ENVIRONMENT PROTECTION & HERITAGE COUNCIL

Co-operative Studies on Priority Air Quality and Health Related Issues

Air Pollution and Health: Identifying Research Priorities for Policy Development

1. Introduction

Air quality continues to be a major environmental concern for Australians. Studies worldwide have shown that air pollution is linked to adverse health effects such as increases in mortality and morbidity. Even though Australian cities experience better air quality than most European and US cities of comparable size, Australian studies have shown adverse health effects associated with current levels of pollution.

In terms of exceedances of air quality standards, the main focus of concern in Australian cities is on ozone (as an indicator of photochemical smog – also termed 'summer smog') and fine particles (the highest levels of which occur mainly in the autumn and winter but also arise from natural causes during the summer such as bushfires). Ozone is a secondary pollutant formed by the action of sunlight on primary pollutants (oxides of nitrogen and volatile organic compounds). The main sources of these precursor pollutants are industry and motor vehicles. The main sources of particles are domestic wood heating, motor vehicles (in particular diesel vehicles) and industry.

In June 1998, the National Environment Protection Council (NEPC) made the Ambient Air Quality (AAQ) NEPM that establishes national air quality standards for six criteria air pollutants – ozone, PM_{10} (particles of aerodynamic diameter less than 10 microns), nitrogen dioxide, carbon monoxide, sulfur dioxide and lead (see Attachment 1 for information on NEPC). Recently, advisory reporting standards[1] for $PM_{2.5}$ were included into the Ambient Air Quality NEPM. Apart from lead, all these pollutants are ubiquitous in the air environment in urban areas. These standards are set at levels to protect human health and are based on the understanding of the health effects of these pollutants at the time of making the NEPM. Associated with the standards in the AAQ NEPM, with the exception of $PM_{2.5}$, is a 10-year goal setting a maximum number of exceedances to be met at the end of that time period. For $PM_{2.5}$ the associated goal is to ensure that sufficient data is collected to facilitate a review of those standards as part of a full review of the NEPM, scheduled to commence in 2005.

[1] An advisory reporting standard is a health-based standard that does not have a time frame set for compliance associated with it. It is not a compliance standard but a health-based benchmark to be used to assess the results of ambient air quality monitoring.

The task of the Cooperative Studies Working Group is to identify priority areas of research in Australia to support the forthcoming review of the air quality standards in the AAQ NEPM, as well as any future reviews.

2. Use of Health Data in Setting Air Quality Standards

In setting air quality standards a risk assessment approach is often used. The risk assessment can be either qualitative or quantitative. As discussed in the NEPC Risk Assessment Taskforce (RATF) Report and the enHealth Risk Assessment Guidelines, risk assessment is usually comprised of five stages:

- Issues identification;
- Hazard identification;
- Dose-response assessment;
- Exposure assessment; and
- Risk characterisation.

In conducting a quantitative risk assessment all of the stages outlined above would be undertaken. However a qualitative assessment would not require quantification of the risk to the population at the risk characterisation stage.

In the process of setting air quality standards either approach can be taken. For pollutants where a threshold can be identified below which no adverse effects are observed, a semi-quantitative risk assessment can be used to derive an air quality standard. These levels are usually termed No Observed Adverse Effects Levels (NOAELs) or Lowest Observed Adverse Effects Levels (LOAELs). Uncertainty or 'safety' factors are applied to the NOAEL or LOAEL to derive a standard protective of sensitive members of the population.

For non-threshold pollutants, such as ozone, particles and carcinogens, there is assumed to be no 'safe' level of exposure, even at low concentrations, and therefore a NOAEL or LOAEL cannot be identified. In this case a quantitative risk assessment approach may need to be undertaken.

The health data that feeds into the risk assessment process comes from a variety of studies including epidemiological and toxicological research. This data feeds into the hazard identification and the dose response assessment. For the criteria pollutants much of the health data has arisen from broad population based epidemiological studies as well as controlled exposure studies. The associations observed in these studies have been used to determine dose-response (or exposure response) relationships and NOAELs and LOAELs from which safety factors can be applied to derive a standard.

Whichever approach is taken, the critical part of the risk assessment process in deciding where the standard should be set is the exposure assessment. The quality

of the exposure assessment is dependent on the available air quality data and the measures taken to assess population exposure. A number of approaches can be used for an exposure assessment that range from simply averaging the pollutant levels monitored at air monitoring stations across an airshed through to complex models that require significant monitoring data and modelling approaches. The decision on any exposure assessment model needs to be made on a pollutant-by-pollutant basis taking into account the types of epidemiological studies used as a basis for the dose-response relationships and available air monitoring data. Most air pollution epidemiological studies simply average the data from non-peak air monitoring sites. In some panel studies, more detailed exposure data may be available but this is rare. In time-series studies the use of personal exposure data has not changed the results of the study when compared to the use of ambient air monitoring data. In many instances the relationship between ambient air pollution and adverse health effects is stronger than that for personal exposure measures.

Air quality standards are usually set at levels to protect the most sensitive groups within the population. All standards developed by the USEPA, WHO, NEPC and other bodies around the world all take this approach. In some cases however, such as the setting of SO_2 standards to protect asthmatics, it is not possible to protect the most sensitive of these groups.

In the US, legislation has been passed that requires special consideration of children in assessing and monitoring air quality. In California, air monitoring networks must be set up to ensure that the exposure of infants and children to air pollution is measured. It is also required that all air quality standards must be assessed to ensure protection of children's health. In setting this legislation, the following issues were identified as needing to be addressed when assessing the health impacts of air pollution:

- Children have narrower airways than adults. Thus irritation or inflammation by environmental factors such as air pollution may be mild in adults but could result in a potentially significant obstruction of the airway in a young child;
- Children's ventilation rates and the surface area of their lungs differ from adults and make them more susceptible to the effects of air pollution;
- Infants' and children's developing organs and tissues are more susceptible to damage from some environmental contaminants than are adult organs and tissues;
- Exposure patterns for children may be different to adults leading to disproportionately high levels of exposure in comparison to the general population. Children spend significantly more time outdoors than adults; and
- Air pollution exacerbates asthma which is particularly prevalent in children.

In Australia, in the development of the standards in the AAQ NEPM, consideration of children as a sensitive group was included.

3. Types of Epidemiological Studies

Several types of epidemiological studies are used worldwide in examining the associations between exposure to air pollution and adverse health effects. Much of the data that exists has arisen from studies looking at short-term changes in air pollution and daily changes in health outcomes such as premature mortality and hospital admissions. Most of the evidence for the adverse effects of air pollution has arisen from time-series studies.

Investigating the health effects of air pollution follows a multi-disciplinary approach using epidemiology, controlled human exposure studies, and animal toxicology:

- *Epidemiological Studies* examine the relationship between air pollution exposure and health effects in the community. They can investigate acute or chronic (long-term) effects. Accurate estimation of exposure to a pollutant is usually difficult. Exposures are generally estimated from fixed monitoring sites and many pollutants occur as components of complex mixtures. The extent of potential confounding factors (eg cigarette smoking, health status), time considerations in air pollution effects (eg lags and latencies), individual variation in air pollution exposure, and exposure misclassification cause uncertainty in any observed associations with the health outcome (Lambert et al, 1992);
- *Controlled Human Exposure Studies* (or chamber studies) investigate mechanisms of injury and permit strict control of the exposures and the characteristics of the exposed persons. Ethical and practical considerations limit the use of controlled human exposure studies, and chronic effects cannot be readily addressed. Despite these constraints, such studies have contributed significantly to quantification of the relationship between respiratory function and air pollution (eg lung function to ozone exposure); and
- *Toxicological Studies* of animals can evaluate mechanisms of injury by pollutants using methods that cannot be applied to human subjects. Uncertainty is introduced from extrapolating animal models to humans.

Each approach has specific strengths and weaknesses in evaluating the human health effects of air pollution.

The epidemiology strategies most commonly used in air pollution health studies are of four types:

1. ecologic studies;
2. time-series semi-ecologic studies;
3. longitudinal panel and prospective cohort studies; and
4. case-control and crossover studies.

