cent of winter PM_{10}. Particulate matter levels are highest during the winter in this area. The first study was one of the initial mortality time series studies which indicated an association between relatively low PM_{10} levels and increased daily mortality (90). A recent study of asthma emergency room visits in Santa Clara County and winter PM_{10} found a consistent relationship. Specifically, a 10 $\mu g/m^3$ increase in PM_{10} was associated with a 2-6 per cent increase in asthma emergency room visits (91). These results demonstrate an association between ambient winter time PM_{10} and increased daily mortality and exacerbation of asthma in an area where one of the principal sources of PM_{10} is residential wood smoke.

Two other studies (92, 93) conducted in North America focused on other sources of biomass burning besides wood burning stoves or fireplaces. In a small study of 7 medicated asthmatics, subjects were walked 0.5 mile with and without exposure to burning leaves on the same day, under very similar environmental conditions. Significant decreases in lung function were observed in the asthmatics within 30 min of exposure to leaf burning, while lung function of non-asthmatics was not affected (92). In a recent study, 428 subjects with moderate to severe airways obstruction were surveyed for their respiratory symptoms during a 2-week period of exposure to combustion products of agricultural burning (straw and stubble). During the exposure period, 24-hour average PM_{10} levels increased from 15-40 $\mu g/m^3$ to 80-110 $\mu g/m^3$. 1-hour level of carbon monoxide and nitrogen dioxide reached 11 ppm and 110 ppb, respectively. Total volatile organic compound levels increased from 30-100 $\mu g/m^3$ before the episode to 100-460 $\mu g/m^3$ during the episode. While 37 per cent of subjects were not bothered by smoke at all, 42 per cent reported that symptoms (cough, wheezing, chest tightness, and shortness of breath) developed or became worse due to the air pollution episode and 20 per cent reported that they had breathing trouble. Those with symptoms were more likely to be female than male and ex-smokers than smokers. Subject with asthma and chronic bronchitis were also more likely affected (93). The results of these studies indicate that other forms of biomass air pollution, in addition to wood smoke, are associated with some degree of impairment, and suggest that individuals with pre-existing respiratory disease are particularly susceptible.

Perhaps the study with the most relevance to the issue of biomass air pollution in Southeast Asia is an analysis of emergency room visits for asthma in Singapore during the 1994 "haze" episode (94). The study, described briefly in a letter to Lancet, indicates an association between PM_{10} and emergency room visits for childhood asthma. During the "haze" period, mean PM_{10} levels were 20 per cent higher than the annual average. Although a time series analysis was not conducted, the authors suggest that the association remained significant for all concentrations above 158 $\mu g/m^3$.

Two studies (95, 96) have been conducted regarding asthma emergency room visits and PM_{10} levels associated with smoke from bushfires in Sydney Australia. During 1994, PM_{10} levels were elevated (maximum hourly values of approximately 250 $\mu g/m^3$) for a 7-day period. Ozone levels were not elevated during the period in which smoke impacted Sydney. Neither study detected any increase in asthma emergency room visits during the bushfire smoke episode. Both studies used relatively simple analyses. One study had little power to detect small changes in emergency room visits as they related to air pollution and the other only used relatively short periods for comparison; neither detected any association. The results appear to conflict with those of studies conducted in North America. Possible reasons are differences in study design and sample size as well as differences in chemical composition of the particulates and differences in the relative toxicity of the specific particle mixture.

In a similar analysis to the studies of Australian bushfires, Duclos et al (97) evaluated the impact of a number of large forest fires in California on emergency room visits. During the approximately 2½ week period of the fires, asthma and chronic obstructive pulmonary disease visits increased by 40 and 30 per cent, respectively. PM_{10} concentrations as high as 237 $\mu g/m^3$ were measured. Based on TSP concentration, PM_{10} levels were significantly higher in other regions without PM_{10} monitoring.

