

# COMMITTEE ON THE MEDICAL EFFECTS OF AIR POLLUTANTS

## STATEMENT ON LONG-TERM EFFECTS OF PARTICLES ON MORTALITY

### Introduction

1. Two studies in the United States have shown that those living in less polluted cities live longer than those living in more polluted cities. After adjustment for other factors, an association remained between ambient concentrations of fine particles and shorter life expectancy. We considered these studies in 1995 and concluded that it was prudent to regard this association as causal. In 1998, we did not recommend that these studies should be used as a basis for quantifying the effects on health of long term exposure to particulate air pollution in the UK but noted that, had these studies been used, our assessment of the overall impacts of air pollution would have been considerably increased.

2. Since 1998, a reanalysis of these studies has been published by the Health Effects Institute (HEI Reanalysis) and a multi-disciplinary team co-ordinated by the Institute of Occupational Medicine has developed a methodology for quantifying long term effects (IOM Report). We have been asked to update our opinion on the long term effects of particles in the light of these and other studies.

### *Developments since 1998*

3. We noted previously that the cohort studies may not have taken confounding by socioeconomic factors sufficiently into account. The HEI reanalysis has now examined a wider range of factors such as poverty and unemployment and has found no marked impact on the all cause mortality results. Level of education was a strong effect modifier (the effect of particles on mortality decreasing with increasing education). Regional correlations were found between mortality rates in cities suggesting unknown factors affecting mortality. Controlling for this reduced the risks associated with particles.

4. Since particle levels were measured over only a few years, the studies cannot take account of different durations of exposure or differences in historical levels of pollution in cities. The HEI reanalysis could not be expected to resolve this limitation in the original dataset. However, the HEI reanalysis did find that risks were similar in those over and under 50. This suggests that exposure durations of under 50 years are sufficient to have an effect although no lower limit of necessary exposure has been defined. A UK study found that exposure to coal-derived air pollution in early childhood was not a predictor of respiratory mortality in later life. This suggests that very long lag-times between exposure and effect are unlikely but does not rule out an effect of air pollution exposure after early childhood.

5. The HEI reanalysis found that mainly cardiovascular mortality was affected. The apparent lack of an effect on respiratory mortality is puzzling. It was also found that the risks were similar in those with and without pre-existing disease and in smokers and non-

smokers. This suggests that the mechanism does not involve a worsening of previous disease.

6. We noted the absence of any UK or European studies and consequent concerns about transferability of the US results when last considering quantification of the long term effects in 1998. Since then, the UK study mentioned above has examined one aspect (early childhood exposure) and studies in the Netherlands and France are underway but not yet complete. In the US, a study in Seventh Day Adventists found a positive association between all-cause mortality and particle levels above  $100 \mu\text{g}/\text{m}^3$  in males but not females. An earlier study in 1991 from the same group had found no effects on mortality. The implications of these results for the general population are unclear given the substantially different lifestyle of Seventh Day Adventists and are difficult to use for extrapolation to other populations.

7. The HEI reanalysis found an effect of sulphur dioxide on mortality and the inclusion of sulphur dioxide in the models reduced the effects of fine particles and sulphate. The HEI reanalysis also found evidence of regional heterogeneity. This suggests that care is needed in transferring results from one place to another.

**8. The recent findings support our previous view that it is prudent to consider these associations as causal and that the size of the effect could be substantial. We now know more about the effects although we still know little about possible mechanisms or how much different durations of exposure matter. The IOM report has now provided the methodology to quantify the effects. If true, the observed associations between long-term exposure to particles and shortening of life expectancy are important, and this leads us to believe that we should attempt to quantify the possible effects in the UK. It is stressed that any attempt to quantify these possible effects should be accompanied by and, under no circumstances separated from, a statement of the attendant uncertainties.**

**9. Because many factors affect mortality and there are also likely to be factors affecting susceptibility to the long term effects of air pollution, the quantitative impact of pollution could vary between countries with different cultures and lifestyles. This variation cannot be predicted. For this, and other reasons, we consider it unwise to give a single estimate of possible effects. We develop below a range of estimates along with comments on our confidence in them.**

### *Quantification*

10. We have expressed the results in terms of a  $1 \mu\text{g}/\text{m}^3$  drop<sup>1</sup> in annual mean  $\text{PM}_{2.5}$ . The results of the calculations apply to the population of England and Wales alive in 2000 assuming a  $1 \mu\text{g}/\text{m}^3$  drop in annual mean  $\text{PM}_{2.5}$  is maintained for the rest of their lifetime (up to 105 years). Coefficients range from a 0.1% to 0.9% decrease in hazard rate based on relative risks and confidence intervals from the largest cohort study. Lag times vary from an

---

<sup>1</sup> Concentrations are given as gravimetric measurements.

immediate effect to a step change after a delay of 40 years. These changes are only applied to those over 30. A separate rough estimate of the life years gained, if the effect of short-term exposure on mortality is reduced, is also given for a 1 µg/m<sup>3</sup> drop in annual mean PM<sub>10</sub> (not PM<sub>2.5</sub>). For simplicity, this includes the under 30s and assumes an effect on all ages. As explained in paragraph 42 of the attached report, the calculation is done in a different way, with several assumptions and is based on a different type of study (time-series studies). It is intended only for the purposes of a rough comparison.

Table S1 Estimated total gains in life years (millions) in population of England and Wales 2000, followed to extinction with a range of reductions in hazard rates in those aged 30 years and over. Total effects immediate, phasing in gradually or step function after up to 40 years based on a 1 µg/m<sup>3</sup> drop in annual mean PM<sub>2.5</sub>. (This is why the figures are given as a range in the second column of the table.) Estimate of effect in time-series studies based on a 1 µg/m<sup>3</sup> drop in annual mean PM<sub>10</sub> assuming a coefficient of 0.075%, a loss of life expectancy of 2 to 6 months per death brought forward and a similar effect on all ages. CI – confidence interval. ACS - American Cancer Society study.

<b>Reduction in mortality rate</b>	<b>Total life years gained (millions)</b>	<b>Comments</b>
<i>Rough comparison based on PM<sub>10</sub> effect in time-series studies</i>	0.007 – 0.02	Estimate considered highly likely to be at least this large. Time-series studies well replicated. Represents the possibility that the apparent long term effect of particles is actually explained by unknown confounders.
0.1% from lower adjusted relative risks in HEI report	0.2 – 0.5	Estimate considered most likely to be around this size. This takes account of the small number of confounding factors that substantially reduced the relative risks in the HEI reanalysis.
0.3% from lower CI 1.09 (ACS)	0.6 – 1.4	Estimate considered reasonably likely but higher than predicted by some of the adjusted relative risks in the HEI reanalysis.
0.6% from RR 1.17 in ACS study	1.2 – 2.8	Estimate considered less likely. In most cases, factors examined in the HEI reanalysis did not markedly affect the relative risk but some did and there may also be unknown confounders. Higher exposures in the past may also lead to an overestimate of the risk at current levels.
0.9% from upper CI 1.26 (ACS)	1.8 – 4.1	Estimate considered implausibly large for the reasons given above and in comparison with other risks or total changes in life expectancy in recent years.

