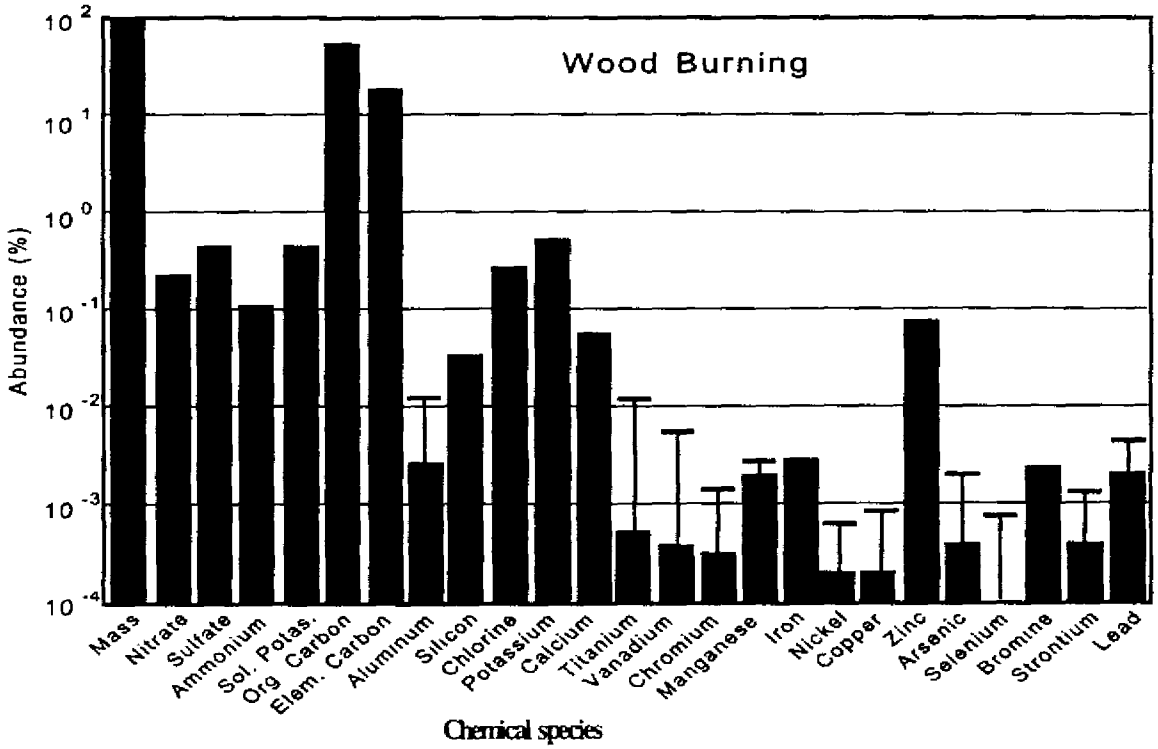


Figure 4
Typical profile of trace elemental composition of emissions from wood burning



HEALTH IMPACTS OF BIOMASS AIR POLLUTION

Michael Brauer

The University of British Columbia
Occupational Hygiene Program and Department of Medicine
2206 East Mall, Vancouver, BC V6T 1Z3 Canada

SUMMARY

In 1997, uncontrolled forest fires burning in Indonesia resulted in a regional air pollution episode of smoke which impacted several Southeast Asian nations. Beginning in late July 1997, elevated levels of particulate matter air pollution were observed for a period of approximately 2 months in many areas, with a severe episode occurring during most of the month of September. During this episode, particle levels in some areas were up to 15 times higher than normal levels. Exposures to "haze"-type air pollution can be substantial and are of public health concern due to the large numbers of individuals who may be exposed.

Smoke from biomass burning (in the following referred to as "biomass smoke") contains a large and diverse number of chemicals, many of which have been associated with adverse health impacts. These include both particulate matter and gaseous compounds such as carbon monoxide, formaldehyde, acrolein, benzene, nitrogen dioxide and ozone. Exposures to high concentrations of carbon monoxide and other pollutants are highly variable and only occasionally observed in individuals such as wildland firefighters and people who cook with biomass fuels. Particulate matter is itself a complex mixture which is associated with a wide range of health impacts. Review of the literature on exposure and health impacts, as well as initial evaluation of the available air monitoring data from the 1997 episode, indicate that the pollutant variable most consistently elevated in association with biomass smoke is particulate

matter. Accordingly, the emphasis throughout this paper and of recommended future studies will be focused on particulate matter.