All of these are observational studies rather than experimental studies, since participants are not assigned at random to air pollution exposures. In general, the exposure of the participant is not directly observed, and the concentration of air pollutants at one or more stationary air monitors is used as a proxy for individual exposure to ambient air pollution.

Longitudinal study designs have been largely of two types - time series studies and cohort studies. In a time series study, air pollution concentrations over a period of time are compared to another time series of data that consists of measurements of an adverse health outcome. This type of analysis has been most frequently used in the assessment of the association between particulate air pollution and a variety of health effects. Time series analysis aims to evaluate the association between the air pollution data and the health data while controlling for a number of potential confounding variables that also vary with time. Such confounders include weather and other air pollutants.

In cohort studies, subjects are selected based on exposure status and are followed to monitor the development of a specific health end point (US EPA, 1996; UK Department of Health, 1995; Vedal, 1997). Cohort studies can be conducted prospectively or retrospectively. In a prospective cohort study, exposure status is determined from current or historical records and the subjects are followed to monitor the development of disease. This design is not appropriate for rare diseases but works well for common end points. For prospective cohort studies, extensive exposure assessment can be undertaken. Prospective cohort studies are especially efficient for assessing acute associations of air pollution exposures and respiratory health end points that vary over time. Known risk factors for mortality include age, race, occupation, economic status, smoking status, use of alcoholic beverages and body mass index. If the individuals selected are representative of air pollution exposures across different communities, the effects of individual risk factors can be separated from exposure to air pollution. This epidemiological design also allows the evaluation of cumulative exposure to air pollution over several years, where acute effects study design only allows assessment of effects of short-term exposure changes (US EPA, 1996). One interesting question is whether the effects of chronic exposure to air pollution are greater than the sum of acute effects.

These strengths of prospective cohort studies are generally reduced if only occasional air pollution measurements are available, so that only crude exposure comparisons across cities or regions can be made. The disadvantages of this design are the potential difficulty and high cost of implementation. The follow-up of study populations over extended periods of time is difficult. Large numbers of subjects are required if rare diseases are to be considered. This study design generally has weak power to measure interactions. Prospective cohort studies have been used successfully to evaluate the acute effects of time varying exposures to single air pollutants on daily reports of symptoms and changes in pulmonary function.

In cross-sectional studies, health and exposure information are determined at a single point in time. These studies are often described as surveys (US EPA, 1996; Vedal, 1997). This approach is most appropriate for acute rather than chronic effects, that is, health effects that are temporally close to the exposures, eg decreases in lung function or exacerbation of asthma. They are also appropriate for exposures that have been stable over time. Cross-sectional studies are readily feasible with manageable costs. In such study designs, it is possible to perform intensive monitoring of exposures to complex mixtures. Cross-sectional studies are not appropriate for studying the effects of exposures or mixtures that are changing over time or health effects that occur after a long latency (not suitable for cancer studies). In particular, cross-sectional data cannot describe the longitudinal relation between exposure and the health endpoint. The potential for selection and information bias in such studies must be carefully considered.

Ecologic studies are a class of cross-sectional studies in which a group rather than an individual is the unit of comparison. Aggregate information rather than individual information is used to describe both exposure and effect. However, confounding can be a severe problem in these studies. In air pollution epidemiology in particular, semi-ecologic (such as time series) studies are common in which health-status data is collected but exposure is determined from ambient air pollution monitors. In designing cross-sectional studies, it is often possible to select study populations such that exposures are limited to only one pollutant. Such restrictions allow the effects of individual pollutants that usually are found in mixtures to be assessed.

In *ecologic studies*, the responses are at a community level (eg annual mortality rates), as are the exposure indices (eg annual average particulate matter concentrations) and co-variates (eg the percentage of the population greater than 65 years of age). No individual data is used in the analysis, therefore the relationship between health effect and exposure calculated across different communities may not reflect individual-level associations between health outcome and exposure. The use of proxy measures for individual exposure and co-variates or effects modifiers may also bias the results, and within-city or within-unit confounding may be overlooked.

Time series studies are more informative because they allow study of associations between *changes* in outcomes and *changes* in exposure indicators preceding or simultaneous with the outcome. The temporal relationship supports a conclusion of a causal relation, even when both the outcome (eg the number of non-accidental deaths in a city during a day) and the exposure (eg daily air pollution concentration) are community indices. The issue of confounding is not as great in time series studies as confounders such as smoking and body mass index do not vary on a day-to-day basis.

Case-control studies are retrospective studies in that exposure is determined after the health endpoint occurs (this is common in occupational health studies). The *case-crossover design* is suited to the study of a transient effect of an intermittent exposure on the subsequent risk of a rare acute-onset disease hypothesised to occur a short

time after exposure. The principle of the analysis is that the exposures of cases just before the event are compared with the distribution of exposures estimated from some separate time period. This distribution is assumed to be representative of the distribution of exposures for those individuals while they are at risk of developing the outcome of interest. When measurements of exposure or potential effect modifiers are available on an individual level, it is possible to incorporate this information into a case-crossover study unlike a time-series analysis. A disadvantage of the case-crossover design, however, is the potential for bias due to time trends in the exposure time-series. Since case-crossover comparisons are made between different points in time, the case-crossover analysis implicitly depends on an assumption that the exposure distribution is stable over time (stationary). If the exposure time-series is non-stationary and case exposures are compared with referent exposures systematically selected from a different period in time, a bias may be introduced into estimates of the measure of association for the exposure and disease. These biases are particularly important when examining the small associations that appear to exist between air pollution and health outcomes.

4. Health Effects of Air Pollution

The health effects of the six criteria air pollutants have been known for many years. This information has been derived mainly from controlled human exposure and population-based epidemiological studies as well as animal toxicological studies. Health effects such as increases in daily mortality, hospital admissions and emergency department attendances (respiratory and cardiovascular disease) have been associated with exposure to pollutants such as particles, ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Exacerbation of asthma and increases in symptoms such as cough, wheeze and medication usage have also been associated with exposure to these pollutants. Elevated levels of blood lead leading to IQ deficits in children have been the most common health effect associated with exposure to lead. There appear to be groups within the population that are more sensitive to the effects of air pollution and these include people with existing disease (mainly respiratory and cardiovascular), people with infections such as influenza and pneumonia, asthmatics, the elderly and children.

Particles

In recent years much of the focus of air pollution epidemiology has been on particles – PM_{10}, $PM_{2.5}$ and $PM_{2.5-10}$. Studies conducted in various parts of the world consistently show significant associations between exposure to particles and adverse health effects such as increases in mortality and hospital admissions. There is an increasing database showing effects on infants and children including reduced birth weights and premature deliveries.

The consistency of results among hundreds of epidemiological studies provides substantial evidentiary support for causality of the health effects of particles. The ranges of effects estimates in all these studies have been remarkably similar, despite the different sources of particles and size distributions, co-pollutant distributions, weather patterns, population characteristics (distributions of age, baseline health

status, and access to health care). Daily mortality and morbidity have also been linked with different measures of particles including TSP, PM_{10}, $PM_{2.5}$, the coarse fraction ($PM_{2.5-10}$), black smoke, and ultrafine particles. The associations between particles and increases in mortality appear to be both short-term and long-term with a greater influence from the long-term exposure.

A number of panel studies have been conducted to examine the relationship between exposure to particles and increases in symptoms in asthmatic children. These studies typically follow a panel of subjects who record daily health outcomes over several months. Several outcomes have been measured, including specific symptoms (eg cough, shortness of breath, wheeze, chest tightness, phlegm), medication use, and lung function changes [eg peak expiratory flow rate (PEF), forced expiratory volume (FEV), and forced vital capacity (FVC)]. Air pollution is recorded along with potential confounders that also change on a daily basis and might be associated with the health outcome such as weather factors, environmental tobacco smoke (ETS) or wood smoke exposure, activity patterns, time spent outdoors, use of air conditioning, and day of week. Generally, the study of air pollution and asthma is analytically challenging since the disease and its triggers are complex. Several of the studies combine individuals with different levels of asthma severity and medication use, or combine asthmatics and non-asthmatics. Nevertheless, evidence for a fairly consistent effect of particles on asthmatics has emerged over the last several years.

