



ROYAL COMMISSION
ON
ENVIRONMENTAL
POLLUTION

CHAIRMAN: PROFESSOR T. R. E. SOUTHWOOD

NINTH REPORT
LEAD IN THE ENVIRONMENT

*Presented to Parliament by Command of Her Majesty
April 1983*

LONDON
HER MAJESTY'S STATIONERY OFFICE

£9.20 net

Cmnd. 8852



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ROYAL COMMISSION ON ENVIRONMENTAL POLLUTION

NINTH REPORT

To the Queen's Most Excellent Majesty

MAY IT PLEASE YOUR MAJESTY

We, the undersigned Commissioners, having been appointed “to advise on matters, both national and international, concerning the pollution of the environment; on the adequacy of research in this field; and the future possibilities of danger to the environment”;

And to enquire into any such matters referred to us by one of Your Majesty's Secretaries of State or by one of Your Majesty's Ministers, or any other such matters on which we ourselves shall deem it expedient to advise:

HUMBLY SUBMIT TO YOUR MAJESTY THE FOLLOWING REPORT.

“It is one thing to show a man he is in error and another to put him in possession of the truth.”

John Locke 1632–1704
An Essay concerning Human Understanding (1690)

“Practical wisdom is deliberation about things which it is within our power to change.”

Aristotle 384–322
Nicomachean Ethics

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CHAPTER I

INTRODUCTION

The choice of study

1.1. In September 1981, having completed the last in a series of reports on specific aspects of environmental pollution, we decided that it would be timely to look across the whole field of environmental pollution and to study both general and specific issues; the last time this had been done was in the Fourth Report of the Royal Commission, published in 1974 ⁽¹⁾. As a first step we invited a wide range of organisations and individuals to give us their views on the types of pollution which they perceived to pose the greatest threat to the environment and to comment on our own provisional choice of topics for study. Among those topics was the problem of environmental contamination by heavy metals and their possible effects on health, and from the responses to our invitation it was clear that the specific problem of lead was an issue of major and continuing concern to the public and the scientific community.

1.2. It has been recognised for several centuries that lead is a poison and there is a long history of human exposure to lead in food and drink, for example in ancient Rome ⁽²⁾, in amounts which must have caused many cases of frank* lead poisoning. Over the last century many cases of lead poisoning at work have been documented ⁽³⁾. Frank lead poisoning is rare today and is usually associated with exposure to specific localised sources. In recent years, however, there has been growing concern that lead in the body resulting from general environmental exposure may be harmful at concentrations which fall short of those at which clinical signs and symptoms appear. Particular attention has been paid to the possible effects on the intelligence and behaviour of young children.

1.3. Our original plan was to deal with this as only one of several issues in a wider report. As our investigations proceeded, however, we came to the conclusion that it would be in the public interest for us to complete and publish separately the results of our study of lead as soon as possible and to deal with them in a greater degree of detail than we had earlier envisaged. Compared with lead the other issues which we have been studying, although important and in some cases urgent, do not at present give rise to nearly the same degree of public anxiety and debate. We therefore propose to report on them in our Tenth Report, which we plan to complete later this year.

Dispersion of lead through human activity

1.4. Lead is present in large quantities in the earth's crust; from there some of it reaches the soil, the air and living organisms through natural processes.

*See footnote to paragraph 5.4 for a definition of 'frank' and other terms used to describe lead poisoning.

Chapter I

But this natural distribution is insignificant when compared with the distribution which results from man's activities.

1.5. Man has used lead for thousands of years. Its ore is plentiful, accessible and simple to smelt. The metal is heavy, pliable and very resistant to corrosion and weathering. It is easily melted down and re-used. These properties account for its widespread traditional uses—for instance in building, plumbing (to which it gives its name), printing, shooting and fishing—many of which continue today. Even where substitutes are now preferred or required, artefacts from earlier times survive and are still in widespread use. Since the industrial revolution, other properties and uses of lead have been discovered and widely exploited. In its metallic form lead is uniquely suitable for use in heavy electrical insulation, radiation shielding and battery manufacture. Various compounds of lead are used in paints, plastics, ceramics, glass and petrol.

1.6. The cumulative effect of centuries of use is that lead is now one of the most widely dispersed of environmental pollutants. Moreover, so far as is known, there is no innocuous form into which it can be converted in the environment. Once in the environment lead and its compounds do not move readily through natural pathways to remoter locations such as the ocean bed, and they have a long environmental residence time compared with other pollutants, particularly in the soil (Table 1.1). Thus not only is there widespread human exposure to lead today but future generations too will be exposed to the lead which is already in the environment and is being added to all the time.

TABLE 1.1
Environmental residence times for various pollutants*

<i>Pollutant</i>	<i>Situation</i>	<i>Time</i>	<i>Percentage remaining</i>	<i>Reference</i>
Carbon monoxide	1m column of air in contact with soil	30 minutes	50%	(4)
2, 4, 5-T (herbicide)	Soil	Several weeks	50%	(5)
MCPA (herbicide)	Soil	Several days	50%	(5)
DDT (pesticide)	Soil	4 months	74%	(6)
Parathion (pesticide)	Soil	20 days	50%	(7)
Oil	Sea water	4-5 weeks	70%	(8)
Radioactive iodine (^{131}I)	—	8 days	50%	(9)
Radioactive strontium (^{90}Sr)	—	28 years	50%	(9)
Cadmium	Upper layers of moorland soil	6-20 years	90%	(10)
Lead	Upper layers of moorland soil	70-200 years	90%	(10)

*The fall in concentration can be caused by various processes including microbial and chemical modification and leaching.

1.7. Besides lead there are other heavy metals in the environment which are potentially hazardous, notably mercury and cadmium. Poisoning by cadmium or mercury is extremely rare in the UK, but it is generally agreed that the release of both metals to land or sea (for example from sewage sludge) needs to be controlled because of the possible risks to health. There is similar concern about possible health effects of cadmium in phosphate fertilisers and in land contaminated by mineral workings. Policies for control of these heavy metals and priorities for research are now well established (¹¹, ¹²). What makes lead different from other heavy metals is the very much greater scale on which it is used (Table 1.2), dispersed and accumulated. This factor, when coupled with its known and postulated effects on health in amounts which may be encountered in the environment and found in the human body, makes lead unique amongst environmental pollutants.