Non-cancer health effects

Studies of wildland firefighters, an occupational group exposed to high levels of biomass smoke clearly indicate an association between exposure and acute effects on respiratory health. Longer term effects, lasting for a 3-6 month firefighting season, have also been observed in most studies although these effects appear to be relatively small and may be reversible. Firefighters are an extremely fit and healthy group and cannot be considered representative of the general population. Accordingly, the demonstration of health effects in this occupational group indicates the plausibility, but not the magnitude, of an association between biomass smoke exposure and adverse effects in the general population.

The health effects of biomass smoke inhalation have also been documented in developing countries where women, and in some cases, children spend many hours cooking over unvented indoor stoves. Approximately 50 per cent of the world's population uses biomass fuels for cooking and/or heating. In particular, exposure to smoke from cooking fires has been identified as a risk factor for acute respiratory illness. Women and children are also at risk for chronic respiratory diseases. As these exposures last for 20 or more years, they are much higher than those associated with "haze" episodes. However, the studies conducted in developing countries indicate the serious consequences of exposure to high levels of biomass smoke. Increased acute respiratory illness in children is likely a major cause of infant mortality and the development of chronic lung disease in adults is associated with premature death and increased illness.

Many recent studies have also indicated that levels of air pollution currently measured in most urban areas in the world are associated with a range of adverse health outcomes. The most startling finding of these studies, is the association of particulate air pollution, with increased daily mortality. These studies have been conducted by different investigators in a variety of locations, using a variety of study designs. In nearly all cases, the studies indicate an association between particle air pollution and

increased risk of death, primarily in the elderly and in individuals with pre-existing respiratory and/or cardiac illness. Recent studies have also suggested an association between particulate matter and infant mortality. Increased risk of hospital admissions and increased emergency room visits have also been associated with short-term increases in the levels of particle air pollution. These data strongly suggest that any combustion-source particulate air pollution, including that produced during forest fires, is associated with a whole range of adverse health outcomes.

Specific studies of exposure to biomass smoke indicate a consistent relationship between exposure and increased respiratory symptoms, increased risk of respiratory illness and decreased lung function. These studies have mainly been focused on children, although the few studies which evaluated adults also showed similar results. A limited number of studies also indicate an association between biomass smoke exposure and visits to hospital emergency rooms. There are also indications from several studies that asthmatics are a particularly sensitive group. By analogy to the findings of numerous studies associating increased mortality with urban particulate air pollution mixtures, there is no evidence that particles from different combustion sources have different impacts on health, while particles generated by natural processes such as volcanic eruptions and windblown soil do appear to have less of an impact on health. Therefore, there is little reason to expect that biomass smoke particles would be any less harmful than other combustion-source particles and it is prudent to consider that "haze" exposure will also be related to increased mortality. The studies also do not show evidence for a threshold concentration at which effects are not observed.

Nearly all of the studies of biomass smoke health effects conducted in North America evaluated impacts of concentrations which were much lower than those associated with the 1997 Southeast Asian haze episode. Similarly, these studies involved exposure duration which were of comparable length to those experienced in Southeast Asia. Based on these studies, it is reasonable to expect that the Southeast Asian haze episode resulted in the entire spectrum of acute impacts, including increased mortality, as well as seasonal effects on lung function, respiratory illness and symptoms. It is not possible at this time to determine the long-term effect, if any, from a single air pollution episode, although repeated yearly occurrences of haze should be cause for serious concern. Long-

term (several years) exposure to particulate air pollution in urban areas, at levels much lower than those experienced in Southeast Asia in 1997, has been associated with decreased life expectancy and with the development of new cases of chronic lung disease.

Cancer

The available, although limited, data on biomass smoke and cancer do not indicate an increased risk even at very high levels of exposure. This evidence includes studies of long-term exposure to high levels of biomass smoke from domestic cooking in developing countries. Evidence for a relationship between urban particulate air pollution and lung cancer is also limited, but is suggestive of a small, but measurable, increased risk. There have not been enough studies conducted to evaluate the consistency of any increased risk for different particle sources. However, while biomass smoke clearly is potentially carcinogenic, it is much less so than motor vehicle exhaust.

