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MEASUREMENT OF PARTICULATE LEAD ON THE M4 MOTORWAY AT HARLINGTON, MIDDLESEX (FIFTH REPORT)

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ABSTRACT

The concentration of lead in the air at a site on the M4 motorway has been monitored annually since 1971. Results are given for the years 1984–1987. During this period (January 1986), the maximum permitted lead content of petrol sold in the UK was reduced from 0.4 to 0.15 g/l and this caused a corresponding reduction in the average airborne lead concentration, from typically 9 $\mu g/m^3$ to less than 3 $\mu g/m^3$.

1 INTRODUCTION

From the beginning of 1986, the maximum permitted lead content of petrol sold in the UK was reduced from 0.4 g/l to 0.15 g/l. This was the latest and largest of a series of reductions introduced since 1973, when a mandatory limit was first imposed (Table 1).

The primary motive for reducing the lead content of petrol has been the protection of health. In 1972 (HANSARD, 1972) and 1976 (HANSARD, 1976), the advice of the Chief Medical Officer of Health was that there was no evidence that prevailing levels of lead emissions constituted a danger to health but that they should not be exceeded and, if possible, should be reduced. On this advice, the Secretary of State for the Environment implemented a phased reduction in the lead content of petrol that was designed to maintain the usage of lead additives at a constant level while total usage of petrol increased. This policy was followed between 1972 and 1978. Subsequently, in 1981, the maximum lead content was further reduced in compliance with EC Directive 76/611/EEC, which required Member States to set maximum levels in the range 0.15–0.40 g/l (Official Journal of the European Communities, 1978).

TABLE 1

Lead content of petrol

Year	Lead Content of Petrol (g/l)	
	Maximum Permitted	Average
1971	0.84*	
1972		0.55
1973	0.64	0.53
1974		0.52
1975	0.55	0.49
1976		0.48
1977	0.50	0.45
1978	0.45	0.42
1979		0.41
1980		0.42
1981	0.40	0.38
1982		0.37
1983		0.37
1984		0.37
1985		0.33
1986	0.15	0.14
1987		0.14

* Voluntary maximum

During this period, there were a number of studies of the effects on people of low level exposure to lead, and in particular of the effects on children (for example Landrigan et al, 1975; Hrdina and Winneka, 1979; Needleman et al, 1979). Conculsions were often conflicting and when, in 1980, the DHSS Working Party on Lead in the Environment reported, they concluded that airborne lead was not a major contribution to the body burden of the vast majority of the population. Nevertheless, they recognised that lead from vehicle exhaust could be the major contribution to uptake for some individuals and that adverse effects on the intelligence, behaviour and performance of children could not be discounted. They recommended that the emission of lead to the air from traffic and other sources should be progressively reduced. In response, the Government announced that the maximum permitted lead content of petrol would be reduced from 0.4 to 0.15 g/l (the minimum then allowed by EC regulations) from 1 January 1986 (House of Commons, 1981).

Further changes to the regulations controlling the use of lead in petrol have been made for two main reasons. Concern over possible health effects continued even though significantly less lead was permitted. In 1983, the Royal Commission on Environmental Pollution reviewed lead in the environment. They concluded that the results of behavioural studies with children were difficult to interpret but that effects, if any, at low lead concentrations were small. They reported, however, that environmental levels of lead were higher, relative to the levels at which clinical symptoms may occur, than any other known toxin and therefore recommended that measures should be taken to reduce the anthropogenic dispersal of lead wherever possible. Among a number of specific measures for the reduction of environmental lead from many sources, they recommended that new cars should be required to use unleaded petrol from the earliest possible date. The Road Vehicles (Construction and

Use) Regulations 1988 (House of Commons 1988) required petrol engined vehicles first used on or after 1 April 1991 to be designed and constructed for running on unleaded petrol and prohibit their use if they have been altered or adjusted to be incapable of running on unleaded petrol.

The second major factor was the growing concern in Europe over the effects of gaseous emissions from motor vehicles. Ecological damage to lakes and forests was increasingly observed and links were postulated with acidic air pollutants (including nitrogen compounds derived in part from vehicle emissions) and oxidants, primarily ozone, resulting from chemical reactions of pollutants in the atmosphere. It was proposed within the European Economic Community (EEC) that more stringent limits should be set for the control of vehicle emissions. The imposition of such limits requires vehicles to be equipped with effective emission control systems, and in some cases with catalytic converters for the removal of pollutants from the exhaust. Because emission control catalysts are poisoned by lead, their use is only possible if vehicles are operated on unleaded petrol.