Summary of wood and biomass community/cohort studies

The epidemiological studies of indoor and community exposure to biomass smoke indicates 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. 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. A notable exception is the analysis of populations exposed to large bushfires in Australia, which did not show any association between PM_{10} and asthma emergency room visits. There are also indications from several studies that asthmatics are a particularly sensitive group. No studies have explicitly evaluated the effect of community exposure to biomass air pollution on hospitalisation or mortality, although one study indicated a relationship between PM_{10} and mortality in an area where wood smoke is a major contributor to ambient PM_{10}. By analogy to the findings of numerous studies associating increased mortality with urban particulate air pollution mixtures, it is reasonable to conclude that similar findings would also be observed in locations exposed to biomass smoke. From the vast number of particulate studies, there is no evidence that airborne particles from different combustion sources have different impacts on health. 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 particulate would be any less harmful than other combustion-source particles and it is prudent to consider that biomass smoke exposure is also related to increased mortality. The particulate mortality studies also do not show evidence for a threshold concentration at which effects are not observed. If such a threshold level does exist it is likely to be a very low level, below those levels measured in most urban areas to the world.

Nearly all the low-level indoor and community biomass smoke studies mentioned above evaluated impacts of concentrations which were much lower than those associated with the 1997 Southeast Asian haze episode. Similarly, the studies of seasonal exposure to wood smoke 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 subchronic (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 high biomass smoke exposure should be cause for serious concern. Chronic (several years) exposure to particulate air pollution in urban areas, at much lower levels than 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

Cohen and Pope (98) recently reviewed the evidence associating air pollution with lung cancer. Studies suggest rather consistently that ambient air pollution resulting from fossil fuel combustion is associated with increased rates of lung cancer. Two recent prospective cohort studies observed 30-50 per cent increases in lung cancer rates associated with exposure to respirable particulates, best viewed as a complex mixture originating from diesel exhaust, coal, gasoline and wood. One of these studies suggested that sulfate particles (likely originating from coal and diesel combustion) appeared to be more strongly associated with lung cancer than fine particles. The results of these cohort studies are generally consistent with other types of exposure to combustion-source pollution such as occupational exposure and environmental tobacco smoke. While biomass smoke may be similar in some respects to cigarette smoke, the excess lung cancer risk associated with ambient air pollution (relative risks of 1.0-1.6) is small compared with that from cigarette smoking (relative risks of 7-22) but comparable to the risk associated with long-term environmental tobacco smoke exposure (relative risk of 1.0-1.5).

There is little direct information regarding the human cancer risks associated with biomass air pollution. The US EPA studied the contribution of wood smoke and motor vehicle emissions to the mutagenicity of ambient aerosols in Albuquerque, NM. This study found that, despite wood smoke being the major contributor to the mutagenicity of ambient particulate matter, it was 3 times less potent as a mutagen than extractable organic associated with vehicle emissions (99). The mutagenic potency of air samples decreased linearly with increased fraction of samples originating from wood smoke.

In an application of this and other work, the estimated lifetime cancer risk associated with 70 years of exposure to air pollution dominated by wood smoke (80 per cent) was calculated to be approximately 1 in 2,000. This calculation assumes lifetime exposure to PM_{10} levels of 25-60 $\mu g/m^3$ of which wood smoke is a major component for approximately 3 months every year. Extrapolating these estimates to an environment of 100 per cent wood smoke estimates an individual lifetime cancer risk of approximately one in 10,000 (83). It must be emphasized that these risk estimates do not mean that out of every 10,000 exposed people, one will develop cancer, but rather serve as estimates upon which different exposure scenarios and pollutants can be compared and to evaluate whether certain exposures can be considered as significant risks. For environmental exposure, regulatory agencies often consider lifetime cancer risk greater than one in one million to be significant.

BaP is a human carcinogen as defined by the International Agency for Research on Cancer (IARC) and is present in biomass smoke at high levels. Smith and Liu (18) reviewed studies of BaP levels in biomass smoke and discussed studies which have evaluated lung cancer risks. Despite high exposures to a known human carcinogen, there is relatively little evidence for a relationship between lung cancer and biomass smoke exposure. If any effect does exist it is thought to be small, relative to other risk factors such as diet or exposure to air pollution from coal burning. Lung cancer is itself relatively rare in areas of biomass fuel use, even if age-adjusted cancer rates are analysed (18). A similar argument is presented for nasopharyngeal cancers, which are also rare in areas of biomass smoke use (100).