Research questions

Given the uncertainty regarding the potential for long-term effects associated with "haze" type air pollution, it would seem reasonable to initially evaluate the acute health impacts, especially since these are likely to include severe impacts such as increased mortality. To help understand the potential for adverse health effects and to evaluate the effectiveness of various mitigation measures, there is also a need to investigate several exposure issues. Several major research questions are summarized below. However, before these questions can be addressed, it will be necessary to identify the availability of data, specifically air monitoring data and valid data on health indicators such as daily mortality, hospital visits, clinic/emergency room visits, etc.

1. What were the short-term human impacts associated with exposure to biomass air pollution in Southeast Asia?

   For the range of identified impacts, were the effects reversible or permanent?

2. What were the long-term human health impacts (if any) associated with exposure to biomass air pollution in Southeast Asia?

3. Which (if any) population groups were especially susceptible to adverse health effects of biomass air pollution in Southeast Asia?

4. What was the size of the exposed population?

   Using study results and available air monitoring data (possibly including satellite data), can the region-wide health impacts be estimated?

5. What was the relationship between differences in exposure and health impacts across the affected region?

   Were there exposed areas in which health impacts were larger/smaller than others?

   Can an exposure-response relationship be demonstrated throughout the region?

6. What was the effectiveness of the following health protection measures?

   a) The use of dust masks

   b) Advising the population to remain indoors

7. What was the composition of the biomass air pollution which affected Southeast Asia?

   Can specific biomass marker compounds be identified?

   To what extent is it possible to distinguish biomass air pollution from the "background" urban air pollution?

Recommended studies

With regard to the general research questions identified above, everal possible study designs are proposed:

a. Formal study of the acute impacts of forest fire-related air pollution episodes should be conducted. Ideally, these studies should be directed towards the most severe health outcomes, while considering that impacts of air pollution will be small relative to all other causes of morbidity and mortality. To the extent possible, specific study protocols should be standardized and conducted in several regions where ambient air concentrations differed.

b. Formal study of the long-term impacts of forest fire-related air pollution may be attempted although it must be acknowledged that these studies are extremely difficult to conduct, and even the best studies are unlikely to provide firm results.

c. A region-wide composite database of ambient air concentrations should be developed. Estimated air pollution contour plots can be developed using available air monitoring data, and, if feasible, supplemented with airport visibility and remote sensing data. With this type of a database, the regional health impact of biomass air pollution episodes can be estimated.

d. The effectiveness of masks for use by the general public should be evaluated. An additional aim should be an adequate understanding of the variables which determine mask effectiveness, including technical factors such as filtration efficiency and leakage, as well as non-technical issues such as population compliance and comfort. Identification of the most important variables determining mask effectiveness will enable the design of new masks that are specifically applicable for general public use.

e. The effectiveness of remaining indoors during haze episodes should be investigated. Specifically, the effectiveness of air cleaners, air conditioners, open/closed windows within various building types as they relate to indoor penetration of fine particles should be assessed.

f. Detailed chemical analysis of particle samples should be conducted to identify the proportion of various functional groups within the haze particulate matter. While this analysis may be useful in future risk assessment and in comparing the toxicity of these particulate samples to those collected in other locations, the current emphasis should be on identifying marker compounds which may be used to distinguish air pollution originating from biomass burning from other sources.