TABLE 1.2

Annual use of cadmium, lead and mercury in the UK

Cadmium	1,350 tonnes ¹
Lead	274,000 tonnes ²
Mercury	510 tonnes ³

Sources: ¹Reference (¹²); ²Lead Development Association; ³Reference (¹¹) (Mean of range of figures for several years).

Physical and chemical properties of lead

1.8. Lead is present in the environment in a wide range of physical and chemical forms which strongly influence its behaviour and its effects on life. For example, particle size is the principal influence on the distance which airborne lead is carried at any given wind speed before deposition, and is a key factor in determining the extent to which inhaled lead is taken up by the lung. Solubility is particularly important when considering the behaviour of lead in water.

1.9. Most lead in the environment is in the form of inorganic salts or oxides; most attention has been paid to inorganic lead and most is known about it. Lead is added to petrol, however, as organic compounds and, although most of the lead in petrol engine exhausts has been converted to inorganic compounds, some organic lead does reach the atmosphere. In this report we refer simply to 'lead' except where a particular chemical form is specified.

Problems of measurement

1.10. During the course of our study we have noted that widely different values have been reported for the concentration of lead that gives rise to a particular biological effect. To some extent this is because the physical and chemical forms of the lead present are not known and measurement of the total amount of lead present does not necessarily give a measure of the amount available for a particular reaction or effect. However, there are also difficulties in sampling and analysis.

Chapter I

LEAD		
Chemical symbol	Pb	
Atomic number	82	
Atomic weight	207.19	
Natural isotopes	204, 206, 207, 208, 210	
Melting point	327.5°C	
Boiling point	1,740°C	
Density	11.34 g/cc	
<i>Simple compounds:</i>		<i>solubility in water at 20°C per 100 ml</i>
acetate	Pb(C ₂ H ₃ O ₂) ₂	44.3g
bromide	PbBr ₂	0.84g
chloride	PbCl ₂	0.99g
chromate	PbCrO ₄	5.8μg
oxides	PbO ₂ plattnerite	insoluble in pure water
	PbO litharge	0.0017g
	Pb ₃ O ₄ minium (red lead)	insoluble in pure water
phosphate	Pb(PO ₃) ₂	14μg
sulphate	PbSO ₄	0.004g
	<i>melting point</i>	<i>boiling point (at normal atmospheric pressure)</i>
tetraethyl lead	-136.8°C	200°C
tetramethyl lead	- 27.5°C	110°C
<i>Common ores:</i>		
galena	PbS	
cerussite	PbCO ₃	
anglesite	PbSO ₄	
crocoite	PbCrO ₄	

Source: Reference (9)

1.11. As concern has progressively extended to the possible effects of lead at ever-decreasing concentrations, there has been a corresponding need to measure lead at very low concentrations in many kinds of materials. With lead so widely dispersed throughout the environment there is a real risk that samples will become contaminated during collection or analysis. Considerable advances have been made in sampling and analytical methods in recent years but when considering past data it is not always possible to distinguish the effects of changes in methods of measurement from actual changes in lead concentration. It is certain that many published measurements of lead are unreliable, and comparisons of data from different laboratories must be treated with caution unless full details are available of the sampling and analytical techniques.

1.12. Even with present day measurements it is important to approach the data critically. If published data on the measurement of small amounts of lead, whether in blood, water, dust or other media, do not provide information on precision, sensitivity and accuracy, it is impossible to assess the reliability of the figures. We have no doubt that the difficulties (some of which have only recently been appreciated) of sampling and analysing materials in which lead is present at very low concentrations have been an important factor behind the lack of consensus on the effects of lead.

Previous reviews

1.13. The Fourth Report of the Royal Commission, published (under the chairmanship of Lord Flowers) in 1974⁽¹⁾, recognised that there was already some public concern about lead and noted the measures which were then in hand to reduce the lead content of petrol. Without making any specific recommendations, the Report suggested that there was a need for more research into the effects of low levels of lead from all sources and in particular the extent to which lead from motor exhausts found its way into the human body. The evidence suggested that there was no immediate cause for alarm and no need for emergency action. It should be noted, however, that these comments were made in the context of proposals by the Commission of the European Communities to reduce the maximum lead content of petrol to 0.4 g/l in 1976 and, for regular grade petrol, to 0.15 g/l in 1978—a faster rate and a lower overall level than have actually been achieved. The Royal Commission declared its intention to keep the situation under review and promised to undertake a study of the subject if at any time it seemed necessary.

1.14. Since 1974 much more information has become available about the extent of lead pollution and its biological effects, and improved analytical techniques now enable lead to be measured at very low concentrations in blood and other media. During this period successive governments have taken various steps to reduce exposure to lead in the environment, including progressive reductions or planned reductions in the maximum permitted lead content of petrol and the introduction of new regulations limiting lead levels in paint. Measures have also been taken to improve public awareness of the dangers of lead. These actions are discussed in detail in Chapters VI and VII.

1.15. Many of the more recent actions have been in response to recommendations by the working party chaired by Professor Patrick Lawther, which reported in 1980⁽¹³⁻¹⁶⁾. It was set up in 1978 by the Department of Health and Social Security to 'review the overall effects on health of environmental lead from all sources and, in particular, its effects on the health and development of children and to assess the contribution lead in petrol makes to the body burden'.

1.16. The Report of the Lawther Working Party concluded that for the majority of the population food contributed most to the body burden of lead and that airborne lead (including that derived from petrol) was usually a minor contributor. It considered that the small proportion of the population whose blood lead concentration fell into the upper part of the distribution of blood lead concentration derived their relatively raised blood lead concentration not from petrol lead but from a miscellany of sources such as lead-containing paint, special cosmetics and medicines containing lead, or tap water in certain areas. The Report however advised urgent attention to 'hot spots' with a high air lead concentration. It recommended: the progressive reduction of emissions of lead into the air from all sources, including the reduction in the lead content of petrol; the reduction of the lead level in tap water in areas where this was a problem; controls on the lead content of paints; and measures to reduce exposure to lead in food, cosmetics and toys. The Report also recommended

Chapter I

that action should be taken to keep the annual average concentration of lead in the air to less than $2\mu\text{g}/\text{m}^3$ in places where people were liable to be exposed continuously for long periods.