11. The estimates range from 0.007 to 4.1 million life years gained over the rest of the lifetime of the population alive today. This range could be expressed as from a day or less to 1 month per person but it should be noted that the gains in life expectancy are unlikely to be evenly distributed across the population. For example, the estimate we considered most likely (0.2 to 0.5 million life years) could be expressed as 1.5 to 3.5 days (say 2.5 days) gained per person for all 52 million people; 5 days for 25 million people; nearly 2 months for 2.5 million people or 4.5 months for 1 million people or a mixture of these. We cannot distinguish these possibilities at present.

12. The results derived from the cohort studies can also be expressed on the basis of a single birth cohort born in 2000 and followed up for their lifetime. This is less relevant for assessing the size of the effect but is a useful standard measure for comparing with other risk factors such as smoking. This shows that the answers can range from about 0.5 to 4.5 weeks.

### ***Conclusions***

13. Although there are many uncertainties, the quantification exercise highlights what these are and what difference they make. The range of estimates is wide but may nonetheless be useful. When using the results, the following points should be noted.

(i) Our comments on the key uncertainties (see below) should be quoted.

(ii) Application of the results to large changes in pollution adds to the uncertainties (see paragraph 38 of accompanying report).

(iii) The composition of the particles is important; it cannot be assumed that these results extend to pollution climates very different from those typical of US cities. For example, we do not know whether these estimates would apply around point sources.

(iv) These results relate not only to a  $1 \mu\text{g}/\text{m}^3$  change in  $\text{PM}_{2.5}$  but also to a particular population (those alive in 2000) and a particular length of follow-up (105 years). We acknowledge that cost-benefit analysis of particular policy scenarios may require different populations and follow-up periods. We consider that this could be dealt with by performing new lifetable calculations, provided the same methodology was used.

14. Our conclusions are as follows:

(i) We consider it more likely than not that a causal association exists between long term exposure to particles and mortality. We consider that this association is transferable to the UK, although the quantitative impact may not be exactly the same.

(ii) We consider that, given there is information regarding the size of the effect, it is preferable to assess this and comment on it rather than ignore it. Nonetheless there are great uncertainties in this process and it is vital that these are made clear. We

consider that the long-term effects are more uncertain than the short-term effects but that it would be unwise to dismiss them completely.

- (iii) It is possible, although unlikely, that there are no long term effects, if the results are explained by unknown confounders, confounding by sulphur dioxide or lack of control for spatial variation. If so, the only effect on mortality would be that detected in the time-series studies.
- (iv) An approximate calculation assuming a loss of 2 to 6 months of life per death brought forward suggests a gain of 0.007 to 0.02 million life years per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{10}$  for mortality from short-term exposure as detected in time-series studies. Although intended only as a rough comparison, this does suggest that the gain in life years from the cohort studies is at least 10 fold greater than that from the time series studies alone.
- (v) The above calculation and those below are based on the population of England and Wales alive in 2000 followed for 105 years as an illustration. Other populations and years of follow-up could be used provided the same methodology is followed. The calculations below are expressed per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$  representing around a 5 % reduction from current levels.
- (vi) Using a range of possible coefficients from the cohort studies leads to an estimate of 0.2 to 4.1 million life years gained per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$ . This could be expressed as up to 1 month per person on average if everyone was affected but could also represent a larger gain for fewer people.
- (vii) We consider that estimates at the lower end of the range are more likely. We know that a few of the confounders in the HEI reanalysis reduced the relative risks and there may be other unknown confounders. If higher exposures in the past are contributing to the effect, then the predicted effect of current levels will be overestimated. We consider the upper end of the range to be implausibly large compared with risks in other contexts and with the total changes in life expectancy seen in the last 20 to 30 years when particle levels have been dropping dramatically.
- (viii) The majority of the Committee considered that an estimate of 0.2 – 0.5 million life years (1.5 to 3.5 days per person or more) could be used to estimate the benefits of pollution reduction. The higher estimates could be included in sensitivity analysis in increasing bands of uncertainty as the size of the estimate increases. The possibility of there being no long term effects should also be included in sensitivity analysis.
- (ix) For a birth cohort born in 2000 and followed up for their lifetime, the gain in life expectancy for the same reduction is estimated as between 0.5 and 4.5 weeks.
- (x) Taking actual exposures into account, the estimates are less than those for active smoking but the relative risk for mortality from heart disease is similar to that for

passive smoking. The estimates are in line with others for air pollution in the literature.

- (xi) The key uncertainties are whether the results can be explained by undetected confounding, whether high exposures in the past lead to an overestimation of the effect, what lagtimes and what duration of exposure are required for the effect and a lack of understanding of the underlying mechanism. These uncertainties need to be addressed by further research.

**March 2001**

# COMMITTEE ON THE MEDICAL EFFECTS OF AIR POLLUTANTS

## REPORT ON LONG-TERM EFFECTS OF PARTICLES ON MORTALITY

### 1. Introduction

1. The Committee reviewed the evidence for health effects of long-term exposure to particles for the COMEAP report on 'Non-Biological Particles and Health' in 1995 (1). Two cohort studies (2,3) found that people who lived in cities with high particle levels died sooner than people who lived in cities with low levels. We discussed some of the limitations of the studies but advised that it would be prudent to consider these associations as causal.

2. The Committee considered the evidence again in the 1998 Report 'Quantifying the Effects of Air Pollution on Health in the UK' (4) when assessing whether the studies could be used for quantification. We considered it likely that long-term exposure to air pollutants could damage health but, due to the absence of suitable UK or European cohort studies, the Committee did not proceed to quantification. However, we noted that, if associations found elsewhere did apply in the UK, they suggested that the overall impacts could be substantially greater than the effects that had already been quantified.

3. Since that time, a multi-disciplinary team co-ordinated by the Institute of Occupational Medicine (IOM) has completed a report on the feasibility of quantifying a range of health effects of particles in the UK (5). This includes a detailed analysis of the possible implications of the effects of long-term exposure to particles on the UK population. In addition, the Health Effects Institute (HEI) in the United States has published a reanalysis (6) of the original cohort studies (2,3). There are also some other more recent studies (7,8,10).

#### *Cohort Studies available before 1998*

4. The "Six Cities" study (2) examined the mortality experience of over 8000 adults living in six cities in relation to measurements of air pollution in the cities in which they lived. They were followed up for 14 to 16 years between 1974 and 1991. All cause mortality rates, adjusted for sex, age, smoking, education, occupational exposure and body mass index, were shown to be associated with levels of fine particles (measured from 1979 to 1985) and sulphate (1979 to 1984). The ratio of the adjusted mortality rate in the most polluted city to that in the least polluted city (using fine particles as a measure) was 1.26 (95% confidence intervals 1.08-1.47). Air pollution was positively associated with death from lung cancer and cardiopulmonary disease but not other causes.

5. The ACS study (3) made use of a cohort of 552,138 adults living in 151 cities across the United States. The cohort was followed for 7 years from 1982 to 1989. Again, there was an association between all cause mortality (adjusted for age, sex, race, smoking, occupational exposure, education, body mass index and alcohol use) and sulphates (measured in 1980 in all 151 cities) or fine particles (measured from 1979 to 1983 in 50 of the cities). The adjusted relative risk for the most polluted areas compared with the least polluted areas (as indicated by fine particles) was 1.17 (95% confidence intervals 1.09-

1.26). Positive associations were found with cardiopulmonary mortality and, for sulphates only, with lung cancer.