The findings of relatively low mutagenicity for wood smoke, have, to some extent, been validated in an ongoing study (101) of indoor environmental exposure risks and lung cancer in China. Cross-sectional comparisons of population subgroups in Xuan Wei, China, an area noted for high mortality from respiratory disease and lung cancer, suggested that the high lung cancer rates cannot be attributed to smoking or occupational exposure. Since residents of Xuan Wei, especially women, are exposed to high concentration of coal and wood combustion products indoors, a study was undertaken to evaluate the lung cancer risks of these exposures. On average women and men in Xuan Wei spend 7 and 4 hours per day, respectively, near a household fire. A 1983 survey indicated that the lung cancer rate in Xuan Wei was strongly associated with the proportion of homes using smoky coal in 1958 (101). No relationship was observed between lung cancer and the percentage of homes using wood.

A follow-up study (102) compared exposures in two otherwise similar Xuan Wei communities, one with high lung cancer mortality (152/100,000) where smoky coal was the major fuel and another with low lung cancer mortality (2/100,000) where wood (67 per cent) and smokeless coal (33 per cent) were used. Lung cancer mortality was strongly associated with indoor burning of smoky coal and not with wood burning. This association was especially strong in women who seldom smoked and were more highly exposed to cooking fuel emissions than men. Indoor PM_{10} concentrations measured during cooking were extremely high (24, 22 and 1.8 mg/m^3 for smoky coal, wood and smokeless coal, respectively). In contrast to other studies of wood smoke particle size distribution, measurements in Xuan Wei indicated that only 6 per cent of the particles emitted during wood combustion were smaller than 1 μm in size, whereas 51 per cent of the smoky coal particles were submicron. Mutagenicity tests of particulates collected from the various combustion processes indicated that smoky coal was approximately 5 times more mutagenic than wood (103). This study suggests that there was little association between open-fire wood smoke exposure and lung cancer, despite very high exposure with long duration (women generally start cooking at age 12). One possible explanation is the relatively low biological activity of wood smoke particulate matter combined with less efficient deposition of the larger particles.

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 is clearly mutagenic, it is much less so than motor vehicle exhaust, on a comparable mass basis.

RESEARCH NEEDS

The studies discussed above indicate that biomass air pollution is clearly associated with some degree of adverse health outcome. By analogy to the general particulate epidemiology, it is likely that the exposures encountered during biomass air pollution episodes in Southeast Asia will result in acute health impacts spanning the entire range of severity, from sub-clinical impacts on lung function to increased daily mortality. Shorter duration episodes at lower air pollution concentrations have been linked with adverse impacts, while chronic exposure to higher levels of biomass air pollution and to lower levels of urban air pollution have been associated with development of chronic lung disease and decreased life expectancy. Therefore, the Southeast Asian biomass air pollution scenario falls into a relatively unique exposure category in which acute effects are highly probable but at exposure levels much lower (especially in terms of duration) than those experienced in studies which have demonstrated chronic impacts. Given the uncertainty regarding the potential for chronic effects, it would seem reasonable to initially evaluate the acute health impacts, especially since these are likely to include severe impacts such as increased mortality. Further, acute impacts are expected to be much easier to detect with a high degree of confidence than chronic health endpoints. 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 exposures issues. Several major research questions are summarised 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 health 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?

   a) Can specific biomass markers compounds be identified?

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

POSSIBLE RESEARCH DESIGNS

In developing study designs for epidemiological investigations, it is important to note that, in general, the more serious the outcome measure, the smaller the affected population will be. In turn, the more serious the outcome measure, the greater the availability of data. The pyramid (Figure 1) illustrates these tradeoffs, with the size of each level representative of the number of people affected. Severe outcomes such as mortality will only be seen in a relatively small group of people, and will therefore require a large sample size to detect an effect. However, such information is often easily available from administrative databases (death registries, for example). Less severe outcomes such as reduced lung function will generally be evident in a larger segment of the population, therefore requiring a smaller sample population to detect an effect. To obtain this information, however, requires individual assessment.