There is emerging data that exposure to particles (TSP, PM_{10}, $PM_{2.5}$ and $PM_{2.5-10}$) has an adverse effect on infants. Exposure during pregnancy can lead to low birth weights, intra-uterine growth retardation (IUGR), premature births and possibly congenital birth defects. These results have been found in studies in different parts of the world.

Recent research provides support for a causal relationship between exposure to ambient particles and the cardiopulmonary morbidity and mortality consistently observed in time series studies by providing evidence of plausible biological mechanisms for the observed effects. Such support derives from clinical, epidemiological, and toxicological studies of a variety of pathophysiological events that could result in adverse cardiovascular outcomes. Localised airway inflammation and absorption of particles not only into the lung interstitium, but into the circulation, may result in systemic impacts, including effects on factors influencing blood coagulation, altered cardiac autonomic control, and recruitment of inflammatory cells from the bone marrow. Several epidemiological studies have shown associations between changes in these outcomes and PM_{10}. This information provides a possible explanation of the biological mechanisms leading to the adverse health effects observed in the epidemiological studies.

The elderly, children and people with existing chronic respiratory and cardiovascular diseases appear to be at greater risk from exposure to particles. No threshold for adverse effects has been observed in the epidemiological studies.

Ozone

The health effects of ozone range from irritation of the airways through to more serious effects that may result in hospitalisation or in some cases premature death in susceptible groups. These groups include the elderly, children, asthmatics and people with existing cardiovascular and respiratory disease (in particular COPD). Impacts on 'normal, healthy' individuals (such as decrements in lung function and impaired athletic performance) have also been observed. There has been no identified threshold for the adverse effects of ozone. Much of the evidence of the health effects of ozone has been derived from controlled exposure studies and population based epidemiological studies. In these studies the populations studied have primarily involved people in outdoor environments (as exposure to ozone only occurs outdoors) or people in controlled environments where the exact concentration of ozone and duration of exposure are known. In addition, the level of activity that these populations were undertaking at the time of exposure was also known.

Recent studies have shown that long-term exposure to ozone may lead to chronic respiratory disease. Exposure to ozone has been linked to reductions in lung function in children, and possibly to an increase in the incidence of new cases of asthma in children and adult males. Whether this is due to repeated short-term exposures or to continuous exposure to low levels of ozone is unclear. Changes in lung function are important to asthmatics whose baseline lung function is already low.

Carbon Monoxide

The health effects of carbon monoxide (CO) are associated with the level of carboxyhaemoglobin (COHb) levels in blood. It is generally accepted that maintaining a COHb level below 2.5% will be protective of adverse effects related to exposure to CO. The binding of CO with haemoglobin to form COHb reduces the oxygen carrying capacity of the blood and impairs the release of oxygen from haemoglobin. The toxic effects of CO first become evident in organs and tissues with high oxygen consumption, such as the brain, heart, exercising skeletal muscle and the developing foetus.

The health effects of CO include increases in daily mortality and hospital admissions (mainly cardiovascular disease), increases in angina attacks (patients with ischaemic heart disease), decreases in athletic performance and low birth weights. Many of the early studies showing these effects were conducted on populations exposed to relatively high levels of CO. Until recently it was thought that current exposure levels were unlikely to produce serious health outcomes. However, more recent studies have shown that increases in daily mortality and hospital admissions for cardiovascular disease are observed at levels currently experienced in most cities in Australia and overseas (Linn et al, 2000; Sheppard et al, 1999; Yang et al, 1998; Schwartz 1997; Schwartz 1999; Morris and Naumova 1998; Burnett et al, 1997b; Morris et al, 1995; Burnett et al, 1998; Polniecki et al, 1997).

There have been several studies that have shown associations between increases in daily mortality and increases in ambient CO levels. Early studies showed associations between daily mortality and ambient CO levels but at levels much higher that those currently observed in urban areas (UK Department of Health 1998; Bascom et al, 1996). More recent studies have also shown such an association even at the lower levels currently experienced. People with ischaemic heart disease and congestive heart failure appear to be most at risk. Studies examining the association between exposure to CO and hospital admissions have also found that people with ischaemic heart disease and congestive heart failure are the group for which the strongest associations have been found.

Nitrogen Dioxide

Exposure to nitrogen dioxide has also been associated with increases in daily mortality, increases in hospital admissions and emergency room attendances (respiratory and cardiovascular disease). Exacerbation of asthma, increases in respiratory symptoms and decreases in lung function have also been associated with exposure to NO_2. Asthmatics and children are particularly susceptible to the effects of NO_2. Some studies suggest that there is a concentration of NO_2 below which adverse effects are not observed – a No Observed Adverse Effects Level (NOAEL). This NOAEL is approximately 0.2 ppm (Bascom et al, 1996; WHO, 1999a). However recent epidemiological studies have shown that adverse health effects occur at levels well below 0.2 ppm.

Nitrogen dioxide may also sensitise individuals to the effects of other pollutants. In some controlled human exposure studies, prior exposure to NO_2 increases the subjects response to ozone and sulfur dioxide compared to subjects not exposed to NO_2. Nitrogen dioxide has also been shown to increase the response to allergens. This may be significant for asthmatics. Exposure to NO_2 may impair the host defence mechanisms of the body leading to an increase in susceptibility to infection. This is thought to be significant in children, as a higher incidence of respiratory infections in children has been associated with the development of chronic respiratory disease in adult life (Bascom et al, 1996; Streeton, 1997). Exposure to NO_2 has also been shown to cause reversible effects on lung function and airway responsiveness. Repetitive exposure in animals can produce changes in lung structure, lung metabolism, and lung defences against bacterial infection.

With acute ambient exposures to NO_2, immediate effects within one to two days can be demonstrated. These take the form of increased bronchial hyper-responsiveness in asthmatics; and in those with chronic inflammatory lung disease, leading to increased frequency of wheezing, cough, sputum production, with, as a secondary effect, increased frequency of respiratory infections (DoH, 1995). On the other hand, longer-term exposure in a chronic indoor environment appears to have more direct effects on the patterns of respiratory infection in young children. Animal toxicological studies suggest that peak concentrations contribute more to the toxicity than does prolonged exposure although the latter is still important.

Epidemiological studies on lung function response to NO_2 have shown that exposure to ambient levels of NO_2 causes decreases in FEV, FVC and PEF in asthmatic children. Effects in healthy children appear to be minimal. A considerable number of studies have investigated the lung function response to NO_2 in healthy subjects, asthmatics and to a lesser extent, patients with chronic obstructive pulmonary disease (COPD).

Sulfur Dioxide

The health effects of SO_2 have been recognised for many years. High SO_2 and particle concentrations have been associated with increased mortality and morbidity in air pollution episodes such as those experienced in London, 1952; Meuse Valley, Belgium, 1930s; and Donora, Pennsylvania. Early analyses of these episodes were unable to separate the effects of individual pollutants.

Most information on the acute effects of SO_2 has arisen from controlled human exposure studies. These studies have involved the exposure of volunteers to SO_2 for periods ranging from a few minutes up to one hour. The results of controlled exposure studies have been reviewed extensively (Bascom et al, 1996; US EPA, 1982, 1986). Acute responses occur within the first few minutes after inhalation. Further exposure does not increase the observed effects. Observed effects include reductions in mean forced expiratory volume over one second (FEV_1), increases in specific airway resistance (sRAW), and symptoms such as wheezing or shortness of breath. These effects are enhanced by exercise. Asthmatics appear to be the most susceptible group to the effects of SO_2. Recent studies have shown that exercising asthmatics are sensitive to brief exposures to SO_2 with bronchospasm occurring at exposures as low as 0.25 ppm. Such exposures lead to immediate responses and do not appear to cause delayed or prolonged effects.

Recent epidemiological studies have revealed increases in daily mortality from respiratory and cardiovascular causes associated with current ambient SO_2 levels found in various parts of the world. In addition, associations between daily hospital admissions for asthma, chronic obstructive pulmonary disease (COPD) and respiratory disease have also been observed. These effects persist when other pollutants, such as particles, are controlled for. No obvious threshold for the health effects associated with SO_2 has been identified and it is widely accepted that there will be some asthmatics within the population that will react to any exposure, even to low levels of SO_2.