6. Although not a study of the general population, Abbey *et al* (1991) (9) studied a cohort of 6303 non-smoking Seventh-Day Adventists in California. The cohort was followed up for 10 years from 1977 to 1986. Particles were measured as total suspended particulate (TSP) from 1966 to 1987. An interpolation method was used to create individual air pollution profiles based on zip-code and monthly residence histories. No association was found between all cause mortality (adjusted for age, sex, education, past smoking and airways obstructive disease symptoms) and mean TSP or hours with TSP above specified concentrations from 60 to 200  $\mu\text{g}/\text{m}^3$ .

## 2. Developments since 1998

7. We discuss the key new developments below in the context of

(i) how they change our overall view of the cohort studies, of the possible mechanisms involved and whether our previous concerns regarding confounding and limited information on duration of exposure have been resolved;

(ii) how they affect our view of transferability of results from studies in the US to the UK;

(iii) how they affect our view of whether quantification should be attempted.

### 2.1 Are the results of the cohort studies real?

8. The most significant new information comes from the HEI reanalysis (6) of the original cohort studies (2,3). An audit of the raw data was performed – although a few minor errors were found, they did not have any marked effect on the results. Nor did the use of alternative models to analyse the data. The analysis was also extended to cover some of the questions raised when the original studies were published. Key points from this analysis are discussed further below (see also Table 1).

9. Abbey *et al* (1999) (8) have updated the previous study (9) of Seventh-Day Adventists in California described in paragraph 6. 6,338 subjects were followed up from 1977 to 1992.  $\text{PM}_{10}$  measurements were available from 1987 to 1992 but  $\text{PM}_{10}$  was estimated from TSP from 1973 to 1987. As before, individual air pollution profiles giving cumulative personal exposure were interpolated from monitoring data. Relative risks were adjusted for age, past smoking, education, occupation and body mass index. The study found a positive association between all-cause mortality and the number of days with  $\text{PM}_{10}$  above 100  $\mu\text{g}/\text{m}^3$  in males but not females (adjusted relative risk for interquartile range 1.12(1.01-1.24) for men). (This cannot be compared with results in the other cohort studies since they had no equivalent type of measure of particles.) No association was found with mean  $\text{PM}_{10}$  or with cut offs below 60  $\mu\text{g}/\text{m}^3$ . There were no significant associations with cardiopulmonary or respiratory mortality. However, there were positive associations with days with  $\text{PM}_{10}$

above 100  $\mu\text{g}/\text{m}^3$  and respiratory disease as a contributing or underlying cause of mortality in men only. There were stronger associations with lung cancer, again in men only.

10. Preliminary results of a study by Lipfert (10) in US veterans have been published recently. They did not find an effect of particles but did find an effect of nitrogen dioxide and ozone. However, we have not as yet had time to fully assess this paper.

11. Strachan (2000) (7) has examined the associations between early life exposure to coal smoke pollution and respiratory mortality. This is discussed further below.

### *Confounding*

12. We have mentioned previously (1) that the cohort studies may not have taken possible confounding by socioeconomic factors sufficiently into account. The largest study by Pope *et al* (3) used only level of education as an indicator of socioeconomic differences. The HEI reanalysis (6) of this study has now examined the effect of controlling for the level of income, income disparity, poverty and unemployment in the cities and found no marked impact on the estimated relationship between air pollution and all cause mortality. Level of education was looked at in more detail. It was not a confounder but was a strong effect modifier with mortality risks decreasing significantly with increasing educational attainment (Table 1). Education is presumably acting as a proxy for socioeconomic factors. Adjusting for population change (thought to be related to level of education) and sulphur dioxide (see paragraph 25) also reduced the relative risk. Occupational exposures to dust and fumes are likely to be higher in those with less education but although the Six Cities study found a higher risk with self-reported occupational exposure, confounding was not found with a more detailed occupational exposure index in either study.

13. The HEI reanalysis (6) also examined spatial variations in mortality in the ACS study more closely. Even after control for confounders such as those above, there remained correlations between mortality rates in cities in the same region. This suggests the presence of unknown regional factors affecting mortality. Controlling for this spatial variation reduced the risks associated with fine particles. The techniques used to analyse spatial correlations are still developing, and the HEI Health Review Committee advised interpreting these results with caution.

14. We note that there are some potential confounders that have not been examined such as diet, birth weight, blood pressure or serum cholesterol. However, these would have to be strongly correlated with air pollution levels to act as actual confounders.

### *Duration of exposure*

15. We pointed out, in our 1995 report (1), that the cohort studies (2,3) were unable to take account of different durations of exposure or of the differences in historical levels of air pollution in the cities. Particle levels measured over relatively brief periods (6 years at most (2)) were used to represent the pollution experience of cities. The HEI reanalysis (6) was not able to address this problem fully since it is dependent on the same dataset. It provided

a few hints in support of both recent exposure and exposure in the more distant past being important but none of these points were conclusive. Stratification by age in the ACS study indicated that risks were not reduced in those under 50 as would be expected if more than 40 to 50 years of exposure were needed before the onset of an effect. In addition, at least some of the effect is expected to be short-term as indicated by the time-series studies.

Table 1 Selected extracts from HEI Reanalysis Tables 4 and 21 (6)

Personal Factors	Six Cities Study	American Cancer Society Cohort	
	All cause mortality	All cause mortality	
	Fine particles PM <sub>2.5</sub>	PM <sub>2.5</sub>	Sulphate
<b>Age at Enrolment</b>			
≤ 40	2.11 (0.88-5.07)		
41-55	1.66 (1.17-2.35)		
> 55	1.17 (0.98-1.40)		
<50		1.19 (0.91-1.56)	1.14 (0.91-1.42)
50-60		1.13 (0.97-1.30)	1.12 (0.99-1.26)
>60		1.19 (1.09-1.29)	1.16 (1.09-1.24)
<b>Educational Level</b>			
Less than high school	1.45 (1.13-1.85)	1.35 (1.17-1.56)	1.27 (1.13-1.42)
High school	1.30 (0.98-1.73)	1.23 (1.07-1.40)	1.20 (1.08-1.33)
More than high school	0.98 (0.72-1.36)	1.06 (0.95-1.17)	1.05 (0.96-1.14)
<b>Heart or lung disease</b>			
Yes	1.32 (1.06-1.63)	1.15 (1.05-1.26)	1.15 (1.07-1.23)
No	1.24 (0.99-1.57)		
<b>Cancer</b>		1.34 (1.15-1.57)	1.19 (1.05-1.34)
<b>FEV<sub>1</sub></b>			
> 85% predicted	1.24 (1.03-1.49)		
< 85% predicted	1.35 (1.00-1.84)		
<b>Occupational exposure to dust and fumes</b>			
Yes	1.39 (1.13-1.72)	1.08 (0.93-1.27)	1.14 (1.01-1.28)
No	1.17 (0.92-1.50)	1.20 (1.11-1.30)	1.15 (1.08-1.23)
<b>Smoking status</b>			
Never smoked	1.36 (1.02-1.82)	1.25 (1.11-1.40)	1.18 (1.08-1.29)
Former smoker	1.29 (0.97-1.72)	1.21 (1.07-1.37)	1.14 (1.03-1.25)
Current smoker	1.35 (1.04-1.74)	1.14 (0.99-1.31)	1.21 (1.08-1.35)
<b>D particles</b> most polluted-least polluted	18.6 µg/m <sup>3</sup>	24.5 µg/m <sup>3</sup>	19.9 µg/m <sup>3</sup>

16. A case-control study in the UK (7) has investigated specifically whether early childhood exposure to smoke and sulphur dioxide pollution is related to mortality from chronic respiratory disease in adults. Deaths from chronic obstructive airways diseases and

population-based controls who were born in the 1930s were compared in the mid-1990s. Place of residence in 1939, imputed from NHS number, was related to a four-point index of air pollution derived from local domestic coal consumption during wartime rationing. Individual smoking data were not available, but the analysis adjusted for individuals' social class, county of residence in the mid-1990s and in 1939, and a range of socioeconomic and infant mortality data linked at the level of local government district in 1939.