Recommended health protection measures

Due to the limited effectiveness of other health protection measures during regional haze episodes, priority emphasis must be given to elimination of the source of the air pollution, which in this case is extinguishing fires or preventing their occurrence. Close interaction between health, environment and meteorological agencies could result in effective forecasting of future air pollution episodes, be they related to forest fires or local sources of air pollution. However, despite efforts to prevent and control fires it is acknowledged that other measures may be necessary to help mitigate public health impacts. If the control or prevention of fires is not feasible, this should be followed by exposure avoidance activities such as reduced physical activity and remaining indoors. To enhance the protection offered by remaining indoors, individuals/building managers should take actions to reduce the infiltration of outdoor air. There is evidence that air conditioners, especially those with efficient filters, will substantially reduce indoor particle levels. To the extent possible, effective filters should be installed in existing air conditioning systems and individuals should seek environments protected by such systems. There is strong evidence that portable air cleaners are effective at reducing indoor particle levels, provided the specific cleaner is adequately matched to the indoor environment in which it is placed. Unfortunately, economics will limit the distribution of such devices throughout the population. As with air conditioners, the increased use of such devices by a large segment of the population may have a significant impact on energy consumption. The least desirable measure of health protection is the use of dust masks. While these are relatively inexpensive and may be distributed to a large segment of the population, at present, their effectiveness for general population use must be questioned. Despite this reservation, it is likely that the benefits (even partial) of wearing dust

masks will outweigh the (physiological and economic) costs. Accordingly, in the absence of other mitigation techniques, the use of dust masks is warranted, Education of the population regarding specific mask types to purchase, how to wear masks and when to replace them will increase their effectiveness as will the development of new masks designed for general population use.

INTRODUCTION

In 1997, uncontrolled forest fires burning in the Indonesian states of Kalimantan and Sumatra, in combination with a severe regional drought, depressed mixing heights and prevailing winds resulted in a regional air pollution episode of biomass smoke which impacted Indonesia, Malaysia, Singapore, southern Thailand, Brunei, and the southern Philippines. In particular, several large urban areas such as Singapore, Kuala Lumpur and Kuching were affected. Emissions from biomass burning resulted in elevated levels of particulate air pollution for a period of approximately 2 months in many areas (beginning in late July 1997), with a severe episode occurring during most of the month of September. During this episode, a state of emergency was declared in Sarawak, Malaysia, as 24-hour PM_{10} levels reached as high as 930 $\mu g/m^3$, more than 15 times higher than normal levels. Intermittent episodes occurred in Indonesia, Malaysia and Singapore until mid-November.

Several recent review papers have discussed the health impacts and pollutants associated with wood smoke air pollution (1-3). Although the emphasis of these reviews was on North American exposures, many of the conclusions are relevant to the broader understanding of biomass air pollution, which is the subject of this paper. This chapter will describe materials presented in these reviews as well as updated information. In addition, this paper will cover additional exposures to biomass air pollution encountered by forest firefighters and by individuals who use biomass for cooking and heating in developing countries. The available data on health impacts associated with community exposure to forest/bush fire related air pollution will also be presented. Emphasis will be placed on epidemiological studies on human health impacts and on peer-reviewed literature. The emission of pollutants from forest fires will also be addressed, with particular emphasis on tropical rain forests. As data

regarding the specific concentration measurements and health impacts associated with the 1997 Southeast Asian biomass air pollution ("haze") episode are just becoming available, these will not be addressed directly in the review portion of this paper. The second part of this paper will specifically be directed to the situation experienced in Southeast Asia and will cover research needs, suggest several possible research designs and discuss measures which national governments may employ or recommend to mitigate public health impacts associated with biomass air pollution originating from forest fires.

AIR POLLUTION RESULTING FROM BIOMASS BURNING

Biomass smoke contains a large and diverse number of chemicals, many of which have been associated with adverse health impacts. These include both particulate matter and gaseous compounds such as carbon monoxide, formaldehyde, acrolein, benzene, nitrogen dioxide and ozone. Particulate matter is itself a complex mixture which is associated with a wide range of health impacts. Components of particulate matter such as polycyclic aromatic hydrocarbons (PAHs) are also found in biomass smoke. The transport of biomass burning emissions over hundreds of kilometres in Brazil has been extensively documented (4). Haze layers with elevated concentrations of carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), and nitric oxide (NO) have been observed. During transport, many of the gaseous species are converted to other gases, such as ozone, or into particles, such as nitrate and organic nitrogen species. Table 1 summarises the major pollutants of biomass burning.

Pollutants

Gaseous

The main gaseous components in smoke which are potential health hazards are carbon monoxide and aldehydes. A number of studies have also reported elevated concentrations of ozone, as well as ozone precursors (nitrogen oxides and hydrocarbons), in plumes from forest fires. In particular, fires burning in the savanna regions of Central Africa and South America have been studied in detail. In Brazil, ozone

concentrations reach equilibrium values of approximately 20 ppb above background levels throughout a 2 million km^2 region during fire seasons (5).