Studies into the long-term health effects of SO_2 investigated the associations between ambient levels of SO_2 and prevalence of respiratory symptoms, respiratory illness frequencies or differences in lung function in locations with differing levels of SO_2 and particles (WHO, 1999). These studies are complicated by the fact that long-term effects are liable to be affected by not only current conditions but by pollution levels and composition that may have differed in earlier years. Cohort studies looking at differences in daily mortality across areas with differing pollution levels have found that the associations are more closely associated with particles than with SO_2. As

elevated SO_2 levels are usually associated with elevated particle levels in the northern hemisphere apportionment of these effects is often difficult.

Lead

Studies of the health effects of lead exposure have been noted for many years and have been extensively reviewed (WHO, 1995; Bascom et al, 1996; Needleman and Bellinger, 1991). Lead is absorbed after being inhaled or ingested. It can result in a wide range of biological effects depending on the level and duration of exposure. Its toxicity can largely be explained by its interference with different enzyme systems, which it affects in a number of ways. It is for this reason that lead exposure may result in a very wide range of adverse health effects. Effects at the subcellular level, as well as effects on the overall functioning of the body, have been noted and range from inhibition of enzymes to the production of marked morphological changes and death (WHO, 1995).

Absorbed lead is distributed among the soft tissues (eg blood, liver, kidneys, brain) and 'mineralising' systems (teeth and bones). Bones form the major lead storage site in the body, and lead accumulates in the bones over a persons lifetime (WHO, 1995). Because of retention of lead in bone, conditions associated with increased bone catabolism may lead to increased circulating blood lead even when environmental exposures have been reduced or eliminated (Streeton, 1997).

The concentration of lead in whole blood has gained almost universal acceptance as the best available surrogate for cumulative exposure, and surveys of blood lead concentration have come to be regarded as measuring community exposure (Donovan, 1996). The concentration of the lead in blood is usually expressed in micrograms per decilitre (μg/dL).

Foetuses, babies and children (especially those below the age of 4) are considered to be more susceptible to the adverse effects of lead exposure than adults. The reasons for this include their smaller body size (they inhale, eat and drink more per unit of body weight than adults so their relative lead intake is increased) and higher rates of gastrointestinal absorption (approximately 50 per cent compared with 10 per cent in adults). A greater prevalence of nutritional deficiencies, such as iron and vitamin D, which enhance absorption of lead, incompletely developed nervous systems (neurological effects of lead occur at lower thresholds than in adults) and higher rates of and rapid growth (WHO, 1995; Streeton, 1997) also influence the susceptibility of children.

Over the past two decades, attention has focused on children as a risk group for central nervous system (CNS) effects, at increasingly lower levels of exposure. As a global measure of CNS-functioning, intelligence quotient (IQ) has received particular attention in such studies. Some analyses have shown that a blood lead increase from 10 μg/dL to 20 μg/dL may be associated with an IQ drop of 1-3 points (Schwartz, 1994; Pocock et al, 1994; WHO, 1995). At blood lead levels greater than 25 μg/dL this relationship may differ (Streeton, 1997).

Existing epidemiological studies do not provide definitive evidence of a threshold (WHO, 1995; Donovan, 1996). Some research suggests that below a blood lead level range of 10-15µg/dL there is increasing uncertainty attached to identified effects (WHO, 1995). Children subject to such exposures may also show impairment of motor abilities, visual attention and spatial skills, and of their memory for sights or sounds. Greater amounts of blood lead correlate statistically with low levels of educational achievement in reading, spelling and mathematics in some studies (Sciarillo et al, 1992; Needleman et al, 1992). There is some evidence that these effects are persistent and may be irreversible where exposure occurs up to age seven (WHO, 1995).

As can be seen from the brief overview above, epidemiological studies provide important information about the adverse health effects arising from exposure to ambient air pollutants. The people at most risk appear to be asthmatics, children, the elderly, people with existing cardiovascular disease (in particular, ischaemic heart disease and congestive heart failure) and people with existing respiratory disease (in particular the elderly with COPD).

5. Public Health Importance

As seen from the previous sections there are a number of diseases that have been shown to make people more susceptible to the effects of air pollution. These include cardiovascular disease – especially ischaemic heart disease and congestive heart failure, COPD, asthma and other respiratory diseases. There is evidence emerging that diabetics may also be susceptible to the effects of air pollution, in particular to particles.

The National Public Health Partnership has established a series of National Public Health Priority Areas (NPHPAs).

These are:

- Cancer;
- Cardiovascular health;
- Diabetes mellitus;
- Mental health;
- Asthma and other respiratory diseases; and
- Injury and poisoning.

In 2003, a further area was added:

- Musculoskeletal conditions.

As discussed above, several of these diseases are known to be exacerbated by air pollution which in some cases may lead to premature deaths. Table 1 provides a summary of the evidence for the link between environmental factors and the NPHPAs.

The diseases and conditions targeted as NPHPAs were chosen because they are:

- areas where significant gains in the health of Australians can be achieved;
- of importance to the community;
- the source of a high overall burden of disease in terms of mortality, morbidity and disability; and
- relevant interventions have a measurable impact.

Taken together, the NPHPAs represent around 70% of the burden of illness and injury currently experienced by the Australian population, comprising 81% of years of life lost (YLL) and 56% of years of life lost due to disability (YLD) (AIHW, 1999 cited in NPHP 2001).

Table 1 Evidence* Linking NPHPAs to Air Quality

NPHPA	Induction	Exacerbation	Indoor factors*	Ambient Factors	Likelihood of demonstrable positive intervention
Cancer	(+/-)		(+/-)	(+/-)	-
Cardiovascular health					
Ischaemic heart disease		++	+	++	+
Diabetes mellitus		+		+	
Mental health					
Asthma and other respiratory diseases					
Asthma		+	+++	+++	+++
COPD		+	++	++	++
Injury and poisoning					
Musculoskeletal conditions					

*Key: (+/-) – equivocal evidence; + - weak evidence; ++ - reasonable evidence; +++ - strong evidence.

Cardiovascular Disease

[2]Coronary heart disease is the most common cause of sudden death in Australia. It consists mainly of acute myocardial infarction (heart attack) and angina. In 1999-2000, cardiovascular disease accounted for 443,068 hospital separations (7.5% of all hospitalisations) from all public acute and private hospitals in Australia. Of these, 36% were attributed to coronary heart disease, 12% to stroke, 11% to heart rhythm

[2] Some of this material has been taken from publications produced by the AIHW. These documents are available on the AIHW website.

disorders, 9% to heart failure, 3% to peripheral vascular disease and 2% to hypertensive disease.

Cardiovascular disease was the leading cause of death among Australians in 2000, accounting for 49,741 deaths or 39% of all deaths. Coronary heart disease was the major cardiovascular cause of death accounting for 53% of all such deaths, followed by stroke (25%), heart failure (5%) and peripheral vascular disease (5%). Cardiovascular mortality is higher among Indigenous Australians, in rural areas of the country and among socioeconomically disadvantaged groups.

Cardiovascular disease was estimated to account for 22% of the disease burden in Australia in 1996, 33% of premature mortality and 9% of years of equivalent 'healthy' life lost through disease, impairment and disability (AIHW, 1999). In 1993-94, cardiovascular disease accounted for the largest proportion of health system costs in Australia, $3.7 billion or 12% of total health system costs (Mathers & Penn, 1999a).

Asthma

Asthma is an inflammatory disease of the lung's air passages that makes them prone to narrow too easily and too much in response to 'triggers', causing episodes of shortness of breath and wheezing or coughing. The symptoms are usually reversible, spontaneously or with treatment. However, death can occasionally result if the asthmatic episode is severe enough and not managed properly (NHLBI, 1992). People with asthma can experience reduced quality of life and require a range of health services, from general practitioner care to emergency department visits or hospital in-patient care.

Asthma is highly prevalent in Australia. Based on self-reports in the 1995 National Health Survey, an estimated 11.3% of people had asthma as a recent or long-term condition. This is equivalent to approximately 2 million Australians (ABS, 1997b). Asthma prevalence was the highest among 5-14 year olds at 19.2%. Prevalence was also high among 15-24 year olds at 14.9%. Up to 15 years of age, asthma was more common among males than among females. In older age groups, however, asthma was more common among females than among males.