1.17. The Working Party was unable to come to definite conclusions on the effects of small amounts of lead on the intelligence, behaviour and performance of children. It recommended, however, that where a child was found to have a blood lead concentration of more than $35\mu\text{g}/\text{dl}$ steps should be taken to identify the source of lead and to reduce the exposure.

1.18. The conclusions and recommendations of the Report of the Lawther Working Party have been criticised, for example by the Conservation Society⁽¹⁷⁾ and more recently by the Campaign for Lead-free Air (CLEAR), on the grounds that they understated the effects on health of low lead concentrations and the importance of lead from petrol, and that they failed to recommend sufficiently stringent measures for reducing the levels of lead in the environment. The activities of such groups have served to heighten public awareness of the issues.

1.19. Since the Report of the Lawther Working Party several other reports on lead have been published. The US National Academy of Sciences⁽¹⁸⁾ and the Australian Academy of Science⁽¹⁹⁾ have reported comprehensively on the subject. Although some of their conclusions and recommendations relate to conditions which do not necessarily apply to the UK, both these reports recommended that exposure of the general population to lead should be reduced and drew attention to the particular risks to which children were exposed. Other reviews have dealt with particular aspects, notably the effects on health at low concentrations^(20, 21) and the question of lead in petrol^(22, 23).

Scope and nature of this study

1.20. Having decided that lead should be a subject for detailed study, we invited evidence with particular reference to the following issues:

- (i) The sources of environmental lead pollution and pathways to man, in particular quantitative data having a bearing on the relative significance of different sources and pathways to the body burden in man.
- (ii) Methods of reducing lead in the environment and human uptake.
- (iii) Technical and economic implications of different options for further reducing or eliminating lead from petrol, and their environmental effects.
- (iv) Lead pollution and wildlife.

1.21. For the purposes of our study, we felt it would not be profitable to attempt to go over again all the ground covered by the Lawther Working Party by inviting specific contributions on the possible effects on human health of lead at low concentrations. Nevertheless we have made it our business to examine carefully the various reports, both general and specialist, which have been published since the Lawther Working Party reported, and this has formed

an essential element of our study. Within this area we have not hesitated to consult medical and scientific experts on particular points where we thought it appropriate.

1.22. In two areas we decided to appoint consultants to assist us in evaluating evidence of a specialist and technical nature. Professor Alan Cowey of the Department of Experimental Psychology at Oxford University and Mr Richard Wheeler of Atlantic Research Associates (and formerly of Ricardo Consulting Engineers) have greatly helped us in the fields of experimental animal behaviour and motor vehicle technology respectively by contributing much to the factual material which we include as background to our conclusions on these subjects. We wish to record our thanks to Professor Cowey and Mr Wheeler for their expert contributions to our study.

1.23. We are pleased also to record our gratitude to the very large number of organisations and individuals who have provided evidence or assisted us in other ways. We have attempted to give as complete a list of them as possible in Appendix 2, whilst conscious of the fact that it is not always practicable to single out individuals where there has been a collective effort or to acknowledge every case where somebody has been helpful to us in supplying a publication or simply alerting us to an important reference.

1.24. In the chapters which follow we consider in more detail the presence of lead in the environment and the effect of man's activities on its dispersal, the various pathways along which lead reaches man and other forms of life, and its effects on them. We consider the various measures which have been taken to reduce both the levels of lead in the environment and human exposure to it and then consider what other measures should be adopted to effect further reductions. We comment on the adequacy of those measures, and set them in the context of the economic and technical arguments for the continued use of lead, particularly lead in petrol. In the final two chapters we present a summary of our major conclusions and our list of recommendations.

1.25. Despite the claims that have been made by parties with very different viewpoints, the subject of lead in the environment continues to raise issues of uncertainty and risk. In the final analysis, a judgement must be made on the comparative weight of the advantages and disadvantages of the continued use of lead in any particular application. Our aim has been to clarify and put into better perspective the range of issues which must collectively form the basis of a final judgement.

CHAPTER II

LEAD IN THE ENVIRONMENT

Natural and anthropogenic sources

2.1. Although lead is released to the earth's surface by natural weathering of rocks, by igneous activity and (in the form of the isotope ^{210}Pb) from the radioactive decay of naturally occurring radon gas, nearly all the lead present today in the air, soil, waters and man's built environment is anthropogenic (the result of man's activities). Nriagu⁽²⁴⁾ has estimated a worldwide annual lead emission to the air of 24.5 thousand tonnes from natural sources, compared with 449 thousand tonnes from anthropogenic sources. Table 2.1 shows the same author's compilation of figures for the historical consumption and anthropogenic emissions of lead worldwide.

TABLE 2.1

Historical worldwide consumption and anthropogenic emissions of lead to the air

	<i>Lead consumption</i> (thousand tonnes)	<i>Anthropogenic lead emissions</i> (thousand tonnes)
Pre -1850	55,000	2,420
1850-1900	25,000	1,100
1901-1910	10,700	471
1911-1920	11,200	493
1921-1930	14,200	1,120
1931-1940	14,600	1,639
1941-1950	14,900	1,672
1951-1960	24,000	2,694
1961-1970	33,000	3,704
1971-1980	38,000	4,265
Total	241,000	19,578

Source: Reference (24)

2.2. Since man has been mining and using lead for many thousands of years (for example, lead artefacts have been dated to 6500 bc), it is difficult to quantify the natural concentrations of lead in the environment. Some estimates, however, may be made from measurements in areas, such as the deep ocean and polar ice caps, which are most remote from sources of pollution. Estimates of natural and present day lead concentrations in the environment are compared in Table 2.2, from which it can be seen that man's activities have resulted in increased lead concentrations in nearly all environmental media, particularly the air. The extent of this increase is greater than previously believed, for recent work, using ultraclean techniques, has demonstrated that

TABLE 2.2

Lead concentrations in the USA today and estimated as natural

Medium	Present day concentration	Estimated natural concentration	Ratio of concentrations
Air			
Rural/remote	0.1–100 ng/m ³	0.01–0.1 ng/m ³	10–1,000
Inhabited	0.1–10 µg/m ³	0.1–1.0 ng/m ³	100–10,000
Soil			
Rural/remote	5–50 µg/g	5–25 µg/g	1–2
Inhabited	10–5,000 µg/g	5–25 µg/g	2–200
Water			
Fresh	0.005–10 µg/l	0.005–10 µg/l	1
Marine	0.005–0.015 µg/l	0.001 µg/l	10
Food	0.01–10 µg/g	0.0001–0.1 µg/g	100

Source: Reference⁽¹⁸⁾

most of the estimates of natural lead concentration in the environment made before the last decade were too high because of contamination during sampling and analysis⁽²⁵⁾. Many studies have shown how lead levels have risen over the whole of the earth's surface, especially since the start of the industrial revolution, and how twentieth century man is having a profound effect on the amount of lead in his environment (Table 2.1; Figures 2.1 and 2.2).