17. This study found an increased risk of death from chronic respiratory disease in adults brought up in more heavily polluted areas but this effect was removed after adjustment for the confounding variables. Adjustment for these variables was also sufficient to remove any association between childhood air pollution exposure and lung cancer mortality, suggesting that any residual confounding by smoking habits was minimal. In this study, early childhood exposure to levels of smoke and sulphur dioxide pollution much higher than encountered nowadays did not increase the risk of later respiratory mortality. Cardiovascular mortality was not assessed, nor were the effects of air pollution exposure during early or later adult life. However, the findings suggest that the correlation between contemporary air pollution levels and adult mortality in the American cohort studies cannot be explained by exposure to higher levels of pollution in these cities in childhood.

#### *Susceptible groups*

18. The HEI reanalysis also looked at whether the associations between fine particles and mortality varied in different subgroups (Table 1). Age, education and occupational exposure have already been discussed. Those with pre-existing heart or lung disease are one plausible susceptible subgroup but the relative risk was not increased in this group in the ACS study and the increase seen in the six cities study was not statistically significant. Similarly, the increased relative risk in those with reduced FEV<sub>1</sub> in the six cities study was not significant. There was also no difference in relative risk between smokers and non-smokers. (There would still be a difference in absolute risks as baseline risks differ between the groups.)

19. The original studies found positive associations with cardiopulmonary mortality but did not examine cardiovascular and respiratory mortality separately. When the HEI reanalysis did this, it seemed that only cardiovascular mortality was affected in both studies. It might be suggested that the apparent lack of an effect on respiratory mortality might be due to misclassification between cardiovascular and respiratory deaths. (It is well known that death certificates can be inaccurate - one author (11) estimates 20 to 50% of death certificates are contradicted by a post-mortem). It can be particularly difficult to attribute the final specific cause of death in a patient with underlying cardiac and pulmonary disease. However, random errors of classification are unlikely to have generated an association of one cause of death and not with another. (We have no information on whether non-random errors of classification could have occurred). Schwartz (12) has shown that cardiac deaths associated with short-term exposure to air pollution more often have respiratory disease as a contributing cause of death. It is unknown whether this is the case for the long-term effects.

#### *Comment*

20. The HEI reanalysis has confirmed that the original studies were of good quality and, on the whole, the associations were robust to a whole range of additional tests. Additional socioeconomic confounders have been examined, at least at city level, without showing a marked effect on the association, although the increased effect in those with less than high school education may suggest some influence of socioeconomic factors. Adjustment for some factors such as population change and levels of sulphur dioxide did markedly reduce the risk. The updated study by Abbey *et al* (8) in Seventh Day Adventists (non-smokers) with detailed estimates of pollutant exposure now shows a positive association with days of PM<sub>10</sub> above 100 µg/m<sup>3</sup>, although the effect was only in men and did not apply to mean concentrations. It is uncertain to what degree the results in this unusual subgroup can be extrapolated to the general population.

21. Some doubts remain. Geographical variations in mortality are not fully understood and there is at least a possibility that a factor other than pollution explains the results. The studies examine mortality in relation to spatial rather than temporal differences in pollution so there are additional uncertainties when applying them to assess the impact of changing pollution over time.

22. We still know very little about what underlying mechanism could explain the result. If true, the lack of an effect on respiratory mortality is unexpected since the lung is the site of first contact and the acute effects are known to affect respiratory mortality. One plausible scenario that particles worsen symptoms in those already ill over the longer term as well as in response to daily changes, is not supported by the lack of difference in risk in those with pre-existing disease. This does not rule out a role in causing disease. We reviewed the evidence for an association between long-term exposure to particles and morbidity in 1995 (1). The studies did not examine cardiovascular illness. They suggested an adverse effect on bronchitic symptoms but were difficult to interpret given uncertainties over confounding and the relevance of exposures earlier in life. There is a single unpublished study (7), described in paragraphs 16 and 17 above, that suggests early life exposure to coal smoke pollution may not be involved in determining respiratory mortality. The lack of a relative increase in effect on all-cause mortality with age does not suggest that very long periods of cumulative exposure (> 40 to 50 years) are required.

23. Overall, we still regard it as prudent to consider at least some of the association as causal (1). Some of the factors in the HEI reanalysis reduced the risk but a positive association usually remained. Although understanding the mechanism would considerably increase our confidence in the results, the lack of an immediately obvious mechanism does not automatically mean one does not exist.

## ***2.2 Are the results transferable to the UK?***

24. We noted the absence of any corresponding UK or European cohort studies and consequent concerns about transferability of the US results, when last considering quantification of the long-term effects in 1998 (4). Since then, the UK study mentioned

above (7) has examined one aspect (early childhood exposure) and studies in the Netherlands (13) and France (14) are underway but not yet complete.

25. There are many different factors that might affect transferability of the results of the cohort studies. The mix of pollutants in the air may vary between countries and this may be important for transferability of the results. For example, the HEI reanalysis found a strong association between sulphur dioxide and mortality. The inclusion of sulphur dioxide in the models reduced the effects of fine particles and sulphate, raising questions about exactly what aspects of the pollution mixture are most important for health. On the other hand, time series studies have found relationships between ambient particles and daily variations in mortality and hospital admissions in a wide range of pollution mixtures. Another point raised by the HEI Health Review Committee (6) is that sulphur dioxide may be a better marker of local pollution than fine particles and sulphate which are regional pollutants.

26. Although pollution levels are generally higher in the United States, there is considerable overlap. The range of particle levels in the ACS study was 9 – 33.5  $\mu\text{g}/\text{m}^3$   $\text{PM}_{2.5}$  (median)<sup>2</sup> (equivalent to about 15 – 56  $\mu\text{g}/\text{m}^3$   $\text{PM}_{10}$ ) in 1979-1983. Medians are not routinely calculated in the UK but it is known that, for  $\text{PM}_{10}$ , means and medians are reasonably similar (15). The range of annual means in the UK varied from 13 to 35  $\mu\text{g}/\text{m}^3$   $\text{PM}_{10}$  in 1998. The composition of the particle mixture varies across the US but encompasses a similar range of composition to that in the UK.

27. Where there are several causes leading to death from particular diseases, the competing causes can modify the proportion of deaths affected by the cause of interest. This ‘causal field’ could vary in different places as can the proportion of people in particular susceptible groups. The quantitative impact of pollution could therefore vary between countries with different cultures and lifestyles. In fact, the HEI reanalysis found evidence of regional heterogeneity in the effect of air pollution on mortality within the United States.

28. Thus, although the results of the US studies may be transferable to the UK in a qualitative sense, the size of the impact could differ and this variation cannot be predicted exactly.