The proportion of Australians who had asthma (as a recent illness or as a long-term condition) increased by one-third, from 85 per 1,000 in 1989-90 to 113 per 1,000 in 1995 (ABS, 1997b). The increase in self-reported asthma was greater among adults aged 15 and over (41.4%) than among children aged 0-14 (17.3%). For both adults and children, the increase was greater among females than males (ABS, 1999a).

Compared with other countries, the prevalence of asthma among school-age children in Australia is high. The International Study of Asthma and Allergies in Childhood, which administered standardised questionnaires to school children in 56 countries, ranked Australia third highest in the prevalence of current wheeze (a symptom of asthma) among 13-14 year olds and second highest among 6-7 year olds (ISAAC Steering Committee, 1998).

In 1999-2000, asthma was the principal diagnosis for 47,008 hospital separations, or 0.8% of all hospital separations, with an average length of stay of 2.7 days (AIHW, 2001a). It was one of the most frequent reasons for hospitalisation among children aged 0-14. For example, the asthma hospital separation rate in early childhood (0-4 years) was 1,339 per 100,000 males and 765 per 100,000 females. After age 14, the hospital separation rates in both sexes decreased, reaching the lowest rates in the 35-44 age group.

Asthma is one of the more common reasons for visits to an emergency department of a hospital. In the 1995 National Health Survey, an estimated 8,870 people visited a hospital emergency department for their asthma in the two weeks before interview (or 6.4% of all visits). Of these, 349 (3.9%) had more than one visit. Admission to a hospital emergency department was more common among the young, with about half (49.7%) of admissions for asthma occurring in those aged 0-9 years.

Asthma is a major problem managed in the primary healthcare setting, being the sixth most frequently managed problem by GPs. A survey of general practice in 2000–01 found that asthma was managed at a rate of 2.8 problems per 100 encounters, with females (55.0%) presenting more often than males (45.0%). The survey also found about two-fifths (41.4%) of asthma patients were aged under 25 (AIHW: Britt et al, 2001a).

Medications were by far the most common treatment for asthma prescribed by GPs, at a rate of 153 medications per 100 asthma encounters. Salbutamol was the most frequent medication prescribed at 52 prescriptions per 100 asthma encounters. Overall, it was the sixth most frequently prescribed medication by GPs (AIHW: Britt et al, 2001a).

Referrals for asthma were low (2.7 per 100 asthma problems) compared with other problems (7.2 per 100 problems). Referral to a respiratory physician (0.7 per 100 problems) was the most common referral type for asthma in 2000-01. Less than one (0.4) in 100 asthma problems was referred to a hospital (AIHW: Britt et al, 2001a).

From self-reports in the 1995 National Health Survey, an estimated 1.1 million people cited asthma as the reason for taking health-related actions, such as medications, days away from work or school, medical consultation or hospital episodes. This represented just over half (56%) of people who reported the disease (ABS, 1997b).

Episodes of asthma often lead to interruptions in schooling and work. Based on the self-reports from the 1995 National Health Survey, approximately 12% of people who had asthma took days off from work or school in the two weeks preceding the survey, compared with about 4% of the rest of the population (ABS, 1997b). Asthma appears to have caused less disruption to the usual activities of adults than of children, with fewer than 1% of 25-64 year olds with asthma taking a day off work (ABS, 1999).

Asthma is a significant cause of disability and it can have a large impact on quality of life. From the 1998 Survey of Disability, Ageing and Carers, it was estimated that more than 400,000 people had asthma as one of the health conditions causing disability, resulting in restriction of daily living activities such as attendance at work or school. Of these, an estimated 170,902 had asthma as their main disabling condition. Furthermore, approximately 131,400 Australians had difficulties in undertaking specific activities related to self-care, mobility and communication due to their asthma (ABS, 1999c; and unpublished data).

In 2000, asthma was the underlying cause of 454 deaths, less than 1% of all deaths (128,291) in Australia that year. The number of deaths attributed to asthma increases with age. Very few deaths in childhood are attributed to asthma. In 2000, the death rates among children aged 0-4, 5-9 and 10-14 years were less than 1 per 100,000. The rate remains low during early and middle adult life, then increases markedly after the age of 50, peaking at 32.2 deaths per 100,000 in the 85 and over age group. However, death from asthma among older people is often complicated by the presence of chronic obstructive pulmonary disease and hence attribution to asthma in this group may be problematic.

Chronic Obstructive Pulmonary Disease (COPD)

COPD is a permanent and typically progressive disease, where damage to the lungs obstructs oxygen intake and causes breathlessness with exertion and limitation of exercise capacity. In severe cases, breathlessness may occur with little or no exertion. COPD is a cause of substantial morbidity, disability and mortality in Australia. Smoking is the major risk factor for COPD. Chronic bronchitis and emphysema are the two main components of COPD. Each condition can occur on its own, but they usually coexist in an individual (Gold, 2001).

COPD is a large cause of morbidity. This is shown by its prevalence in the population and the large amount of hospital use and primary care required by sufferers. The Australian Burden of Disease and Injury Study estimated that in 1996 there were almost 300,000 people with COPD in Australia, representing about 1.6% of the population, with more than 20,000 new cases every year (AIHW: AIHW, 1999a). The prevalence was higher in males than in females - 1,940 per 100,000 compared with 1,300. It is difficult to obtain prevalence estimates for COPD that allow valid comparisons of rates over time and between population groups. There are major differences in how the disease is defined, the only consensus being the inclusion of chronic bronchitis and emphysema. Also, COPD prevalence based on self-reporting is underestimated because the disease is usually not diagnosed until it begins to restrict a person's lifestyle and is moderately advanced.

COPD is one of the major causes for hospitalisation, especially among the elderly. In 1999-2000, COPD was the principal diagnosis in 48,583 hospital separations, accounting for 0.8% of all separations. Hospital separations for COPD among the elderly, those aged 65 and over (37,024 separations), accounted for more than three-

quarters of all COPD separations and 1.9% of all separations in the 65 and over age group. Male COPD separations were double those of females. The average length of stay for COPD separations was 7.8 days during 1999-2000.

COPD (defined in a way that excludes chronic bronchitis) is not among the top 30 problems managed by GPs. According to the 2000-01 BEACH survey of general practice activity, COPD was managed at a rate of 0.7 problems per 100 encounters (or 0.5% of all problems managed). It was the eighth most frequently managed disease of the respiratory system, accounting for 3.2% of all respiratory problems (AIHW: Britt et al, 2001a).

People in middle age or older with COPD required the most care by GPs. The survey showed that people aged 45 and over accounted for a large proportion of the COPD problems managed by GPs, some 96.5% of COPD problems managed. Males accounted for 60.1% of COPD problems managed.

COPD is a significant contributor to disability, particularly among the elderly. According to the 1998 ABS Survey of Disability, Ageing and Carers, an estimated 52,906 people had COPD (emphysema or bronchitis/bronchiolitis) as their main disabling condition. Two-thirds were males. Older people (aged 65 and over) accounted for two-thirds (65.5%) of those reporting COPD as their main disabling condition.

COPD is a major cause of mortality in Australia, being the fourth leading cause of death among males and sixth among females. In 2000, there were 5,296 deaths (24 per 100,000 people) with COPD recorded as the underlying cause. The age-standardised death rate was higher among males, with 35 deaths per 100,000 compared with 16 per 100,000 females.

COPD deaths occur mostly among older people, in particular those aged 70 and over (80.6% of deaths), mostly reflecting lifelong exposure to tobacco smoking. The death rate for COPD has declined in Australia over the last three decades, reflecting changes in cigarette smoking. Almost all of the decrease is accounted for by reductions in male deaths. Death rates from COPD for males and females have converged as the male rate decreased from 1970, and the female rate increased between 1970 and 1990 and remained steady thereafter.

The Burden of Disease and Injury in Australia

'The Burden of Disease and Injury in Australia' (AIHW, 1999) provides an overview of results from the Australian Burden of Disease and Injury Study undertaken by the AIHW during 1998 and 1999. The Study used the methods developed for the Global Burden of Disease Study, adapted to the Australian context and drew extensively on Australian sources of population health data. It provides a comprehensive assessment of the amount of ill health and disability, the 'burden of disease' in Australia in 1996.