Comparisons have been made between three years of data collected at a coastal site in Brazil not significantly impacted by biomass burning and measurements collected in a savanna region directly downwind of an Amazon forest region with intense burning. During the dry season, elevated levels of CO and O_3 were measured at the savanna site, while during the wet season, levels at the two locations were nearly identical. Monthly average CO levels increased from 100 ppb to 700 ppb and monthly average (noontime) O_3 levels increase from 20 ppb to 80 ppb (6). At these O_3 levels, which are high relative to those in rural areas, adverse health impacts have also been demonstrated.

Hydrocarbon and CO emissions were also measured in a study of savanna and forest regions in Brazil. The emission of hydrocarbons in forest regions were mainly alkanes (ethane and propane) and alkenes (ethylene and propylene) with smaller amounts (13 per cent) of aromatics (benzene and toluene). Some differences in the relative composition of hydrocarbons were observed between forest fire and savanna emissions. CO levels were only slightly (500 ppb) increased in the atmospheric boundary layer. A recent study documented the impact of biomass pollutants transported 300 km from a fire in Alberta, Canada, to the urban area of Edmonton (7). Air trajectory analysis combined with monitoring of O_3, nitrogen oxides and hydrocarbons, indicated that the forest fire had a significant impact on concentrations of gaseous pollutants. O_3 and nitrogen dioxide (NO_2) concentrations were 50-150 per cent higher than seasonal median levels.

Particulate composition and size distribution

The size distribution of wood smoke has been measured by several investigators and indicates that nearly all particles are smaller than 1 μm, with a peak in the distribution between 0.15 μm and 0.4 μm. One assessment of particle size distributions of forest residue indicated that 82 per cent of the particle mass was smaller than 1μm and 69 per cent smaller than 0.3 μm (8). These size ranges are consistent with particle formation via condensation (3). Particles of this size range are not easily removed by

gravitational settling and therefore can be transported over long distances. Constituents of biomass smoke may also undergo atmospheric transformations, although these have not been studied in detail. Hueglin and colleagues (9) reported on a detailed analysis of wood smoke particle size. Particle sizes distributions were sensitive to specific combustion conditions, but generally were bimodal with a peak at approximately 0.1 - 0.2 μm, corresponding to incomplete combustion and larger (approximately 5 μm) particles consisting of unburned material. Only the smaller particles are expected to remain suspended in wood smoke (9). Measurements of particle size distribution inside forest fire plumes in the Amazonian forest indicate that two particle generation mechanisms operate in forest fires: gas to particle conversion resulting in particles smaller than 2.0 μm, and convective dispersion of ash and semi-burned material. Due to high settling velocities of large particles, only the smaller particles (smaller than 2 μm) can be transported over long distances (10).

Biomass smoke contains organic and inorganic particulate matter, including PAHs and a number of trace metals. Larson and Koenig (3) recently reviewed the available information on particle composition. While approximately 5-20 per cent of wood smoke particulate mass is elemental carbon, the composition of the organic carbon fraction varies dramatically with the specific biomass fuel being burned and with the combustion conditions. Accordingly, profiles of specific PAHs, which are of concern for their potential carcinogenicity, are likely to be variable. For this reason, many measurements have focused on a single PAH with probable human carcinogenic properties; benzo[a]pyrene (BaP), as a representative of the PAH group. Detailed analysis of organic wood smoke aerosol were conducted by Rogge et al (11). Nearly 200 distinct organic compounds were measured in wood smoke, many of them derivatives of wood polymers and resins. Wood consists of cellulose (50-70 per cent), hemicellulose (20-30 per cent), lignin (30 per cent), plus small amounts of resins and inorganic salts. In wood, cellulose compounds form a supporting mesh that is reinforced by lignin polymers. Together, these compounds form the rigid wood structure. When burned, lignin polymers produce methoxyphenols, methoxy benzenes, phenols, catechols and benzene. Non-wood biomass does not contain lignin and, therefore, the methoxy phenols and methoxy benzenes are unique tracers of wood smoke combustion. Conifers (softwoods) produce large amounts of resin acids while deciduous (hardwoods) trees do not. Combustion of

hardwoods produces more ash and therefore more trace elements that softwoods (3). Potassium is the trace element found at highest concentrations in wood smoke and has often been used as a wood smoke tracer.