A similar set of trade-off occurs when selecting exposure measurements. At one extreme, regional data on air quality can be obtained from remote sensing data relatively inexpensively and efficiently. These data are imprecise and only provide a crude, but still quantitative, estimate of exposure. It is possible to estimate concentrations for several gases and for particulates by this technique. No detailed information on particle composition can be obtained and the measurements are "snapshots" of selected time intervals. This approach may be most useful for evaluating impacts in rural areas without ambient monitoring stations. Ground-based ambient air monitoring can either provide a continuous or time-integrated assessment of particulate and gaseous pollutants. Integrated particulate measurements have the advantage that post-sampling of chemical analysis of particles is possible. The usefulness of these data is determined by the extent of regional coverage of a monitoring network. In the absence of these measurements, airport visibility data has been used as a surrogate measure of particulate concentrations (73). For particular study populations, specific ambient monitoring stations that more closely reflect the populations' exposure may be required - such as placing specific monitors in selected neighbourhoods.

Since individuals spend the majority of time indoors, more precise exposure estimates are obtained from indoor monitoring. The cost of this enhancement is that an individual monitor must be placed in each residence/workplace of the study population. Often indoor and outdoor measurements can be combined with information about an individual's activity patterns (how much time they spend in particular locations) to estimate their exposure. Large scale models have been developed to estimate population exposure based on census data, time-activity surveys of the population, and information on indoor and outdoor relationships for various pollutants within the various "microenvironments" where individuals spend time throughout their lives (home, work, school, etc.). The US EPA has developed models for CO and O_3. Currently, researchers at the US EPA, Harvard University and The University of British Columbia are working together to develop models for PM_{10} and $PM_{2.5}$ exposure. The most precise exposure measure is obtained by actually monitoring personal exposure - having an individual wear a monitor as they move from microenvironment to microenvironment throughout the day. While it is possible with this approach to accurately measure exposure of a representative population sample, the extent of such monitoring limited by financial and logistical constraints. Further, such monitoring is often inconvenient for subjects and the measurement technology may be constrained to the extent that precision is affected.

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

Acute health impacts

Comprehensive studies 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. Accordingly, the use of adequately large sample sizes is critical, as is the selection of appropriately sensitive statistical modelling techniques. Examples of studies are:

(a) A time-series study of hospital visits in one or more major metropolitan areas with air monitoring and complete hospital visit data. In such studies, daily counts of deaths/hospital admission are compared to daily air pollution concentrations.

(b) A time-series study of acute mortality in one or more major metropolitan areas.

(c) Where feasible, additional time series studies on emergency visits, clinic visits, respiratory symptoms, work or school absenteeism can be conducted.

To the extent possible, individual factors such as age, health status, socioeconomic factors, etc. should be evaluated in the analysis, both to control for potential confounding as well as to evaluate the existence of susceptible population sub-groups.

Further, to the extent possible, specific study protocols should be standardised and conducted in several regions where ambient air concentrations differ.

Chronic health impacts

Comprehensive study of the long-term impacts of forest fire-related air pollution may be attempted although it must be acknowledged that such studies are extremely difficult to conduct, and even the best studies will provide equivocal results due to issues of confounding variables and misclassified exposure. Such issues are particularly complicated in the study of impacts of episodic air pollution events. Furthermore, the cross-sectional and semi-individual study designs depend on the identification of measurable variability in exposure, and in this case, that the impact of the specific haze episode(s) resulted in variability in exposure. Possible study designs might include:

(a) continuation of any ongoing cohort studies of health status (in which individual-level data are available) in locations where air monitoring data are available or where concentrations can be reliably estimated. Studies of large populations with varying exposure to biomass air pollution would be particularly useful. If available, such databases can be linked retrospectively with air pollution data.

(b) cross-sectional comparisons of respiratory/cardiovascular disease incidence and mortality in areas with differing exposure to biomass air pollution.