Mortality, disability, impairment, illness and injury arising from 176 diseases, injuries and risk factors were measured using a common metric, the Disability-Adjusted Life Year or DALY. One DALY is a lost year of 'healthy' life and is calculated as a combination of years of life lost due to premature mortality (YLL) and equivalent 'healthy' years of life lost due to disability (YLD). This report provides estimates of the contribution of fatal and non-fatal health outcomes to the total burden of disease and injury measured in DALYs in Australia in 1996.

Calculated as DALYs (disability adjusted life years), the major chronic diseases and conditions rank in the top ten leading causes of disease burden. This is shown in Table 2.

Key Findings - Burden of Disease and Injury (DALYs)

Inclusion of non-fatal health outcomes provides a substantially different picture to that provided by traditional mortality statistics. Mental disorders are now the third leading cause of overall burden (14% of total) after cardiovascular diseases (20%) and cancers (19%). Central nervous system and chronic respiratory conditions are almost as large a contributor to total burden as injuries.

The male burden (in total DALYs) is 13% higher than the female burden.

The ten leading causes of the burden of disease in Australia for males and females are shown below.

Table 2 Leading Causes of Disease Burden: DALYs* by Sex, Australia, 1996

Males	Contribution to total burden (per cent of total DALYs*)	Females	Contribution to total burden (per cent of total DALYs*)
1 **Ischaemic heart disease**	13.6	1 **Ischaemic heart disease**	11.1
2 Stroke	4.8	2 Stroke	6.1
3 Lung cancer	4.5	3 Depression	4.8
4 **COPD****	4.2	4 Dementia	4.7
5 Suicide and self-inflicted injuries	3.3	5 Breast cancer	4.6
6 Road traffic accidents	3.0	6 **COPD****	3.2
7 Diabetes mellitus***	3.0	7 **Asthma**	3.1
8 Depression	2.7	8 Diabetes mellitus***	3.0
9 Colorectal cancer	2.7	9 Osteoarthritis	2.9
10 Dementia	2.5	10 Colorectal cancer	2.7

Note: Items relevant to air pollution are in bold
*One DALY (Disability-Adjusted Life Year) is a lost year of 'healthy' life and is calculated as a combination of years of life lost due to premature mortality (YLL) and equivalent 'healthy' years of life lost due to disability (YLD)
**Chronic obstructive pulmonary disease (chronic bronchitis and emphysema)
***Includes type 1 and type 2 diabetes

(From AIHW 1999, p66)

Leading Causes of Death

In 2000, there were 128,291 deaths recorded in Australia, consisting of 66,817 male deaths (712 deaths per 100,000 males) and 61,474 female deaths (450 deaths per 100,000 females). The top ten individual causes of death were responsible for about 60% of all deaths in 2000 (Table 3). Coronary heart disease (also known as ischaemic heart disease: heart attack and related disorders) and cerebrovascular disease (stroke) accounted for more than 30% of all deaths. All cancers combined accounted for almost another 30%.

Table 3 Leading Causes of Death in Australia

Males				Females			
	Cause	Number of deaths	% of all deaths		Cause	Number of deaths	% of all deaths
1	Ischaemic heart disease (I20–I25)	14,052	21.0	1	Ischaemic heart disease (I20–I25)	12,469	21.3
2	Cerebrovascular disease (I60–I69)	4,913	7.3	2	Cerebrovascular disease (I60–I69)	7,387	12.0
3	Lung cancer (C34)	4,587	6.9	3	Breast cancer (C50)	2,511	4.1
4	Chronic obstructive pulmonary disease (J41–J44)	3,281	4.9	4	Lung cancer (C34)	2,291	3.7
5	Prostate cancer (C61)	2,663	4.0	5	Colorectal cancer (C18–C21)	2,179	3.5
6	Colorectal cancer (C18–C21)	2,533	3.8	6	Chronic obstructive pulmonary disease (J41–J44)	2,015	3.3
7	Suicide (X60–X84)	1,860	2.8	7	Dementia and related disorders (G30–G32, F01–F03)	1,698	2.8
8	Diabetes (E10–E14)	1,594	2.4	8	Pneumonia & influenza (J10–J18)	1,625	2.6
9	Land transport accidents (V00–V89)	1,374	2.0	9	Diabetes (E10–E14)	1,412	2.3
10	Pneumonia & influenza (J10–J18)	1,312	2.0	10	Diseases of arteries, arterioles and capillaries (I7)	1,296	2.1
	Total leading causes	**38,169**	**57.1**		**Total leading causes**	**34,883**	**56.7**
	All deaths	**66,817**	**100**		**All deaths**	**61,474**	**100**

Note: Codes refer to the International Classification of Diseases, 10th Revision (ICD-10).
Source: AIHW National Mortality Database.

(from Australia's Health 2002a)

Burden of Disease from Ischaemic Heart Disease, Asthma and COPD

Coronary heart disease (CHD) and stroke accounted for 17.8% of the burden of disease and injury in Australia in 1996 (12.4% CHD and 5.4% stroke), as measured by disability-adjusted life years. Eighty four percent of CHD and stroke burden were attributed to years of life lost due to premature mortality. CHD and stroke were the second leading cause of total disease burden after cancer.

Asthma, chronic obstructive pulmonary disease (COPD) and other chronic respiratory diseases accounted for 7.1% of the burden of disease and injury in Australia in 1996 (2.6% asthma, and 3.7% COPD), as measured by disability adjusted life years. Over two million or 11% of Australians has asthma, including one in four primary school children, one in seven teenagers and one in ten adults. Asthma is the major cause of childhood admissions to hospital and is a common cause for school absenteeism amongst children. Asthma is also one of the ten most common reasons for seeing a general practitioner.

Thus these diseases, that have been shown to be exacerbated by air pollution, are clearly priority areas for public health research. The ability to conduct epidemiological studies into the association between air pollution and adverse health outcomes is dependent on available health and air pollution data. The availability of health data in Australia is summarised in Table 4.

Table 4 Quality and Availability of National and State Health Data (quality/availability)

	Asthma	COPD	Ischaemic Heart Disease
Frequency			
Incidence	+/+	+/+	++/++
Prevalence	++/++	++/++	++/++
YLLs	+++/+++	+++/+++	+++/+++
Severity			
Hospital separations	+++/+++	+++/+++	+++/+++
Deaths	+++/+++	+++/+++	+++/+++
Disability-adjusted Life Years (DALYs)	++/++	++/++	++/++
Emergency Department visits	+/+	+/+	+/+
GP visits	(+/+)	(+/+)	(+/+)
Preventability (re air quality)	++/++	+/+	+/+

6. What Do We Know in Australia?

There have been several studies in Australia examining the association between air pollution and adverse health effects (EPA Victoria, 2001; Petroeschevsky et al, 2001; Simpson et al, 2000; EPA Victoria, 2000; Morgan et al, 1998a,b; Simpson et al, 1997). These time-series studies have all focussed on the short-term effects of air pollution on daily mortality and hospital admissions. To date no studies have been conducted examining the long-term effects of air pollution on the health of the Australian population.

The studies referred to above have investigated daily changes in air pollution and their association with adverse health outcomes in Melbourne, Sydney and Brisbane. The pollutants considered in these studies include ozone, nitrogen dioxide, carbon monoxide (in Melbourne), sulfur dioxide (in Brisbane and Sydney) and fine particles (measured by nephelometry which measures PM_1). Similar studies have been conducted in Perth but the results have not yet been published.

In the Melbourne studies ozone, nitrogen dioxide and carbon monoxide were all associated with increases in daily mortality for all causes, respiratory disease and cardiovascular disease (EPA Victoria, 2000; Simpson et al, 2000). The strongest effects were observed in the elderly. The health endpoints considered in this study were total respiratory disease, COPD, pneumonia, total cardiovascular disease, and ischaemic heart disease. The health end points are consistent with those used in overseas studies. Only a weak association was found between increases in daily mortality and fine particles and this was only significant during the warm months.