Daisey et al (12) compared concentrations of respirable particulate matter (RSP), extractable organic matter (EOM) and PAHs inside seven Wisconsin homes when the home's woodstove was operated and when it was not. No statistically significant difference was observed between the two periods for RSP concentrations. Concentrations of EOM, however, were approximately two times higher, and concentrations of PAH were 2 to 46 times higher during the periods when the wood stoves were in operation. Total PAH levels were below 10 ng/m^3. This study indicates that wood burning can increase indoor concentrations of particulate organic matter and PAH, due to direct indoor emissions and/or infiltration from outdoors (12). The atmospheric concentrations of total suspended particulate (TSP) matter and BaP were measured in a mountain community highly dependent on wood for residential space heating. BaP levels ranged from 0.6 to 14.8 ng/m^3. These levels were significantly higher than BaP levels observed in metropolitan US cities which are in the range of 2-7 ng/m^3 (13).

Inorganic particle composition was studied inside biomass fire plumes from Amazonian forest and African and Brazilian savannas. Particles from savanna fires were enriched in K, P, Cl, Zn and Br, while tropical forest fire emissions were enriched in Si and Ca. The authors suggest that K may therefore be useful as a tracer for flaming and not smoldering fires (10). These measurements also indicated that smoldering fires contributed more than flaming fire to fine particle emissions (14). Mass concentrations ranged from 30 $\mu g/m^3$ in areas not affected by biomass burning to 300 $\mu g/m^3$ in large areas (2 million km^2) with intense burning. Additional studies of fine particle (<2 μm) composition associated with biomass burning in the Amazon Basin was reported by Artaxo et al (14). Biomass burning particulate is dominated by elemental (soot) and organic carbon, K and Cl, along with S, Ca, Mn and Zn. 24 hour average inhalable (PM_{10}) and fine ($PM_{2.5}$) mass concentrations as high as 700 $\mu g/m^3$ and 400 $\mu g/m^3$, respectively, were observed. The fine particle mass is composed of naturally released particle - organic carbon, soil dust particles and particles emitted during biomass burning. Dry

season particulate levels were increased as a result of soil dust release during the entire dry season and biomass burning at the end of the dry season.

The issue of particulate matter air pollution and the components responsible for the observed associations between particulates and adverse health impacts is still quite controversial and currently unresolved. However, it may not be an important issue for health impacts, if one agrees with the assumption that even though $PM_{2.5}$ (or PM_{10}) itself may not be the agent responsible for health impacts, it is a good (the best known) surrogate for whatever components of air pollution are responsible. There is however, evidence to support a conclusion that $PM_{2.5}$ particulate is a better measure than PM_{10} (15, 16). Further, there is even reason to believe that combustion-source $PM_{2.5}$ itself is a responsible agent. This is based on the observation that numerous studies which demonstrate a relationship between particulate matter and health outcomes have been performed in different locations, where both the major particulate sources and the particulate composition itself are quite different. The only known common feature in these studies is the presence of combustion-source particulate air pollution.

Exposures

Exposure to biomass air pollution occurs in many settings. The highest concentrations of particles have been measured in forest fires themselves and in indoor air in developing countries where wood and other biomass is used as a cooking and heating fuel. In terms of exposure, domestic cooking and heating with biomass clearly presents the highest exposures since individuals are exposed to high levels of smoke on a daily basis for many years. Perez-Padilla and colleagues (17) developed an index of hour-years, analogous to pack-years for smoking history. In a study of rural Mexican women who cooked with biomass, the mean exposure was 102 hour-years. Pollutant levels measured in these settings have been described in several investigations, some of which are discussed in more detail in the following sections. Daytime respirable particulate matter measurements (approximately corresponding to $PM_{3.5}$) in China were 1600 $\mu g/m^3$ (18). In Kenya (19) and the Gambia (20), 24-hour respirable particulate measurements were 1400 and 2100 $\mu g/m^3$, respectively, while in Guatemala, 24-hour PM_{10} measurements were 850