### ***2.3 Should the potential long term effects of particles on mortality be quantified?***

#### *IOM Report*

29. The IOM report (5) used life-table methods to link the results of the US cohort studies with the age and mortality experience of the UK population. Given certain assumptions, this allowed an estimate of the possible loss of life expectancy due to long-term exposure to particles. It also explored the effect of using different assumptions referred to further below. This analysis was not available in 1998 when quantification was last considered.

---

<sup>2</sup> Concentrations in this report refer to gravimetric measurements.

30. The IOM report has illustrated that, provided the results are transferable, the methodology is available to quantify the effects and the size of the effect could be substantial. We consider that it is more helpful to quantify the implied effects in the UK rather than not, provided the uncertainties are acknowledged. These uncertainties include concerns about how the degree of impact might differ in the UK compared with the US, the lack of a clear understanding of the mechanism and limited knowledge about the duration of exposure needed to produce effects. For these reasons, we consider it unwise to give a single estimate. We develop below a range of possible estimates along with our comments on how likely these estimates are.

### **3. Quantification**

#### ***3.1 Methodology***

31. We have based our methodology on that in the IOM report (5) although we have used slightly different assumptions. IOM have also performed the additional calculations we required. The basic strategy is, for a given population, to

- obtain information on current mortality rates
- predict future mortality using current rates and lifetables and some assumptions about future demography, in the absence of changes in air pollution (the baseline scenario)
- create an alternative scenario by adjusting mortality rates according to evidence regarding the effect of pollution on mortality, but leaving other baseline assumptions unchanged
- compare predicted life expectancy (or some other appropriate summary measure) between the baseline and alternative scenario, to give estimates of the effect of the pollution change,
- examine how sensitive these estimates are to changes in the underlying assumptions.

32. The calculations are for changes in all-cause mortality in those over 30 (as in the cohort studies). This is the simplest end-point and avoids any problems of misdiagnosis of cause of death.

#### ***Baseline scenario***

33. The baseline scenario is based on the numbers of deaths in each sex and age group found in England and Wales in 1995. This is used to predict future mortality. It is assumed that the mortality rates identified in 1995 will not change over time, that birth rates will remain constant and that the net effect of migration does not alter population sizes or mortality rates. (The IOM report found that changing these assumptions had only a small effect on the results.) As an illustration, the calculations were applied to the following populations:

- a single cohort born in 2000 subject to the hazard rates applying in England and Wales in 1995 (this provides a 'standard' which can be compared with the effect of other determinants of mortality such as smoking),
- the population alive at 2000 followed to extinction (this provides an estimate of the long-term impact on the current population).

Different populations and length of follow-up could be used if required for cost-benefit analysis of particular policies.

### ***Alternative scenario***

#### *Selection of studies and particle measure*

34. In the alternative scenario, mortality rates are adjusted compared with the baseline scenario. The adjustment is based on the particular reduction in pollution chosen. We have based the link between pollution change and mortality rate on the American Cancer Society study (3) as it is the largest study and was able to investigate a wide range of confounding factors.

35. The ACS study provides relative risks for mortality for both PM<sub>2.5</sub> and sulphates. The reanalysis (6) showed smaller associations with mortality with PM<sub>15</sub> and PM<sub>15-2.5</sub> (coarse particles) than with fine particles (PM<sub>2.5</sub>). We have used the coefficient for PM<sub>2.5</sub> as the starting point for the calculations. Although using a mass measure, we note that composition can be important and that it cannot automatically be assumed that the results will apply to all types of particles.

#### *Reduction in pollution*

36. For simplicity, we have presented the results of a 1 µg/m<sup>3</sup> reduction in PM<sub>2.5</sub> annual average concentration across the country maintained for the lifetime of those alive in 2000. We have not linked the health effects to maps of predicted changes in PM<sub>10</sub> concentrations as a result of specific policies – this will be done in future cost-benefit analysis work. To put this reduction in context, a series of campaign measurements of PM<sub>2.5</sub> made at 3 urban background sites in London during 2000-2001, using a gravimetric method comparable to that used in the ACS study, gave an average of 18 µg/m<sup>3</sup> (16). A reduction of 1 µg/m<sup>3</sup> PM<sub>2.5</sub> represents around a 5 % reduction from this level.

37. The ACS study (3) represented the PM<sub>2.5</sub> levels in terms of a single value of long-term average concentration in each of the cities studied. It used a median concentration, based on measurements from 1979-1983, as its index of long-term annual average PM<sub>2.5</sub>. Ideally, the concentration change for quantification would be expressed on exactly the same basis but we note that, for particles, changes in annual means would be a reasonable approximation of changes in median concentrations (15). (Annual means are routinely calculated for other purposes so are more convenient to use.) We have therefore chosen to use annual means.

38. The IOM report found that the results were linear with particle concentration i.e. an estimate for a  $10 \mu\text{g}/\text{m}^3$  change would be twice that for a  $5 \mu\text{g}/\text{m}^3$  change. This assumes that there is no threshold for the effect. (The HEI reanalysis did not resolve the threshold issue as it found that both linear and non-linear models could be fitted satisfactorily to the data. In some models no threshold of effect was apparent, in others, some indications of a weakening of the association was found at low concentrations.) We would be concerned about using too large an increment as uncertainties will increase at low concentrations and there is a danger of moving outside the range of the original data ( $9 - 33.5 \mu\text{g}/\text{m}^3$   $\text{PM}_{2.5}$  (median) equivalent to about  $15 - 56 \mu\text{g}/\text{m}^3$   $\text{PM}_{10}$ . UK annual means (similar to medians) varied from  $13$  to  $35 \mu\text{g}/\text{m}^3$   $\text{PM}_{10}$  in 1998. In addition, large changes may be difficult to achieve. Our aim is to describe the benefits that might be produced by reductions in the annual average concentration of airborne particles in the UK: thus we are not attempting an estimate of the total effects of current concentrations but, rather, an estimate of the benefits of a given reduction.

#### *Choice of coefficient*

39. The relative risk for fine particles and mortality in the ACS study (3) was 1.17. This is equivalent to a change in hazard rate of 0.6% for a  $1 \mu\text{g}/\text{m}^3$  change in  $\text{PM}_{2.5}$  (section 10.3.2 of IOM report (5)). This is one choice of coefficient.

40. The 95% confidence intervals around the above relative risk were 1.09 to 1.26 equivalent to changes in proportional hazard rates of 0.3% and 0.9%. These confidence intervals only represent errors in statistical sampling and are dependent on the size of the data set. They are not therefore an ideal basis for alternative estimates. Nonetheless, they do indicate that relative risks above and below the central estimate are possible and could be used as a general indicator of the range of possible estimates.

41. The HEI Reanalysis reconfirmed the above relative risks when auditing the original analyses but also extended the analyses to examine additional factors. Some of these factors reduced the relative risks but, in the majority of cases, the central estimates were still in the range mentioned above. A few were below (including adjustment for more than high school education and for sulphur dioxide) and just one (an adjustment for several important covariates together) was above the range (see Table 37; reference 6). We have not used any of the estimates of relative risks in the HEI reanalysis directly as there were multiple tests and it would be difficult to choose one adjustment over another. However, we have used the HEI results to inform our view of the likelihood of particular estimates and have included an 'extra low' option of a 0.1% change in hazard rates. This represents a relative risk of around 1.03 equivalent to one of the lowest adjusted relative risks in the HEI reanalysis.