In contrast to the Melbourne study, studies undertaken in Brisbane and Sydney found strong associations between fine particles and increases in daily mortality (Simpson et al, 1997; Morgan et al, 1998a). In Sydney associations were also observed between daily mortality and ozone and nitrogen dioxide. In Brisbane, no association was observed between daily mortality and nitrogen dioxide but was observed for the other pollutants including sulfur dioxide. Sulfur dioxide was not included in the Melbourne studies as the levels are too low and are often below detectable limits.

In addition to the mortality studies outlined above, studies examining the association between air pollution and hospital admissions for respiratory and cardiovascular conditions have also been conducted in these cities (EPA Victoria, 2001; Petroeschevsky et al, 2001; Morgan et al, 1998b). All these studies found strong associations between fine particles and admissions for all respiratory diseases, asthma (especially in children under the age of 14 years), COPD in the elderly, ischaemic heart disease and all cardiovascular diseases. Associations were also found for ozone and nitrogen dioxide and admissions for respiratory diseases (including asthma and COPD) and CO and admissions for cardiovascular diseases (including ischaemic heart disease). The associations observed for admissions for asthma were strongest in children less than 14 years old. These associations were stronger than those observed in overseas studies and may be due to the prevalence of asthma in the Australian population providing a large group sensitive to the effects of air pollution.

Although an association has been found between air pollution and adverse health effects in several Australian cities, the size and the strength of the associations vary. This is consistent with the observations in the multi-city studies conducted overseas and in a recent multi-city study conducted in Australia. EPHC has recently agreed to fund an expansion of this study to include additional cities and to include an analysis of $PM_{2.5}$ and PM_{10}.

All of the studies outlined above have been time series studies, which as outlined in Section 3 are of longitudinal design. These studies examine the short-term effects of air pollution on health as they evaluate daily changes in air pollution levels with daily changes in the health outcome under consideration. There have been very few panel studies conducted in Australia and to date no prospective cohort studies. The panel studies that have been conducted have been conducted in NSW as part of the

HARP program in the mid 1990s. There have been no studies conducted examining the long-term or chronic effects of air pollution.

In developing the AAQ NEPM in 1998, there was a strong reliance on overseas data for identified health effects and dose relationships. They were based almost entirely on overseas data, as there were very few local studies and there was concern expressed by key stakeholders as to whether the results obtained from studies conducted in NSW could be generalised to the rest of Australia. There was also debate as to whether the effects identified in overseas studies would be observed in Australia. Since then further work in Europe and Australia has allowed a better comparison of air pollution effects observed in different parts of the world and some indications of the transferability to Australia. During the variation of the AAQ NEPM to include standards for $PM_{2.5}$ there appeared to be general acceptance by a wide group of stakeholders that air pollution in Australian cities is linked to increases in daily mortality and hospital admissions.

In the development of the ambient air quality standards in the original AAQ NEPM, a qualitative risk assessment was conducted together with a review of overseas standards. Although a quantitative risk assessment was undertaken as part of the development of the NEPM, the results of the risk assessment were not used in the final selection of the standards.

The qualitative risk assessment involved a review of the literature on the health effects of air pollution. Key health end points and susceptible populations were identified from these studies. In addition dose-response relationships and NOAELs and LOAELs were also identified. A review of overseas standards was conducted and expert judgement used to assess whether these were appropriate for Australia. The data derived from the health reviews were used to assess whether the overseas standards were protective of sensitive groups within the population. Where appropriate, the overseas standards were adjusted to levels that were, in the opinion of the team developing the NEPM, more appropriate for the Australian situation.

There was criticism from many sectors about the applicability of overseas data for the development of air quality standards in Australia. The NEPC Risk Assessment Taskforce (RATF) and Risk Assessment Working Group (RAWG) were tasked with identifying risk assessment approaches that could be used in the development of air quality standards in Australia (RATF) and the data required for such risk assessments to be undertaken (RAWG). Both groups concluded that although key health research should be undertaken in Australia to inform the development of air quality standards, there would always be a reliance on overseas epidemiological data. This is due mainly to constraints on resources available for research in Australia and the relatively small size of the Australian population limiting the types of studies that can be conducted.

The NEPC agreed to trial the risk assessment approach recommended by the RATF for the development of $PM_{2.5}$ standards for inclusion in the AAQ NEPM. As with the

development of the original NEPM there continued to be a strong reliance on overseas epidemiological studies in the development of the standards as there was only limited data available in Australia on the links between $PM_{2.5}$ and adverse health effects. In the $PM_{2.5}$ review, overseas health data was used to identify key heath end points and dose-response relationships. The results of the Australian studies were used to support the overseas data. In particular, in choosing the appropriate health end points for the basis for the standards, only those for which associations between $PM_{2.5}$ had been observed in Australian studies were used. This limited the range of health outcomes considered.

One limitation of using the overseas database was that dose-response relationships were not always available for the key health outcomes of importance in Australia. For example, although children with asthma were a sensitive group identified in the Australian population and Australian air pollution epidemiological studies had found strong links between $PM_{2.5}$ and hospital admissions for asthma in this group, overseas dose-response data was not available for this age group. Therefore a compromise was made where asthma admissions were considered for all ages instead of the most sensitive group. However, the resulting standards are considered to be protective of children as the levels at which they have been set are lower than those at which health effects have been previously observed. It should be noted however that as $PM_{2.5}$ is a non-threshold pollutant, any level set as an air quality standard has an inherent risk associated with it. The aim is to minimise that risk as far as practicable.

Both the RATF and the RAWG concluded that any health research conducted in Australia should be targeted and not just repeat the overseas research. The focus of the research should be on particularly sensitive groups within the Australian population, for example asthmatics, and explore any differences in the air pollution mix between Australia and overseas. An example of this is the very low levels of sulfur dioxide that are experienced in Australian cities compared to those in the northern hemisphere. Limited opportunities to conduct some types of Australian epidemiological studies (eg time series studies) means some continuing reliance on overseas data to conduct risk assessments and set air quality standards. The Australian studies will provide information on whether overseas data realistically estimates potential health risk to Australians. Australian air pollution and health research should not just repeat overseas studies but should be targeted on particular questions, eg do Australian relationships differ from those overseas? They should also be focused on differences in the susceptible populations within the community and the greatest burden of disease where intervention may be viable. Such data can provide a basis to estimate the health risk to the Australian population from air pollution.

Studies conducted in areas with lower pollution levels have generally shown weaker associations than those in more polluted cities. As pollution levels in Australia are at the lower range of pollutant concentrations used overseas, differences between Australian and overseas studies may be partly due to the lower pollution levels

experienced here. At lower pollution levels, where weaker associations are observed, relationships are more difficult to detect. The reason for differences is unclear, but may be due to statistical variability or regional factors. This requires further investigation before conclusions can be drawn. While obtaining local data is important, it will still be necessary to rely on overseas data to conduct risk assessments and to guide setting air quality standards in Australia.

Health End Points

Given the discussion above on the public health importance of asthma in children and ischaemic heart disease and COPD in the elderly, these diseases may provide key health indicators on which to base air quality standards. EnHealth Council, as part of the implementation of the National Environmental Health Strategy, are developing environmental health indicators for a range of environmental hazards including air pollution. Hospital admissions for asthma in children and COPD and ischaemic heart disease in the elderly are being considered as suitable indicators. It would seem prudent to base national air quality standards on these same indicators although other health outcomes, such as mortality, should also be considered.

The studies into the health effects of air pollution in Australia have primarily been time series studies with very few panel studies being undertaken. This limits the range of health end points that can be considered as mortality and hospital admissions are broad indicators of population health. They do however provide important information on which to base air quality standards. It my be appropriate however to pursue panel studies that allow the investigation of more sensitive health outcomes such as changes in lung function in children or investigations of birth outcomes. Overseas research is now providing evidence of the biological mechanisms underlying the observed associations between exposure to fine particles and mortality or hospital admissions for cardiovascular diseases. This research indicates the importance of further investigation in this area and given the importance of cardiovascular disease in the burden of disease in Australia this may be another key research area that should be considered for further epidemiological studies in the Australian population.