Following an announcement in 1983 of the Government's intention to make unleaded petrol available in the UK by 1990 at the latest (House of Commons Official Report, 1983), EC Directive 85/210/EEC was negotiated with other Member States to permit this move (Directive 78/611/EEC specified a minimum of 0.15 g/l). This later Directive required that unleaded petrol should be available throughout the EC by 1989 (Official Journal of the European Communities, 1985). Subsequently, the major oil companies have anticipated this requirement and unleaded petrol is now widely available in the UK. The Government has welcomed and encouraged the use of unleaded petrol and, in the budget of 1988, the duty levied on unleaded petrol was not increased whereas that on leaded petrol was, resulting in a price differential in favour of unleaded petrol of about 1p per litre. Usage of unleaded petrol is still low but is increasing and is expected to increase rapidly as more new cars capable of using unleaded petrol replace older cars that cannot.

The proposed and implemented changes in the regulation of the lead content of petrol have achieved the objectives, initially of not allowing an increase and latterly of reducing the usage of lead additives. Figure 1 shows the annual consumption of lead additives in the UK between 1976 and 1986.

Because the majority of airborne lead is derived from vehicle exhaust (DHSS (1980) estimated that industrial emissions were responsible for less than ten per cent of atmospheric lead pollution), these changes in the use of lead in petrol should be reflected directly in changes in atmospheric lead concentrations. In a comparison of measurements throughout the country during the first quarter of 1985 and the first quarter of 1986 (McInnes, 1986), it was shown that there was an average reduction of approximately 50 per cent in airborne lead concentrations. This result is rather lower than would be expected on the basis of the corresponding reduction in the lead content of petrol. However, data from a wide range of sites were included in the