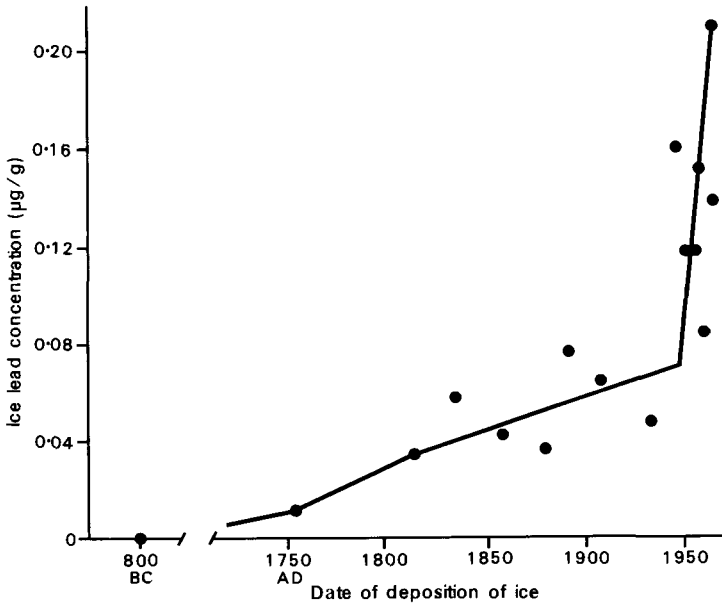


Figure 2.1
Lead content of annual ice layers in Greenland

Source: Reference⁽²⁶⁾

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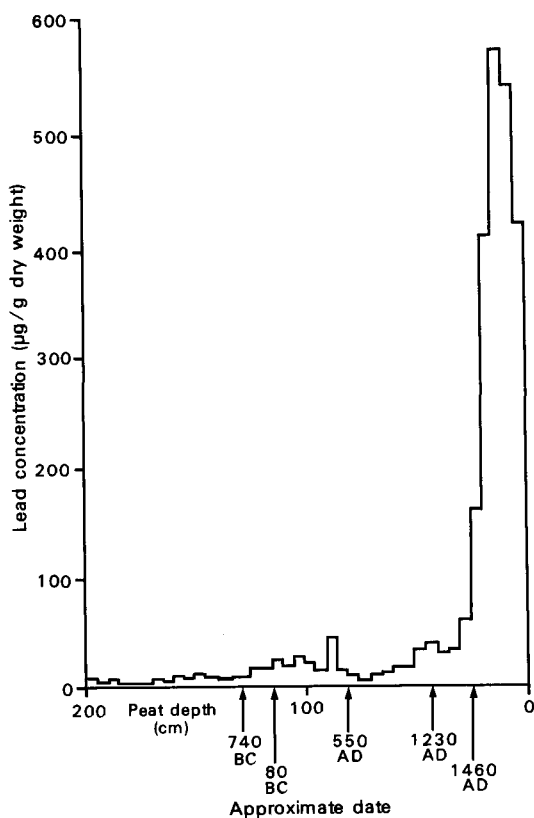


Figure 2.2
Lead analysis of a peat profile from Derbyshire

Source: Reference (²⁷)

2.3. Man releases lead to the environment during the mining, smelting and refining of the metal itself and of other ores in which lead is present. It is also released during the production, use, recycling and disposal of lead-based products and the burning of coal. In 1982 approximately 293 thousand tonnes of lead were processed in the UK, of which 60 per cent were from recycling. About 283 thousand tonnes were made within the UK for a variety of purposes, as shown in Figure 2.3, though some of the products were subsequently exported. Different lead products have different life cycles and amounts of recoverable lead, as illustrated in Table 2.3. Once it reaches the environment lead follows the normal biogeochemical pathways until trapped in a relatively permanent sink such as the soil or ocean sediments. These pathways have dispersed lead so widely that it is doubtful whether any part of the earth's surface or any form of life remains uncontaminated by anthropogenic lead. The sources and pathways of lead discussed in this chapter are not the only ones to which man is exposed: lead is also found in a wide variety of man-made articles, particularly within the home (see Chapter VI).

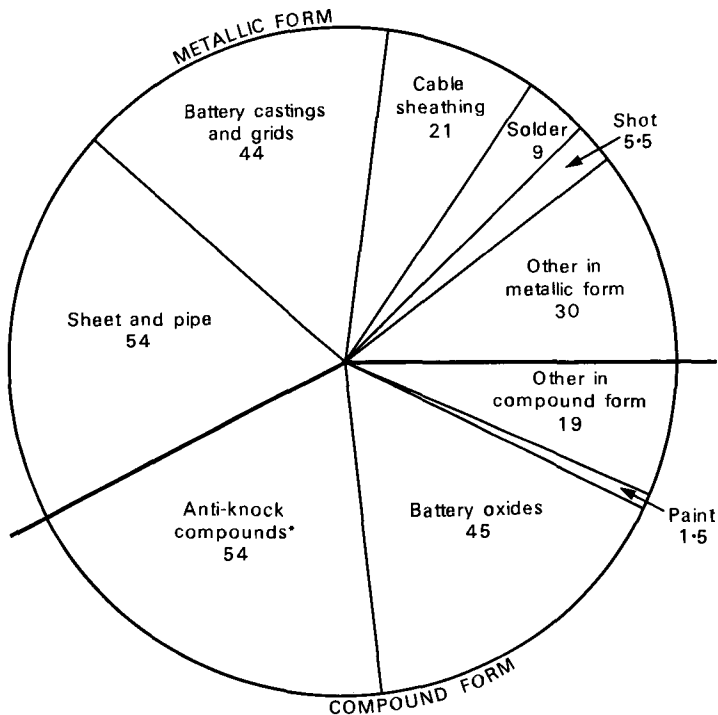


Figure 2.3

UK lead consumption, 1982

Figures in thousand tonnes. Total 283 thousand tonnes.