(c) semi-individual studies in which members of a demographically homogeneous population can be individually evaluated for health outcomes (lung function measurements, for example) and in which potential confounding variables (smoking status, for example) can be measured. The measured health outcome is determined retrospectively by combining subject interviews with ambient air monitoring data. Examples of populations studied by this method are military recruits and students entering university.

(d) Case-control studies have also been used in the past to estimate the risk of chronic health impacts. In such studies, individuals with some well-defined health outcomes are identified and the exposure of these "cases" is compared to a suitable control group which is similar to the case group, except for the presence of the health outcome. It is quite difficult to conduct such studies, primarily since the selection of a suitable control group is critical. If an inappropriate control group is used, biased results can be obtained. To estimate the impact of biomass-related air pollution using this study type would require the identification of a control group which was similar (in terms of age, socioeconomic status, smoking status, etc.) to a group treated for some respiratory illness after the haze episode.

Exposure issues

Regional exposure

A region-wide composite database of ambient air concentration 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. Using such a database combined with region-specific demographic data and with exposure-response relationship determined from epidemiological studies, the regional impact of the biomass air pollution episode can be estimated.

Mask effectiveness

The effectiveness of masks for use by the general public should be evaluated. An additional aim should be an adequate understanding of the variables determining 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.

Indoor penetration

The effectiveness of air cleaners, air conditioners, open/closed windows within various building types (residential or office) as they relate to indoor penetration of fine particles should be assessed. Perhaps the simplest investigation would be to measure air exchange rates in representative building types under different scenarios. As discussed in the Mitigation Measures section, once air exchange rate information is known the infiltration of outdoor particles can be calculated. Verification of these calculated values could then be undertaken on a smaller set of buildings.

Biomass smoke composition

Detailed chemical analysis of particulate samples should be conducted to identify the proportion of various functional groups (PAHs, elemental carbon, trace metals, etc.) 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. If identified, tracer compound(s) may be used to refine exposure assessment in epidemiological studies and to specifically evaluate indoor penetration of biomass particulate. Additional efforts should be directed to the determination of the size distribution of the biomass particulate and to an analysis of impacts of the haze episode on other routinely monitored ambient air pollutants, in particular, carbon monoxide and ozone.

MITIGATION MEASURES

Due to the limited effectiveness of exposure avoidance activities 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 meterological 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. Following from basic principles of exposure control, if source control is not feasible then administrative or engineering controls receive priority, followed by personal protective equipment such as dust masks. In this exposure situation, administrative controls might include recommendations to the population to reduce their level of physical activity, while engineering controls include the use and/or enhancement of air conditioning or indoor air cleaning. Reduction of physical activity will certainly reduce the dose of inhaled air pollutants and will likely reduce the risk of health impacts, although no formal studies have been conducted for particulate matter. Other mitigation measures are discussed in more detail in the following sections.

Dust masks

During the 1997 haze episode, one of the major government and commercial efforts to mitigate public health impacts was the distribution of facial masks. Many different types of masks with variable filtration effectiveness were used. Several of the most effective masks have been tested to meet older United States of America National Institute of Occupational Safety and Health (NIOSH) standards for dust respirators. These masks passed a test procedure which uses 0.5 μm silica particles and have been demonstrated to filter more than 99 per cent of challenge particles. However, in order for these masks to reduce human exposure by the same degree, the masks must provide an airtight seal around the face. As all masks are designed for use by adult workers, the effectiveness of even the highest quality masks for use by the general public (including children) has not been evaluated. It is likely that they will provide more than partial protection. Lower quality masks will offer even less protection. Further, while it is expected that such masks would also filter a high percentage of the smaller (<0.1um) particles present in biomass smoke, no performance data are available.