42. Adjustment for some factors in the HEI reanalysis resulted in the lower confidence intervals falling below one and there may be undetected confounding. Thus, we consider that it is possible that there are no long term effects. This does not necessarily mean that there are no effects on mortality, as there are still the short-term effects shown in the time-series studies. The two types of studies have a different design so it is difficult to compare

them directly but calculations can be done separately to estimate the expected change in number of deaths brought forward due to short-term effects over an equivalent time period. The loss of life expectancy from the short-term effects is not known for certain but, assuming the average is between 2 months and 6 months, an estimate of life years gained from a pollution reduction can be obtained. Recent evidence (17,18, 19) suggests that some of the deaths involve losses of life expectancy exceeding a few days and up to at least a month or two. Examination of much longer timescales is difficult with the method used because there could then be an increase in confounding due to factors such as season. Thus, this method does not rule out losses of life-expectancy greater than 2 months. We have assumed an upper end of the range for the average loss of life expectancy of around 6 months.

43. In summary, we consider that use of hazard rates reductions of 0.1%, 0.3%, 0.6% and 0.9% provides a reasonable range of estimates to cover the values that might be plausible. In addition, an estimate based on the time-series results calculated in a different way should provide a lower bound.

#### *Lagtime and age-dependence*

44. In modelling the effect of a drop in pollution on mortality, it is necessary to know whether there is an immediate drop in mortality or whether there is a delay. Because the ACS study compares different pollutant concentrations across different cities over the same time-period rather than different pollutant concentrations over time in the same location, this study cannot help us directly. As mentioned in paragraph 6, the HEI reanalysis found that relative risks did not differ markedly when the data was stratified by age (< 50, 50-60 and > 60). If the lag-time to an effect were very long (50 years or more), then there would not have been an effect in those under 50. It is likely that the lag-time is short in at least some cases as suggested by the time-series studies. We have therefore assumed a lag-time between 0 and 40 years either phased in gradually or abruptly, i.e. no effect followed by a step change. This is not to imply that we regard the outer extremes of the assumptions (e.g. a step change after 40 years) as particularly likely; they provide outer bounds.

45. We have applied the same change in hazard rates across all age-groups above 30. The ACS study only included adults over 30 so changes in hazard rates have not been applied to the under 30s. (In fact, changes applied to the under-30s make little difference because baseline death rates are low at these ages).

### **3.2 Results**

#### *Population alive in 2000, follow-up 105 years*

46. The results in Table 2 apply to the population of England and Wales alive in 2000 followed to the end of their lives assuming a  $1 \mu\text{g}/\text{m}^3$  drop in annual mean  $\text{PM}_{2.5}$  is maintained for the rest of their lifetime (up to 105 years). The baseline assumes current mortality rates remain unchanged (sensitivity analyses have shown that changing this assumption has little effect on the results). Coefficients range from a 0.1% to 0.9% decrease in hazard rate and lag times from an immediate effect to a step change after a delay

of 40 years. These changes are only applied to those over 30. Results are total gains in life years (millions).

47. The answers range from 0.2 to 4.1 million life years gained over the rest of the lifetime of the population alive today. This could be expressed as 1 day to 1 month per person per  $\mu\text{g}/\text{m}^3$   $\text{PM}_{2.5}$  on average but it should be noted that the gains in life expectancy are unlikely to be evenly distributed across the population.

Table 2 Estimated total gains in life years (millions) in population of England and Wales 2000, followed to extinction with a range of reductions in hazard rates in those aged 30 years and over. Total effects immediate, phasing in gradually or step function after stated number of years.

		<b>Reduction in mortality rate</b>							
		<b>0.1%</b>		<b>0.3%</b>		<b>0.6%</b>		<b>0.9%</b>	
<b>Delay to full effect (years) &gt;</b>		<b>0</b>	<b>40</b>	<b>0</b>	<b>40</b>	<b>0</b>	<b>40</b>	<b>0</b>	<b>40</b>
<i>Follow-up 105 years</i>									
Total life years gained (millions)	Phased	0.5	0.3	1.4	1.0	2.8	2.0	4.1	3.0
	Step	“	0.2	“	0.6	“	1.2	“	1.8

*Population alive in 2000, time-series estimate*

48. The rough estimates of the size of the short-term effects are shown in Table 3. This uses a coefficient of 0.075% decrease in deaths brought forward per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{10}$  from our Quantification report (4). (We have not used a coefficient for  $\text{PM}_{2.5}$  since the Expert Panel on Air Quality Standards (EPAQS) has recently concluded (20) that a contribution from fractions other than  $\text{PM}_{2.5}$  cannot be ruled out). We applied this coefficient to the total number of deaths over 105 years (the same as the size of the population 52,451,959). [This calculation is equivalent to doing calculations for each year and summing them up.] For simplicity, account has not been taken of the fact that the age spectrum will change over time (in 50 years time, none of the population who were alive in 2000 can be less than 50) and this may matter if, as may be the case, air pollution has a greater effect on the elderly.

49. The calculation indicates that, for a  $1 \mu\text{g}/\text{m}^3$  drop in annual mean  $\text{PM}_{10}$ , maintained for the rest of their lifetime (up to 105 years), there would be around 40,000 fewer deaths brought forward. If each of these would have involved a loss of life expectancy of between 2 and 6 months, then the total life years gained would be about 7,000 to 20,000 years or 0.007 to 0.02 million life years. The highest estimate is 10 fold lower than the lowest estimate from the cohort studies. Although, as noted above, some approximations have been used, this is unlikely to make as much as a ten fold difference to the results.

Table 3 Estimated total and per-capita gains in life years in the population of England and Wales 2000 followed to extinction, based on deaths shown to be advanced by  $\text{PM}_{10}$  in time series studies.

Proportion of deaths from all causes that are advanced by $1 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{10}$ (COMEAP Quantification Report – $0.75\% / 10 \mu\text{g}/\text{m}^3$ )	A	0.00075
Population of E&W in 2000 (COMEAP/2000/17 Table 1)	B	52,451,959
Number of deaths that would be postponed by reduction of $1 \mu\text{g}/\text{m}^3 \text{PM}_{10}$	$C=AXB$	39,339
Increase in YOL if $\text{PM}_{10}$ advances death in affected persons by 2 months on average		
Total	$D=2XC/12$	6,557
Average per capita	$E=D/B$ $(=2XA/12)$	0.000124
Increase in YOL if $\text{PM}_{10}$ advances death in affected persons by 6 months on average		
Total	$F=6XC/12$	19,670
Average per capita	$G=F/B$ $(=6XA/12)$	0.000375

Notes:

1. This assumes that the effect is on deaths at all ages, as does the COMEAP Quantification report.
2. To change results assuming effects at age 30+ only would require excluding deaths in the component aged 0-29 occurring before age 30, which would affect results very little, certainly less than 1%.
3. The figures are the same for a 2000 birth cohort, although a different (somewhat greater) correction would have to be made to reflect an effect at age 30+ only.
4. As these are acute effects, there is no delay to full effect.

*Birth cohort born in 2000, lifetime follow-up*

50. The results derived from the cohort studies can also be expressed on the basis of a single birth cohort born in 2000 and followed up for their lifetime. This is less relevant for assessing the size of the effect but is a useful standard measure for comparing with other risk factors such as smoking. These calculations are shown in Table 4 (note that units are in weeks rather than million life years as in Table 2). This shows that the average gain in life expectancy for a 1  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$  can range from about 0.5 to 4.5 weeks.