*This figure is for the manufacture of anti-knock compounds, about 80 per cent of which are exported.

Sources: World Bureau of Metal Statistics; Lead Development Association.

Lead in the air

2.4. Nearly all the lead in the air in the UK comes from the exhaust gases of petrol engines. In 1981 about 9.7 thousand tonnes of lead were used in petrol of which approximately 75 per cent⁽²⁸⁾ was released to the atmosphere. In contrast, the annual emissions from major UK lead industries have been estimated at 0.2–0.25 thousand tonnes⁽²⁹⁾. This figure may underestimate total industrial emissions of lead, but it is unlikely that much more than about 10 per cent of lead in the air comes from industrial sources.

2.5. The concentration of airborne lead close to roads depends on the volume of traffic, and on topographical and weather conditions, but it is usually higher than background values. The concentration in air close to the ground drops sharply with distance from the road (Figure 2.4) as does the rate of deposition (Figure 2.5). About 10 per cent of emitted lead is deposited within 100 metres of a road, where there may be additional deposition through

TABLE 2.3
Recovery of lead products

<i>Product</i>	<i>Life cycle (years)</i>	<i>Product recovery</i>	<i>Recoverable lead (per cent)</i>
Batteries:			
Automobile	3-4	} At least 90 per cent	95-97
Traction	5		
Stationary	20		
Sheet	up to 100	80-90 per cent	} 98-100
Pipe	50	70-80 per cent	
Cable sheathing	40	50 per cent	
Alloys:			
Solder	varies with product in which used	} 20-30 per cent	} 98-100
Bearings			
Type metal	indefinite—constantly recirculating	5 per cent of annual consumption returned as skimmings and residues from melting operations	

Source: Lead Development Association

resuspension of lead from the road surface (including lead from contaminated motor oil), especially in spray⁽³⁰⁾. Lead which is not deposited in the immediate vicinity of roads may be transported in the air over considerable distances. It has been estimated that about half of this lead is deposited in the UK and about half blown out to sea⁽³¹⁾. Similarly we would expect some of the lead deposited in the UK to come from emissions from petrol engines (and other sources) outside the UK. The fate of the petrol lead when released to the environment is shown in Figure 2.6, while Figure 2.7 shows lead emissions from motor vehicles in recent years.

2.6. Although on a national scale only about 10 per cent of airborne lead comes from industrial sources, such 'point sources' are varied and numerous, and largely concentrated in urban areas. They include smelters, scrap yards, incinerators and many other industrial users of lead. Birmingham, for example, has about 50 such premises identified as using lead for industrial purposes, though not all these will emit lead to the atmosphere.

2.7. Under the terms of a recent European Community Directive (82/844/EEC), Member States must take measures to ensure that the lead in the air, expressed as an annual mean concentration, does not exceed $2 \mu\text{g}/\text{m}^3$ by the end of 1987; this is less stringent than the ambient air quality standard in the USA, which is $1.5 \mu\text{g}/\text{m}^3$ averaged over 3 months⁽³²⁾. It is difficult to generalise about the concentration of air lead found in the UK, as there are few long-term series of measurements and the concentration, particularly in urban areas, varies in both space and time. Measurements are not instantaneous: particulate material has to be collected on a filter over a period of time and then analysed for its lead content. Most of the long-term measurements in urban and industrial areas have been carried out by the Warren Spring