Wake and Brown (104) evaluated nuisance dust masks, which are generally not approved by health and safety authorities, for their filtration efficiency. These masks are designed for coarse dusts and not for the fine particles present in biomass smoke. Handkerchiefs and tissues were also tested. Although the smallest particle size used in testing was 1.5 μg/m, they found no difference between wet and dry handkerchiefs and in general found the penetration of 1.5 μm particles to be quite high (60-90 per cent) for all dust masks tested. Penetration for handkerchiefs and tissues was 70-90 per cent. In all case, higher airflow was associated with increased filtration (104).

Qian et al (105) evaluated dust/mist respirators which met older NIOSH regulations and surgical masks, and compared these to new N95 respirators which, by definition, meet newer NIOSH regulations. In 1995 NIOSH issued new regulations for non-powered particulate respirators. The regulations indicate 9 classes of filters (3 efficiency levels - 95, 97 and 99 per cent and 3 series of filter degradation resistance). Criteria are met by testing with aerosols of the most penetrating size (0.1-0.3 μm) at an 85 l/min flow rate. N95 respirators from different companies were found to have different particle penetration for the most penetrating sizes (0.1 -0.3μm), but all were more than 95 per cent efficient. For particles larger than 0.3 μm, the filtration increased with increasing size such than 99.5 per cent of 0.75 μm particles are removed. For welding fumes with sizes smaller than 1 μm, approximately 1.8 per cent of the mass penetrated the respirator, indicating excellent protection if a good face seal exists. Minimum efficiencies at the most penetrating particle sizes were 96, 82 and 71 per cent for the N95, dust mask and surgical mask, respectively.

The devices were also tested at a lower flow rate, which may be more representative of general population use. Under these conditions, efficiencies increased due to the increased time available for particle removal by the electrostatic material in the masks. Efficiencies were 98.8, 86 and 80 per cent for the N95, dust masks and surgical masks, respectively. It should be noted that these efficiencies do not consider face seal leakage. As filter material is loaded the pressure drop across it increases, encouraging air to bypass the filter material through any leaks that are present. Dust masks meeting the older NIOSH certification were used in Malaysia during the 1997 haze. It is unclear whether any N95 respirators were used. Although the N95 respirators have higher collection efficiencies, the dust masks, and even surgical masks will provide a high degree of protection, provided there is an adequate seal around the face and provided that they are changed once loaded.

Chen et al (106) evaluated dust masks and surgical masks for their filtration efficiency of 0.8 μm polystrene latex spheres at a flow rate of 46 l/min. As with the other studies, the effect of facial fit was not addressed. NIOSH has estimated that at least 10-20 per cent leakage occurs in masks not fitted to the wearers' face and measurements have confirmed this problem for dust masks (106). One of the masks tested by Chen et al was used in Malaysia during the 1997 haze. This mask had a mean efficiency of 96 per cent while the surgical mask had an efficiency of 96 per cent (106). The same mask was tested by Hinds and Kraske at a number of flow rates and particle sizes (108). Efficiency decreased with decreasing particle size and increasing flow rate. At normal resting or moderately active respiratory rates and for the particle sizes present in biomass smoke, this mask type would be expected to be 80-90 per cent efficient. However, despite these relatively high filtration efficiencies, the magnitude of the face seal leakage (up to 100 per cent for sub-micron particles) indicates that fit testing and selection of tight-fitting masks is essential for protection. Surgical masks, in contrast to approved dust masks, are not designed for fit testing or for an adequate face seal.

Adverse effects of wearing a disposable respirator (the same type used in Malaysia as described above) were evaluated by doing treadmill exercise. Physiological stress indicators such as heart rate, breath rate, and blood pressure were monitored as well as breath assistance and heat stress imposed by wearing a respirator. Although resistance to breathing through a disposable respirator is not great, a disposable respirator imposes significant physiological stress including increased heart and respiratory rates, especially at moderate and heavy work load (109).