Table 4. Estimated average gains in life expectancy in a single cohort born in 2000 in England and Wales, for a range of reductions in hazard rates at ages 30 years and over. Effects immediate, phasing in gradually or step function after stated number of years.

		Reduction in mortality rate							
		0.1%		0.3%		0.6%		0.9%	
Delay to full effect years >		0	40	0	40	0	40	0	40
Gain in life expectancy (weeks)	Phased	0.5	0.5	1.6	1.4	3.0	3.0	4.5	4.5
	Step	“	0.5	“	1.4	“	2.8	“	4.3

### 3.3 Discussion

51. The above paragraphs have shown that a range of quantitative estimates of the possible effects of long term exposure to particles can be made. However, the range is wide – a 20 fold difference from 0.2 to 4.1 million life years gained per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$  depending on the assumptions made or a 600 fold difference from 0.007 to 4.1 million life years if the option of zero long term effects is included. This reflects the many uncertainties involved. The time series rough estimate is at least 10 fold lower than the cohort study derived estimates illustrating the potential importance of the long term effects.

52. Although the calculation of life years gained derived from the time-series studies is new, in general the time-series studies are well replicated and widely accepted. Thus, the effect is highly likely to be at least this large. In accordance with our earlier comments, we consider that it is more likely than not that there is some long term effect. However, several factors support estimates at the lower rather than the higher end of the range of estimates. A few of

the confounders in the HEI reanalysis reduced the relative risks substantially and there may be other unknown confounders. It is also possible that, at least some of the effect is in fact due to higher exposures in the past, thus leading to an overestimation of the effect of current levels. There are some suggestions that the effect of air pollution on chronic morbidity is not as marked as it used to be (21, 22).

53. For the above reasons, none of the Committee supported the highest estimate. Although opinions varied, the majority of the Committee considered that an estimate of around 0.2 to 0.5 million life years gained was most likely. This is equivalent to between 1.5 and 3.5 days per person if all 52 million people are affected but, as mentioned previously, it is unlikely that the effect is evenly spread across the population. This estimate of life years gained could also refer to 3 to 7 days for 25 million people; 1 to 2.5 months for 2.5 million people or 2.5 to 6.5 months for 1 million people or, of course more likely, a more complex distribution of different losses of life expectancy across the population. We cannot distinguish these possibilities at the present time, particularly since the mechanism underlying the association is not well understood.

54. We suggest that the estimate of 0.2 to 0.5 million life years gained per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$  for the population alive today can be used to estimate the benefits of reductions in pollution with sensitivity analyses for the other estimates including that for zero long term effects. The level of uncertainty increases with the increasing size of the estimate.

55. These results are expressed per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$  but, to compare the estimates with other risks, this needs to be related to actual exposures. In paragraph 38, we noted the increased uncertainties involved in calculations for larger increments, so the following should be regarded only as a rough guide for the purposes of broad brush comparisons. Acknowledging this,  $18 \mu\text{g}/\text{m}^3$   $\text{PM}_{2.5}$  could be responsible for an average loss of life expectancy from birth of about 2- 20 months (derived from Table 4). This compares with an estimate of around 7 years if all the population were smokers (using the relative risk of 2.07 for smokers from the HEI reanalysis (6) and the same methodology). Thus, as would be expected, the impact is considerably smaller than for active smoking. [Purely on the basis of relative particle exposures it might be expected to be smaller than it is but both cigarette smoke and air pollution are complex mixtures of different chemicals with different effects so exact comparisons cannot be taken too far].

56. Another risk for comparison is the risk of ischaemic heart disease events (fatal and non-fatal) from passive smoking (relative risk 1.23 after adjustment for diet) (23). This can be compared with a relative risk of 1.31 for cardiopulmonary mortality (mainly heart disease) for a  $24.5 \mu\text{g}/\text{m}^3$  difference in  $\text{PM}_{2.5}$  from the most polluted to least polluted area. (Further work would be required to relate this to losses in life expectancy, our current methodology is based on all cause mortality only.)

57. These comparisons are very rough but they do indicate that the effects suggested are not wildly implausible. The results (up to 1 month on average per person per  $\mu\text{g}/\text{m}^3$   $\text{PM}_{2.5}$  for the full range of estimates) are also roughly in line with previous estimates of gain in life expectancy from the cohort studies. Brunenkreef (1997) (24) estimated a gain in life-

expectancy of 1.11 years for a  $10 \mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$  for a cohort of 100,000 people in the Netherlands followed from 25 to 90 assuming a 15 year lagtime. This is equivalent to just over a month per person for a  $1 \mu\text{g}/\text{m}^3$  drop. Nevalainen and Pekkanen (1998) (25) estimated the loss of life expectancy for a  $10 \mu\text{g}/\text{m}^3$  rise in  $\text{PM}_{2.5}$  for 100,000 people in Finland using a method involving competing causes of death as 0.6 years (0.7 years ignoring competing causes of death). This is equivalent to just under a month per person for a  $1 \mu\text{g}/\text{m}^3$  drop. Although Ostro (1998) (26) used a different method of calculation, he also used an estimate lower than the central estimate in the ACS study although for different reasons.

58. There is clearly a need for further research to reduce some of the uncertainties regarding these effects. In particular, there is a need for more studies in other countries to increase confidence that the results can be replicated and are transferable to the UK. There is also a need to examine particular aspects contributing to the wide range of estimates, such as the uncertainties about whether there is a lagtime between exposure and effect and what durations of exposure are required. The latter is relevant to the question of whether high historical exposures are leading to an overestimation of the effects of current levels. One study (7) suggests not but it would be helpful to examine this further. A major area of uncertainty is the lack of understanding of the mechanism of the effect; research into this aspect is needed.

#### **4. Conclusions**

59. Although there are many uncertainties, the quantification exercise highlights what these are and what difference they make. The range of estimates is wide but may nonetheless be useful. When using the results, the following points should be noted.

(i) Our comments on the key uncertainties (see below) should be quoted.

(ii) Application of the results to large changes in pollution adds to the uncertainties (see paragraph 38).

(iii) The composition of the particles is important; it cannot be assumed that these results extend to pollution climates very different from those typical of US cities. For example, we do not know whether these estimates would apply around point sources.

(iv) These results relate not only to a  $1\mu\text{g}/\text{m}^3$  change in  $\text{PM}_{2.5}$  but also to a particular population (those alive in 2000) and a particular length of follow-up (105 years). We acknowledge that cost-benefit analysis of particular policy scenarios may need different populations and follow-up periods. We consider that this could be dealt with by performing new lifetable calculations, provided the same methodology was used.

60. Our conclusions are as follows:

(i) We consider it more likely than not that a causal association exists between long term exposure to particles and mortality. We consider that this association is

transferable to the UK, although the quantitative impact may not be exactly the same.