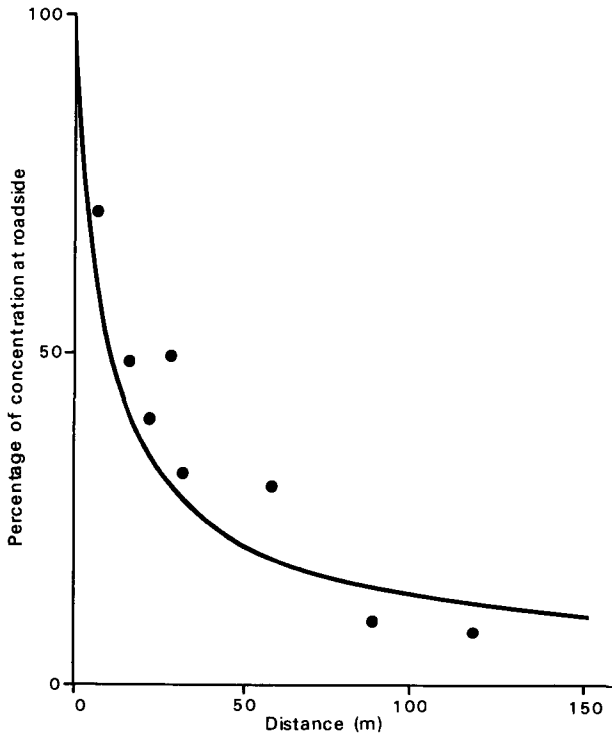


Figure 2.4

Concentration of airborne lead beside a motorway

Line is derived theoretically, while points are from measurements

Source: Reference⁽²⁸⁾

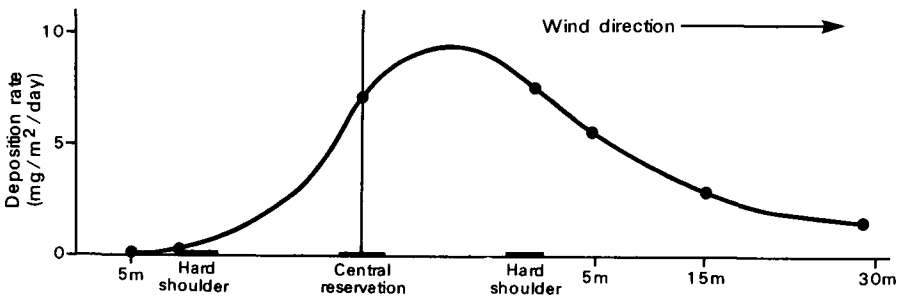


Figure 2.5

Deposition of lead on grass beside a motorway

Source: Reference⁽²⁸⁾

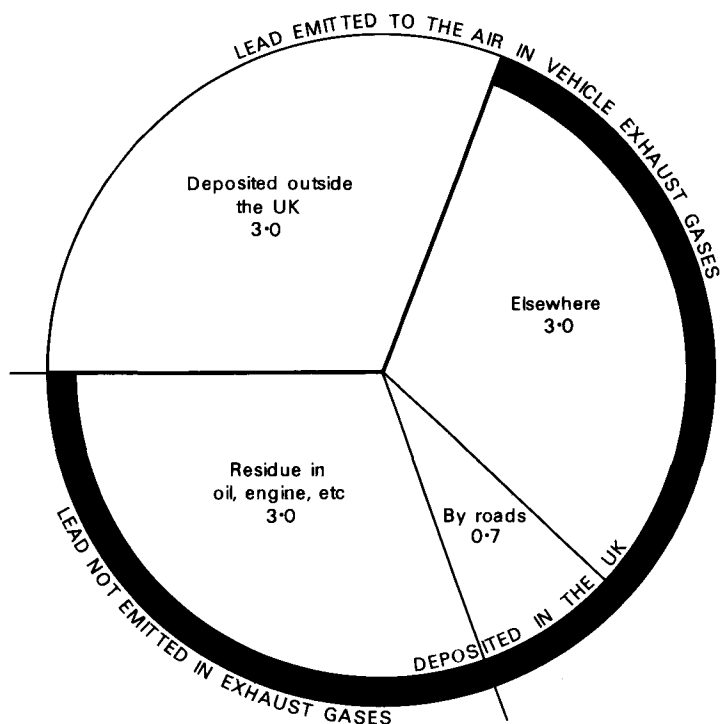


Figure 2.6

Fate of lead added to petrol in the UK

Figures are in thousand tonnes per year and are approximations for 1981.

Laboratory (Department of Industry), and the Harwell Laboratory (Atomic Energy Research Establishment) has undertaken monitoring in some rural areas. In recent years there have been a large number of measurements, particularly in urban areas, by local authorities and others, but these have usually been over short periods and the data have not been readily comparable with those from the longer-term studies.

2.8. In general it appears that the long-term concentration of air lead in rural areas is usually below about $0.15 \mu\text{g}/\text{m}^3$ (Table 2.4) and in most parts of the larger cities below about $1 \mu\text{g}/\text{m}^3$. However, at particular times and places much higher concentrations do occur and there are apparently anomalous data which cannot readily be explained. The trajectories of emissions to the air from industrial sources vary with wind strength and direction, and the average concentration of air lead nearby, which rarely exceeds about $2.5 \mu\text{g}/\text{m}^3$ ⁽³⁴⁾, may mask a much higher value over short periods. Measurements have also been made in the vicinity of motorways and busy urban streets. Roads carrying heavy traffic can be thought of as linear 'hot spots', especially in built-up areas where a combination of narrow streets and lines of tall buildings produces a 'canyon effect' inhibiting air circulation and consequently the dispersal of lead from exhaust gases. A mean concentration over four months of $9.7 \mu\text{g}/\text{m}^3$ was

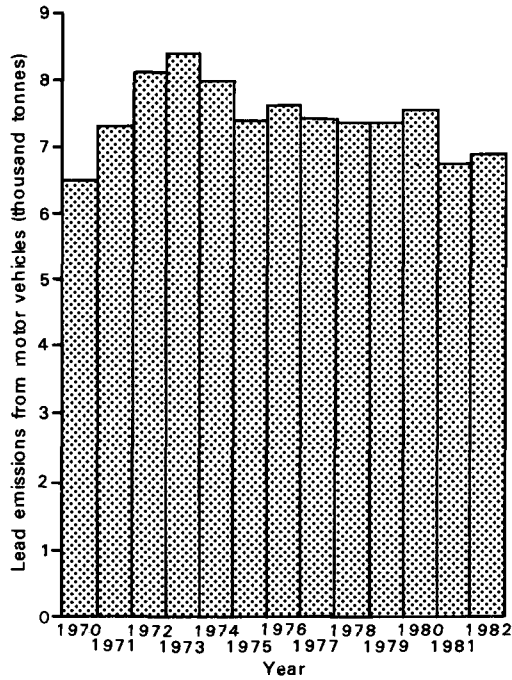


Figure 2.7
Lead emissions from motor vehicles in the UK, 1970–1982
 1982 figure is provisional.

Source: Department of the Environment

TABLE 2.4
Air lead concentration and deposition at rural sites

Year	Annual concentration ($\mu\text{g}/\text{m}^3$)	Annual deposition (mg/m^2)
1972	0.20	43
1973	0.22	29
1974	0.15	27
1975	0.14	20
1976	0.15	17
1977	0.10	
1978	0.10	
1979	0.10	

Figures are the means of measurements at five sites in England and Wales.

Source: Reference (³³)

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measured in summer 1979 in the central reservation of the M4 motorway⁽³⁵⁾, while a mean concentration over three months between 0.4 and 2.2 $\mu\text{g}/\text{m}^3$ was found close to busy main roads in the London suburbs⁽³⁴⁾. Much higher values can be obtained over shorter periods, particularly when traffic is heaviest. The air lead concentration inside cars with closed windows has been found to be about 75 per cent of the concentration outside⁽³⁶⁾, and most reports of the concentration inside buildings are in the same range of 60–100 per cent of the concentration outdoors^(13, 37). Air lead concentrations in the UK are generally similar to those found in other industrial countries. In the USA, for example, most urban areas have an annual average lead concentration between 0.5 and 2 $\mu\text{g}/\text{m}^3$, and the value for most rural sites is below 0.2 $\mu\text{g}/\text{m}^3$ ⁽¹⁸⁾.