The Ministry of the Environment of Singapore (110) developed recommendations for mask use during biomass air pollution episodes. These recommendations suggest that surgical and other similar masks are not useful in preventing the inhalation of fine particles as they are not efficient in the filtration of particles of less than 10 μm, such as those present in biomass smoke. Accordingly, the use of these masks may provide a false feeling of protection to the users. The recommendations also suggest that respirators (which include some types of dust masks) are able to filter 80 per cent to 99 per cent of particles between 0.2 and 0.4 μm. The recommendations indicate that respirators may be useful, but are uncomfortable and increase the effort of breathing. According to some assessments, over an eight-hour period of use, a respirator of 95 per cent efficiency can offer satisfactory filtration without undue breathing resistance to an average healthy adult. At higher efficiencies, breathing resistance increased and the user will experience more discomfort. Respirators may have a role for those with chronic cardio-respiratory illness, but should be used on the recommendation of their attending physicians. The recommendations also suggest that during periods of intense air pollution, it would be better for the public to avoid outdoor activity than to put on a mask and stay outdoor for prolonged periods. However, for those who cannot avoid going outdoors, the use of respirators would provide some relief.

Indoor penetration

Another major recommendation for the population was to stay indoors. Unfortunately, this recommendation is likely to provide only partial protection, and in some cases, no protection at all. Data from studies conducted in the US for combustion-source particulates indicate that in non air-conditioned homes, approximately 88 per cent of outdoor particles penetrate indoor during summer (111). Limited measurements conducted in Singapore in 1994 indicate that during biomass episode periods, the increase in particle concentrations was due to particles smaller than 2 μm and on average 60 per cent penetrated indoors (112). In a sample of 11 homes with air conditioning, an average infiltration factor of 44 per cent was measured. Simultaneous indoor and outdoor measurements with continuous particle monitors were performed in Seattle areas impacted by residential wood burning. These measurements demonstrated a strong correlation between indoor and outdoor levels and an indoor:outdoor ratio of 0.98, presumably due to the high air exchange rates in these homes (113). Brauer et al (114) measured indoor:outdoor ratios in 6 non air-conditioned homes in Boston during summer. Using sulfate as a tracer of outdoor source fine particles, indoor:outdoor ratios of 0.96 was measured. Other studies in homes have measured indoor:outdoor sulfate ratios of approximately 0.7, while a similar value was observed in office buildings with mechanical ventilation systems. The variation between these measurements are likely due to differences in air exchange rates (114), as discussed below. The PTEAM study of nearly 300 homes in Riverside, California indicated that nearly 100 per cent of indoor particle sulfur was of outdoor origin (115).

Since the majority of time is spend indoors, exposure indoors is an important variable to consider, even for pollutants generated outdoors. The impact of outdoor particles on indoor levels was discussed in detail by Wallace (116). Recent research has indicated that the impact of outdoor particle on indoor levels is a function of the particle penetration through the building envelope, the air exchange rate and the particle decay rate. Several studies indicate that penetration is complete for PM_{10} and $PM_{2.5}$. This means that the impact of outdoor particle on indoor levels is determined by the decay of particles indoor and by the rate of ventilation. Particle decay rates for PM_{10} and $PM_{2.5}$ are also known. Therefore, the impact of outdoor particles can easily be calculated for any air exchange rate. In typical North American homes, outdoor air accounts for 75 per cent and 65 per cent of fine and coarse particles, respectively. In North American homes, the geometric mean air exchange rates are 0.45-0.55/hr, but vary by season and specific geographic location. In general, air-conditioned homes typically have lower air exchange rates than homes that use open windows for ventilation. In one study, air conditioned homes had air exchange rates of 0.8/hr, while non air-conditioned homes had rates of 1.2/hr, implying indoor fractions of outdoor $PM_{2.5}$ of 67 and 75 per cent, respectively. Wallace comments that one method of reducing particle exposure would be to decrease home air exchange rates, by weatherizing in cold seasons and by installing air conditioners for hot seasons to reduce the use of open windows (116).

Commercial building studies were also reviewed by Wallace, although little information is available as most studies have been directed toward the impact of smoking and not outdoor air pollution (116). In a study of 40 non-smoking buildings, the mean indoor:outdoor respirable particulate ratio was 0.9, although it is not possible to determine the relative importance of particles originating outdoors or indoors. The infiltration of outdoor particles into commercial buildings is likely to be highly variable as it is dependent upon the air exchange rate and specific