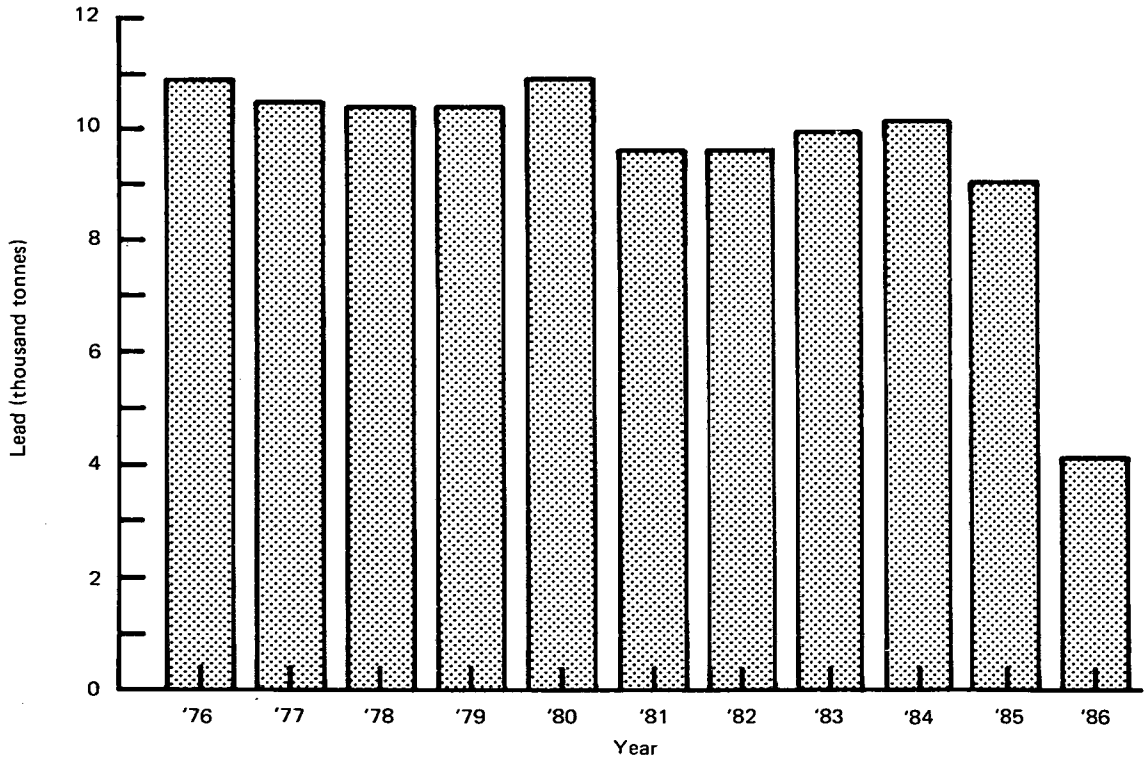

Fig. 1 Annual consumption of lead additives

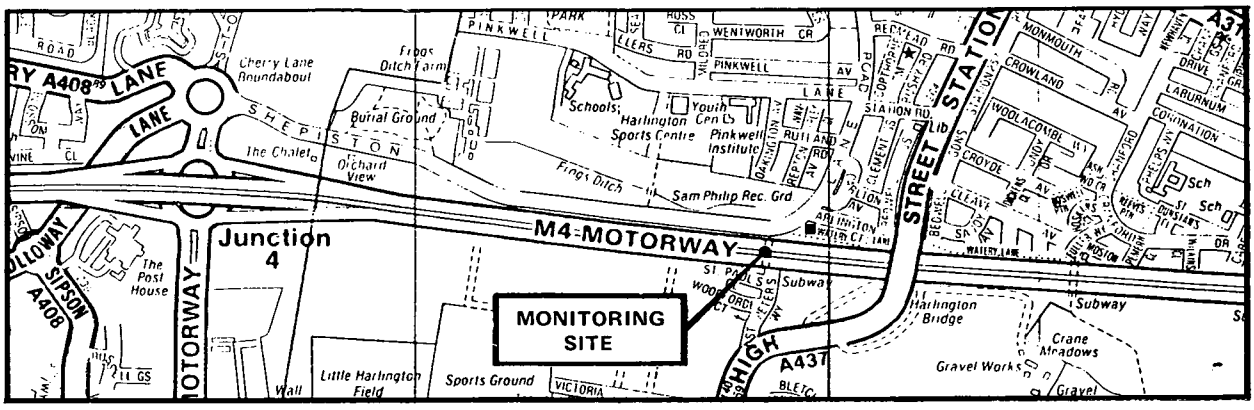

Fig. 2 Site location

study, from the central reservation of a busy motorway to those in remote rural areas. For that reason, and because the comparison was made for the first three months after the change to low-lead petrol, it is possible that conditions at some of the sites were still in transition and that the effect of the change was not fully demonstrated.

Since 1971, the concentration of particulate lead in the air at a site near Harlington, Middlesex, in the central reservation of the M4 motorway, has been annually monitored. The results of the surveys between 1973 and 1983 are given in earlier reports (Bevan et al, 1974; Hogbin and Bevan, 1976; Colwill and Hickman, 1981 and Hickman, 1984). Because of its location, lead measured in the air at this site results exclusively from vehicle exhaust emissions and variations in emissions will be immediately followed by corresponding changes in the atmospheric concentration. It is therefore a particularly suitable site at which to study, in isolation, the impact of changes in legislation and fuel usage on atmospheric lead pollution.

This report gives the results of the measurements made at the M4 site during the period from 1984 to 1987 and includes, therefore, results obtained before, during and after the large reduction in petrol lead content in 1986.

2 EXPERIMENTAL DETAILS

2.1 SITE DESCRIPTION

Samples were taken at a site in the central reservation of the M4 motorway, approximately mid-way between junctions 3 and 4, near Harlington, Middlesex (Figure 2). At this location, the motorway runs due east-west at the same level as the relatively flat surrounding land.

This location was chosen because it is in the centre of one of the busiest motorways in the UK. The influence of non-traffic sources of pollution is minimal and, because of the high flow of traffic, pollution levels are high. Thus, changes in pollution may be clearly observed and, except for random variations due to varying weather conditions, are caused entirely by changes in vehicle emissions. Measurements at this site are not intended to indicate concentrations of lead to which people would be exposed.

2.2 SAMPLING AND ANALYSIS METHODS

Duplicate samples of airborne particulate were collected weekly by drawing air through filters mounted at a height of approximately 1.5 m. Because the site was at the centre of a very busy motorway, it was sometimes unsafe to collect the filters because of adverse traffic or weather conditions. On those occasions the filters were collected the following week, resulting in the two-week samples noted in Table 2. The filter material used was Whatman GFA, which is sufficiently retentive to trap the small lead-containing particles. The airflow rate used was approximately 1.1 litre/min, giving a total volume for each of the weekly samples of approximately 11.5m^3. This total volume was measured accurately using a gas meter.

The samples were returned to the laboratory for analysis of their lead content. The lead was extracted into a nitric acid/hydrogen peroxide solution and determined by atomic absorption spectrophotometry.

3 RESULTS

The measured concentrations of lead in air for all the weekly samples taken between 1984 and 1987 are given in Table 2.