2.9. Data on current trends in air lead concentration in the UK do not show an entirely clear picture. There is evidence of a decrease by some main roads in recent years (Figure 2.8) and the Harwell measurements at rural sites also show a decrease (Table 2.4). The Warren Spring data for urban and industrial sites show moderate to substantial reductions in air lead concentration, from 1976 to 1981, at two urban sites in Scotland, but small or not significant decreases at three urban sites in England⁽³⁸⁾. It has been suggested^(33, 38) that the recession in industrial activity was responsible for the major part of the decrease in air lead concentration both in rural areas and at the two Scottish urban sites; the three English urban sites were remote from industrial sources of lead and the air lead concentration was largely dependent on vehicle emissions. The UK lead emissions from motor vehicles during this period are shown in Figure 2.7. It is interesting to compare the UK position with that in both the USA and the Federal Republic of Germany, where decreasing use of lead in petrol has been

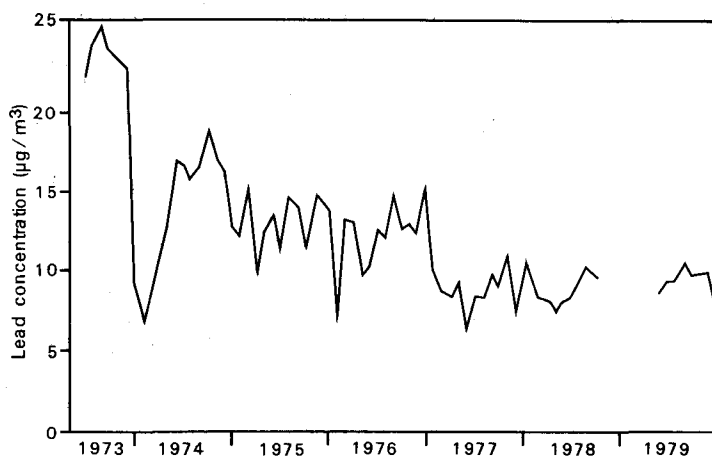


Figure 2.8
Monthly average air lead concentration in the central reservation of the M4 motorway, 1973–1979

Source: Reference⁽³⁵⁾

associated with a lowering of the urban air lead concentration^(39, 40). In Germany, for example, a reduction in the maximum permitted concentration of lead in petrol from 0.4 g/l to 0.15 g/l at the beginning of 1976 was paralleled by a decrease in ambient air lead concentration ranging from about 65 per cent in some inner city areas to about 20 per cent in some rural areas⁽⁴⁰⁾.

2.10. Airborne lead which is transported away from its point of emission is eventually deposited or washed out on to some surface. The surface may be water, soil or vegetation; it may be a man-made structure where lead contributes to dust; or it may be the skin or respiratory tract of man or an animal. Particle size and shape have an important effect on the behaviour of lead in the air and the way in which it is deposited. In rural areas the annual deposition rate is probably below 20 mg/m² (Table 2.4), while in urban areas values up to about 360 mg/m² have been measured; and close to some lead works values may reach 3,000 mg/m²⁽³⁴⁾.

Lead in water

2.11. Lead reaches freshwater from the air, by leaching from soils and mine wastes, by surface run-off, by direct industrial discharge and by discharge from sewage works. Much of the lead in freshwater becomes adsorbed on to particles and is eventually deposited in sediments. The concentration of soluble lead compounds in river water is usually less than about 50 µg/l even downstream of mine wastes where the river sediments themselves are severely contaminated. For Windermere an annual flux of lead to the lake sediment of 125 mg/m² has been estimated, compared with 7 mg/m² in precultural times⁽⁴¹⁾.

2.12. Lead is present in sewage, particularly in industrial and urban areas, and arises from both industrial and domestic discharges and from surface run-off. It has been estimated that over 2,000 tonnes⁽⁴²⁾ of lead annually enter sewage treatment works in the UK, although in its evidence to us the Department of the Environment has suggested that a figure of 700 tonnes is more realistic. Nearly all the lead is rendered insoluble and remains with the sludge, its eventual fate depending on the method of sludge disposal. A detailed survey⁽⁴³⁾ showed that in 1980 about 350 tonnes of lead were included in sludges applied to agricultural land, about 170 tonnes in sludges disposed of at sea, and about 100 tonnes in sludges disposed of by other means. The remaining lead in the sewage is discharged in the effluent from the sewage works, usually into a river. Estimates of the amount of lead annually discharged in the UK in this way range from 50 tonnes⁽⁴³⁾ to 500 tonnes⁽⁴²⁾. It has been put to us that there could be problems in the future in parts of lowland Britain where discharges from sewage works constitute a significant fraction of surface water flows and where there is increasing re-use of water. The possibility is that an appreciable concentration of lead could accumulate in water repeatedly abstracted for drinking supplies and could limit the options of the water authorities in providing domestic supplies. Both the Government and the water authorities are convinced, however, that such a possibility is most unlikely and that the

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routine analytical procedures conducted by the water authorities are capable of detecting any significant fluctuation in the background concentration of lead.

2.13. A survey carried out in 1975–76 showed that the majority of households in Great Britain had a lead concentration in daytime samples of tap water of less than 10 $\mu\text{g/l}$ (Table 2.5). There are many factors which cause lead from plumbing to pass into solution. The amount of solution that takes place depends on the quality both of the water (such as the degree of softness) and of the lead with which it is in contact. It also depends markedly on the amount of time the water remains in contact with lead, and on its temperature. In some areas a combination of these factors can produce a much higher than average concentration of lead in tap water. Lead may also reach tap water from soldering in pipes, but it is not clear how serious a problem this is. Nearly all the lead in tap water is derived from sources of contamination in domestic pipes and storage tanks (i.e. on the householder's side of the main).

TABLE 2.5
Lead in tap water in Great Britain

Lead concentration in daytime sample ($\mu\text{g/l}$)	Percentage of households			
	England	Scotland	Wales	Total
0– 9	66.0	46.4	70.5	64.5
10– 50	26.2	19.2	20.7	25.3
51–100	5.2	13.4	6.5	6.0
101–300	2.2	16.0	1.5	3.4
301 and above	0.4	5.0	0.8	0.9
Total	100.0	100.0	100.0	100.0

Source: Reference (44)

2.14. The sea bed is the ultimate resting ground for much of the water-borne lead from the UK. Most of this reaches the sea by river flow, with direct discharge from sewage outfalls as the next most important route. Deliberate dumping, through the medium of sewage sludge, river dredgings and other waste, accounts for only a small proportion. A recent study of pathways of lead to the North Sea from all bordering countries(45) has suggested that by far the greatest contribution is from atmospheric deposition (see Figure 2.9).