- (ii) We consider that, given there is information regarding the size of the effect, it is preferable to assess this and comment on it rather than ignore it. Nonetheless there are great uncertainties in this process and it is vital that these are made clear. We consider that the long-term effects are more uncertain than the short-term effects but that it would be unwise to dismiss them completely.
- (iii) It is possible, although unlikely, that there are no long term effects, if the results are explained by unknown confounders, confounding by sulphur dioxide or lack of control for spatial variation. If so, the only effect on mortality would be that detected in the time-series studies.
- (iv) An approximate calculation assuming a loss of 2 to 6 months of life per death brought forward suggests a gain of 0.007 to 0.02 million life years per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{10}$  for mortality from short-term exposure as detected in time-series studies. Although intended only as a rough comparison, this does suggest that the gain in life years from the cohort studies is at least 10 fold greater than estimates from the time series studies alone.
- (v) The above calculation and those below are based on the population of England and Wales alive in 2000 followed for 105 years as an illustration. Other populations and years of follow-up could be used provided the same methodology is followed. The calculations below are expressed per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$  representing around a 5 % reduction from current levels.
- (vi) Using a range of possible coefficients from the cohort studies leads to an estimate of 0.2 to 4.1 million life years gained per  $\mu\text{g}/\text{m}^3$  drop in  $\text{PM}_{2.5}$ . This could be expressed as up to 1 month per person on average if everyone was affected but could also represent a larger gain for fewer people.
- (vii) We consider that estimates at the lower end of the range are more likely. We know that a few of the confounders in the HEI reanalysis reduced the relative risks and there may be other unknown confounders. If higher exposures in the past are contributing to the effect, then the predicted effect of current levels will be overestimated. We consider the upper end of the range to be implausibly large compared with risks in other contexts and with the total changes in life expectancy seen in the last 20 to 30 years when particle levels have been dropping dramatically.
- (viii) The majority of the Committee considered that an estimate of 0.2 – 0.5 million life years (1.5 to 3.5 days per person or more) could be used to estimate the benefits of pollution reduction. The higher estimates could be included in sensitivity analysis in increasing bands of uncertainty as the size of the estimate increases. The possibility of there being no long term effects should also be included in sensitivity analysis.

- (ix) For a birth cohort born in 2000 and followed up for their lifetime, the gain in life expectancy for the same reduction is estimated as between 0.5 and 4.5 weeks.
- (x) Taking actual exposures into account, the estimates are less than those for active smoking but the relative risk for mortality from heart disease is similar to that for passive smoking. The estimates are in line with others for air pollution in the literature.
- (xi) The key uncertainties are whether the results can be explained by undetected confounding, whether high exposures in the past lead to an overestimation of the effect, what lagtimes and what duration of exposure are required for the effect and a lack of understanding of the underlying mechanism. These uncertainties need to be addressed by further research.

### March 2001

### References

1. Department of Health. Committee on the Medical Effects of Air Pollutants. Non-Biological Particles and Health. London: HMSO, 1995.
2. Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG, Speizer FE. An association between air pollution and mortality in six US cities. *N Engl J Med* 1993; 329:1753-1759.
3. Pope CA, Thun MJ, Namboodiri MM, Dockery DW, Evans JS, Speizer FE, Heath CW. Particulate air pollution as a predictor of mortality in a prospective study of US adults. *Am J Respir Crit Care Med* 1995; 151:669-674.
4. Department of Health. Committee on the Medical Effects of Air Pollutants. Quantification of the Effects of Air Pollution on Health in the United Kingdom. London: The Stationery Office, 1998.
5. Hurley JF, Holland MR, Markandya A, Miller BG, Anderson HR, Ayres JG, Donnan PT, Harrison RM, King K, Stedman JR, Stevenson KJ. Towards assessing and costing the health impacts of ambient particulate air pollution in the UK. Edinburgh: Institute of Occupational Medicine, 2000.
6. Krewski D, Burnett RT, Goldberg MS, *et al.* Re-analysis of the Harvard Six-Cities Study and the American Cancer Society Study of air pollution and mortality. Cambridge, MA: Health Effects Institute, 2000.
7. Strachan DP. Personal communication (2000). Manuscript in preparation.

8. Abbey DE, Nishino N, McDonnell WF, Burchette RJ, Knutsen SF, Beeson WL, Yang JX. Long-term inhalable particles and other air pollutants related to mortality in nonsmokers. *Am J Respir Crit Care Med* 1999; 159:373-382.
9. Abbey DE, Mills PK, Petersen FF, Beeson WL. Long-term ambient concentrations of total suspended particulates and oxidants as related to incidence of chronic disease in California Seventh-Day Adventists. *Environ Health Perspect* 1999; 94:43-50.
10. Lipfert F W, Perry H M, Miller J P, Baty J D, Wzyga R E and Carmody S E. The Washington University-EPRI Veterans' cohort Mortality Study: Preliminary Results *Inhalat. Toxicol.* 12 (supplement 4): 41-73 (2000).
11. Knight B. Forensic Medicine. In *Oxford Textbook of Medicine* 3<sup>rd</sup> Edition 1996.
12. Schwartz J. What are people dying of on high air pollution days? *Environ. Res.* 1994; 64: 26-35.
13. Hoek G, Brunekreef B, Van den Brandt P, Bausch-Goldbohm S, Fischer P. Long-term effects of air pollution exposure on respiratory mortality: a pilot study. Abstract presented at ISEE 2000.
14. Baldi I, Roussillon C, Filleul L *et al.* Effect of air pollution on long-term mortality: description of mortality rates in relation to pollutant levels in the French PAARC study. *Eur. Respir. J.* 1999; 24(suppl. 30):
15. Stedman J R, King K and Holland H. Quantification of the Health Effects of Air Pollution in the UK for PM10 Objective Analysis. AEA Technology Environment, National Environmental Technology Centre. Report. (in preparation)
16. Professor Roy Harrison (personal communication).
17. Schwartz J. Harvesting and long term exposure effects in the relation between air pollution and mortality. *Am J Epidemiol* 2000; 151:440-448.
18. Zeger SL, Dominici F, Samet J. Harvesting-resistant estimates of air pollution effects on mortality. *Epidemiology* 1999; 10:171-175.
19. Samet JM, Dominici F, Zeger SL, Schwartz J, Dockery DW. National Morbidity, Mortality and Air Pollution Study 2000. Part I. Methods and Methodologic Issues. *Res Rep Health Effects Inst* 2000; Report No 94.
20. Department of the Environment. Expert Panel on Air Quality Standards. Airborne particles: what is the appropriate measurement on which to base a

standard? A discussion document. [Can be obtained via DETR website:  
[www.environment.detr.gov.uk/airq/aqs/index.htm](http://www.environment.detr.gov.uk/airq/aqs/index.htm)]

21. Lunn JE, Knowelden J, Handyside AJ Patterns of respiratory illness in Sheffield junior schoolchildren. A follow-up study. *Br J Prev Soc Med* 24:223-228 1970.
22. Strachan D, Stevenson K and Anderson H R Chronic respiratory health effects of cumulative air pollution exposure: A national birth cohort study. Abstract in *Joint Research Programmes on Outdoor and Indoor Air Pollution – A Review of Progress 1999*. MRC Institute for Environment and Health 2000.
23. Law MR, Morris JK, Wald NJ. Environmental tobacco smoke exposure and ischaemic heart disease: an evaluation of the evidence. *Br Med J* 1997; 315:973-980.
24. Brunekreef B. Air pollution and life expectancy: is there a relation? *Occup Environ Med* 1997; 54:781-784.
25. Nevalainen J, Pekkanen J. The effect of particulate air pollution on life expectancy. *Sci Total Environ* 1998; 217:137-141.
26. Ostro B and Chestnut L Assessing the health benefits of reducing particulate matter air pollution in the United States. *Environ. Res.* 76: 94-106 (1998).

COMEAP papers (COMEAP/2000/17, COMEAP/2001/1 and others) and minutes of Committee discussions which contributed to the development of this report can be found on the COMEAP website <http://www.doh.gov.uk/comeap/index.htm>.