7. Transferability of Overseas Data

In recent years there has been extensive overseas research into the effects of air pollution on health. As stated above this research has included epidemiological studies, controlled human exposure studies and toxicology. The contribution from each area varies significantly between pollutants. For example, the health effects of particles have been derived mainly from epidemiological studies whereas controlled human exposure studies and toxicological studies have contributed significantly to understanding the health effects of ozone. Controlled human exposure and toxicological study results transfer readily to many locations as they relate to a known dose of a particular pollutant and not to a specific pollutant mix.

It is not feasible to conduct sufficient epidemiological studies in Australia to provide a database to support the development of air quality standards on Australian data

alone. This is due mainly to the limitation posed by the size of our population. The question therefore arises whether overseas data can be utilised in Australia. This is discussed below for each of the six criteria pollutants.

Ozone, Nitrogen Dioxide and Sulfur Dioxide

The health effects of ozone, nitrogen dioxide and sulfur dioxide have been widely studied overseas in epidemiology, toxicology and controlled human exposure studies. Epidemiological studies show that ambient levels of these pollutants are associated with increases in daily mortality, increases in hospital admissions for respiratory and cardiovascular disease, increases in emergency room attendances for respiratory disease (including asthma), decreases in lung function and increases in respiratory symptoms. These effects have also been observed in Australian studies although the strength of the association may vary. The results of the epidemiological studies are consistent with those of the controlled experimental settings. Toxicological data support the results of the controlled exposure studies.

As the results of the Australian and overseas epidemiological studies are consistent with the results of the controlled exposure and toxicological studies, it is appropriate to use overseas dose-response data for these pollutants to support Australian studies.

Given the low SO_2 levels in most of urban Australia, it may not be possible to determine associations with daily mortality or hospital admissions using time series analysis. This would mean a strong reliance on overseas data for these health outcomes. In areas with higher SO_2 levels, such as Mt Isa, the population is insufficient for time series analysis, although other types of studies could be conducted. The question then arises as to whether the results of overseas studies are applicable here given that our SO_2 levels are considerably lower than those observed in countries in the northern hemisphere.

Particles

An increasing body of literature reports associations between particles and adverse health effects. Most information comes from epidemiological studies that find increases in daily mortality, hospital admissions and emergency room attendances and exacerbation of asthma associated with daily changes in ambient particle levels. Much of this data comes from US studies. However, in recent years there has been a significant amount of research conducted elsewhere, particularly Europe and the UK. These studies, find that there is variability in the results of studies conducted across different regions within a country in the strength of the association and the size of the effect estimates. This may be due to different particle size distributions and composition of the particles but may also be due to different demographics within the population, eg age distribution. Australian studies suggest similar differences may be observed here but the nature, significance and cause of these differences needs further investigation.

Unlike ozone and NO_2 until recently there has been little toxicological evidence supporting the associations observed in epidemiological studies. This situation is

changing rapidly and toxicological evidence now provides some explanation of a biological mechanism for the effects observed in population based studies, in particular those that relate to cardiovascular outcomes.

Australian studies show associations between particles and daily mortality and hospital admissions. However, Australian studies are currently insufficient to reliably establish specific Australian dose-response relationships. A recently funded multi-city study by EPHC to investigate the association between air pollution and daily mortality and hospital admissions in Australia and New Zealand will provide important data to identify the effect estimates for Australia. However, there will remain a reliance on overseas data in setting of air quality standards in Australia and Australian studies will be used to support the overseas studies. However, the uncertainties associated with using overseas data need to be clearly identified.

Carbon Monoxide and Lead

The health effects of carbon monoxide are related to the presence of carboxyhaemoglobin in the blood. This biological marker is related to the dose of carbon monoxide entering the blood stream. CO health effects have been identified through controlled human exposure and toxicological studies, and epidemiological studies. These results can be used in Australia. The health effects of lead are also associated with a biological marker - blood lead levels. Much of the international literature relating to blood lead levels, especially in children, comes from Australian studies. The results of overseas studies can be readily utilised in Australia.

For Pb and CO the situation regarding transferability is much clearer because exposure to them can be monitored by biological markers – carboxyhaemoglobin for CO, and blood lead levels for Pb. The health effects are related to the biomarkers and therefore the results of overseas studies are likely to be transferable to the Australian situation. However, for CO, recent epidemiological studies have found associations between ambient CO levels and increases in daily mortality (cardiovascular) and hospital admissions for cardiovascular disease at levels below current air quality standards, which are based on currently acceptable levels of carboxyhaemoglobin. These results may lead to a re-evaluation of CO standards.

Questions for Discussion

The Discussion paper provides an overview of the current knowledge on the link between air pollution and adverse health effects and the way that this information is used in the development of air quality standards. To set air quality standards a quantitative estimate of the relationship between air pollution and adverse health effects is required. This requires the identification of dose-response relationships or threshold values (NOAELs or LOAELs). There are still a number of questions that need to be answered in the Australian context even though some of that information exists overseas. These questions, or data gaps, include:

- What are the most appropriate health endpoints for the setting of air quality standards in Australia?

- What is the nature of the dose-response relationships for each of the pollutants and adverse health outcomes of importance in Australia?
- Are there clearly identified thresholds (NOAELs or LOAELs) for the pollutants?
- Do overseas data realistically estimate the potential health risk to the Australian population from air pollution, especially for the most sensitive groups within the population?
- Is there variability in the association between air pollution and adverse health effects? What is the significance and cause of any variability if it exists?
- What are the uncertainties associated with using overseas dose-response data in risk assessments to derive air quality standards for Australia?
- Does Australian dose-response data need to be obtained to inform these processes?
- What is the association between CO and increases in mortality and hospital admissions for cardiovascular disease in Australia?
- What sensitive health outcomes (eg birth outcomes, impact on lung function in children) are of importance in Australia with respect to the impact of air pollution?
- Are there pollutants other than the criteria pollutants that should be investigated for their association with adverse health effects?
- Are there any other questions that need to be answered?

The EPHC Working Group has been tasked with identifying key research that is aimed at filling these data gaps and provide information to guide the development and review of air quality standards. We are seeking you views as to whether the above summary highlights the key data gaps and whether there are any other issues that need to be considered. Please give your reasons if you disagree, or for any additional data gaps that you think are important.

In addition, your views are sought on the following issues aimed at answering the questions above:

<u>Short-term studies</u>

- What short-term health studies are required?
- What health endpoints should be considered?
- What study designs are most appropriate to generate the information required?

<u>Long-term studies</u>

- What long-term studies are required?
- How feasible is it to conduct such studies in Australia?
- What health endpoints should be used?

- What study designs are most appropriate?

ATTACHMENT 1

National Environment Protection Council

The National Environment Protection Council (NEPC) is a body established by each State and Territory government and the Commonwealth Government. It consists of one minister from the government of each State, Territory and the Commonwealth and is a body with law making powers.

The objective of the NEPC is to give all Australians the benefit of equivalent protection wherever they live and to ensure that business decisions are not distorted and markets are not fragmented by variations in environment protection arrangements between member governments.

NEPC makes National Environment Protection Measures (NEPMs) and assesses how well the aims of the NEPMs are being met by each member government when the NEPMs are put into place. NEPMs are broad framework-setting statutory instruments defined in NEPC legislation. They outline agreed national objectives for protecting particular aspects of the environment. NEPMs may consist of any combination of goals, standards, protocols and guidelines. A two-thirds majority of members is required for NEPC to make a NEPM. Implementation of NEPMs is the responsibility of each participating jurisdiction.

The NEPC legislation prescribes that NEPMs may relate to any one or more of the following (section 14(1)):

(a) ambient air quality;
(b) ambient marine, estuarine and fresh water quality;
(c) the protection of amenity in relation to noise;
(d) general guidelines for the assessment of site contamination;
(e) environmental impacts associated with hazardous wastes; and
(f) the reuse and recycling of used materials.

NEPMs may also relate to motor vehicle noise and emissions in conjunction with the National Transport Commission.

Environment Protection and Heritage Council

The Environment Protection and Heritage Council (EPHC) was formed following changes to natural resource and environment related Ministerial Councils agreed by the Council of Australian Governments (COAG) in June 2001.

EPHC was created by amalgamating NEPC, the environment protection components of the Australian and New Zealand Environment and Conservation Council (ANZECC), and Heritage Ministers' Meetings.

As it is a statutory body, NEPC continues to exist and operates under the umbrella of EPHC.