Work during earlier years of the lead survey at this site showed that the average concentration during the period June—September represented with reasonable accuracy the average annual concentration. For that reason, measurements have been taken annually during that period, except during 1986, when the measurements were made in the first half of the year in order that the changes

TABLE 2

Weekly average lead concentration

Date (week ending)	Concentration ($\mu g/m^3$)	Date (week ending)	Concentration ($\mu g/m^3$)
1. 6.84	5.7	3. 1.86	2.9*
15. 6.84	8.1*	24. 1.86	2.9*
22. 6.84	10.5	31. 1.86	3.1
29. 6.84	7.4	14. 2.86	2.9
6. 7.84	8.7	28. 2.86	2.6
13. 7.84	7.5	14. 3.86	3.3
20. 7.84	8.7	21. 3.86	3.1
27. 7.84	9.5	28. 3.86	2.3
3. 8.84	8.3	4. 4.86	2.5
10. 8.84	8.1	11. 4.86	1.3
17. 8.84	9.1	18. 4.86	1.8
24. 8.84	9.6	25. 4.86	2.4
31. 8.84	8.4	2. 5.86	2.8
7. 9.84	7.6	9. 5.86	2.1
14. 9.84	9.5	16. 5.86	1.9
28. 9.84	9.5*	23. 5.86	2.5
5.10.84	9.2	30. 5.86	2.6
12.10.84	10.6	6. 6.86	2.8
31. 5.85	7.8	29. 5.87	3.5
7. 6.85	7.8	5. 6.87	3.4
14. 6.85	9.4	12. 6.87	3.9
21. 6.85	7.9	19. 6.87	3.4
28. 6.85	8.2	26. 6.87	2.3
12. 7.85	7.1	3. 7.87	2.0
19. 7.85	6.2	10. 7.87	2.2
26. 7.85	6.3	24. 7.87	2.4*
2. 8.85	6.1	31. 7.87	1.8
9. 8.85	4.9	14. 8.87	3.3*
16. 8.85	4.4	21. 8.87	3.5
23. 8.85	5.9	3. 9.87	4.5*
30. 8.85	6.9	11. 9.87	2.7
6. 9.85	5.5	18. 9.87	2.5
13. 9.85	8.1	25. 9.87	2.8
20. 9.85	5.5	8.10.87	2.5*
4.10.85	5.6		
11.10.85	5.9		
18.10.85	6.9		
25.10.85	7.4		
1.11.85	6.7		
8.11.85	7.5		
15.11.85	7.9		
22.11.85	5.2		
29.11.85	5.9		
6.12.85	3.3		
20.12.85	3.6*		

* Two week samples

immediately following the reduction in the lead content of petrol could be observed. Figure 3 shows the averages of the measurements for each year and includes results from earlier years of the survey. Also shown are the average daily flow of petrol engined vehicles at the site and the average lead content of petrol for each year.

Until 1984, the Department of Transport operated a continuous automatic traffic count at this location. After 1984, this was discontinued and the data given for later years are based on more limited counts carried out by DTp and extrapolated in accordance with their recommended procedure. It is clear that the year to year variation of the measured traffic flows is far greater after 1984 than previously. This no doubt results, in part at least, from the change in the counting method.

4 DISCUSSION

Figure 3 clearly illustrates that the airborne lead concentrations measured at this site have broadly followed the changes in the average lead content of petrol. During the period from 1981 to 1984, the average lead content of petrol was relatively stable (0.37–0.38 g/l), as it has been during 1986 and 1987 (0.14 g/l). The reduction in lead content between these periods was approximately 63 per cent. The change in the atmospheric lead concentration was from 9.0 (1981–1984) to 2.8 (1986–1987) $\mu g/m^3$, a reduction of 69 per cent. A number of factors may have contributed to the small discrepancy between these figures, including variations in the speed and number of vehicles at the site (this is difficult to confirm because of the uncertainty in the most recent traffic data, see 2.1 above), variations in weather conditions during the sampling periods, and possibly a general improvement in vehicle fuel efficiency (Department of Energy statistics on UK petrol consumption and Department of Tranpsort statistics on vehicle use suggest an improvement of about 5 per cent in average fuel efficiency over the same period).

The correspondence between petrol and atmospheric lead concentrations is, however, very close and was further confirmed by a simple regression analysis performed on the data in Table 3. The table shows the average lead content of petrol, the average daily traffic flow at the site and the average fuel consumption per vehicle for the years 1976–1987. These data were used to calculate the lead emission rate from the traffic per kilometre of road. The results were compared with the measured levels of lead in air.

A linear regression analysis showed the correlation between the calculated rates of emission and the measured airborne lead concentrations to be highly significant, with a correlation coefficient of 0.94 and an intercept not significantly different from zero. It must be realised that the data used for the calculation of lead emissions were for traffic on all types of road throughout the UK and were not, therefore, typical of this site in absolute terms (for example, the fuel consumption of high speed motorway traffic is unlikely to be equal to the average). Nevertheless, the results indicate trends in fuel economy and lead emissions that would be

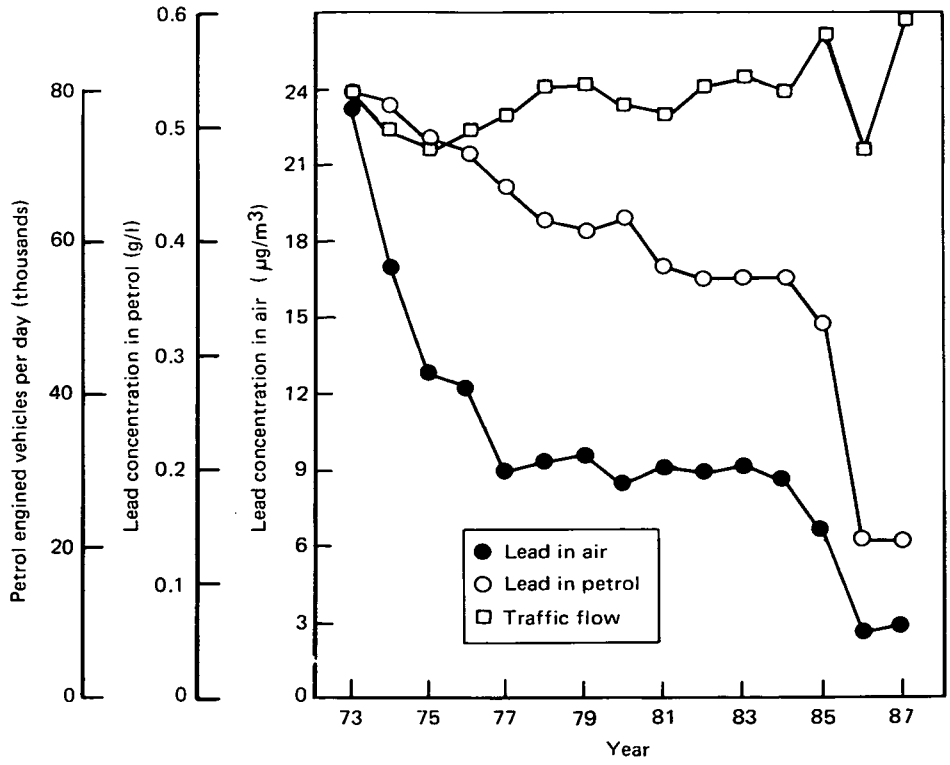

Fig. 3 Average lead in air, lead in petrol and flow of petrol engined vehicles

TABLE 3

Lead emission and concentration data

Year	Average lead in petrol (g/l)	Average traffic flow (veh/day)	Average fuel consumption [note a] (l/100 km)	Lead emission [note b] (g/km. day)	Lead in air (μg/m³)
1976	0.48	75 100	11.7	2 952	12.4
1977	0.45	77 300	11.6	2 825	8.9
1978	0.42	81 000	11.9	2 834	9.4
1979	0.41	80 800	12.1	2 806	9.7
1980	0.41	78 200	11.7	2 626	8.5
1981	0.38	76 900	11.2	2 291	9.1
1982	0.37	80 600	11.2	2 338	8.9
1983	0.37	81 500	11.2	2 364	9.1
1984	0.38	80 000	10.9	2 320	8.7
1985	0.34	87 200	10.8	2 241	6.8
1986	0.14	72 000	10.7	755	2.6
1987	0.14	89 100	10.4	908	2.9

Notes

a. Average fuel consumption calculated from total UK vehicle kilometres (Department of Transport, 1988) and deliveries of motor spirit for inland consumption (Department of Energy, 1988) for each year.

b. Emission rate calculated assuming that 70 per cent of lead in petrol is emitted (Colwill [Ed], 1974).

followed by vehicles using this motorway and clearly show the direct link between the changing lead content of petrol and the level of airborne lead pollution at this site.

5 CONCLUSIONS

In consequence of successive reductions in the permitted lead content of petrol, there has been a significant downward trend in the atmospheric lead concentration measured at a site on the M4 motorway in Middlesex. The reduction in atmospheric lead concentration was directly related to the reduction in the average lead content of petrol.

6 ACKNOWLEDGEMENT

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