Lead in soil

2.15. Lead reaches soils by natural weathering of rocks and from a wide range of anthropogenic sources and pathways. Atmospheric deposition is universal, while more locally lead may reach soils from mine wastes, sewage sludge, run-off of contaminated water and many minor sources such as paint flakes and lead shot.

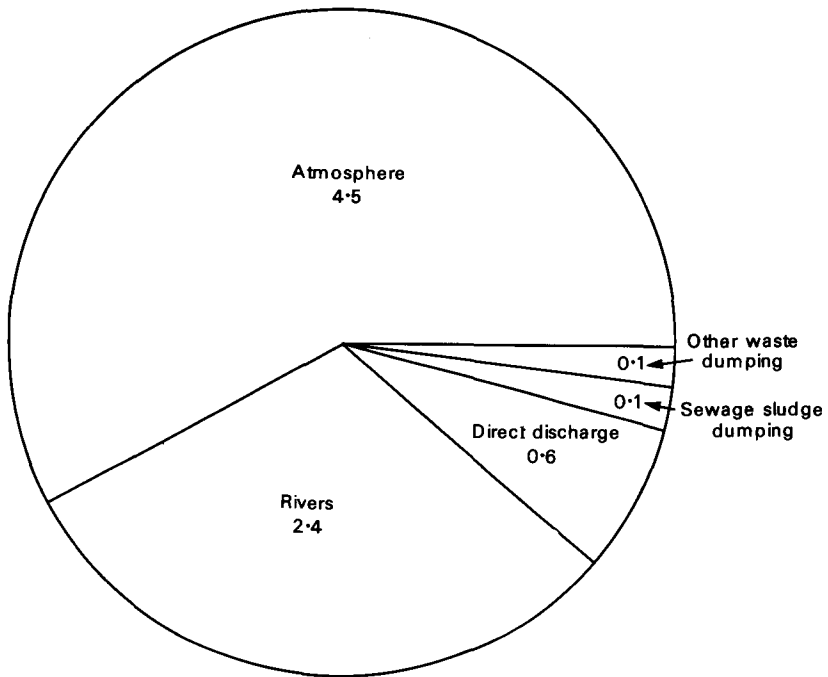


Figure 2.9
Pathways of lead to the North Sea from bordering countries
Figures in thousand tonnes per year.

Source: Reference⁽⁴⁵⁾

2.16. The rocks of the earth's crust are the ultimate source of the lead in the environment and they are the direct source of some of the lead in soil. The average concentration of lead in the earth's crust is less than $20 \mu\text{g/g}$, but there are considerable variations between types of rock. Lead is released to the soil by the natural erosion of lead-containing rocks. There are also considerable variations in the natural concentrations of lead in soils in the UK; most soils contain lead in the range 10 to $150 \mu\text{g/g}$. Soil lead levels above $150 \mu\text{g/g}$ are most likely to have arisen from contamination.

2.17. In the last century lead mining was an important industry in parts of northern and south-western England and Wales. The rock was crushed and the fraction containing lead ore separated by agitation in water. The effluent was usually grossly contaminated with lead ore particles, which were eventually deposited in river sediments and on flood plains. When other metals were mined, lead was also usually present in the ores and consequently in the resulting contamination. Thornton⁽⁴⁶⁾ has estimated that about $4,000 \text{ km}^2$ of agricultural land in England and Wales are severely contaminated as a result of past metal mining and smelting; lead is a major contaminant of most of this land. In old mining areas lead concentrations of up to $28,000 \mu\text{g/g}$ have been found in soils in rural villages⁽⁴⁷⁾.

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2.18. Sewage sludge is spread on agricultural land both as a means of disposal and for its content of plant nutrients. The general pollution problems of sewage sludge applications were considered in the Commission's Seventh Report⁽⁴⁸⁾. The lead content of sewage sludge is very variable and depends upon the origin of the sewage. For example, when the run-off from streets enters the sewerage system this may be a major pathway of lead to the sludge. Recently surveys of sewage sludges in the UK showed lead concentrations ranging from 19 to 45,400 $\mu\text{g/g}$ (dry solid) with half of the sludges having lead concentrations above about 300 $\mu\text{g/g}$ ⁽⁴⁹⁾.

2.19. Lead is added to all soils by atmospheric deposition but this is particularly marked alongside roads. Lead emitted by petrol-engined motor vehicles is deposited close to the road (paragraph 2.5) and results in elevated soil lead concentrations in narrow strips on each side of the road. Assuming that contamination is effectively contained within 20 metres on each side of motorways, trunk and principal roads, and that about 60 per cent of the length of these roads (outside the metropolitan counties) is bordered by agricultural land, an estimate of the agricultural land contaminated in this way in England and Wales is about 775 km^2 ⁽⁵⁰⁾.

2.20. Garden soils tend to have a greater lead concentration than do surrounding agricultural soils and, in general, older houses have greater garden soil lead concentrations than do newer properties (Figure 2.10). Lead in

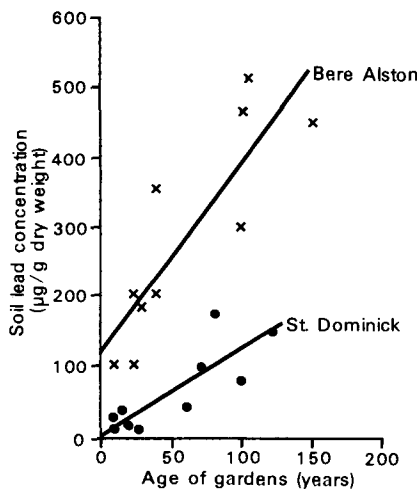


Figure 2.10
Relationship between soil lead concentration and age of garden for two villages in South West England

The higher values for Bere Alston are probably due to atmospheric deposition of lead from local smelting works active in the last century.

Source: Reference ⁽⁵¹⁾

garden soils may come from a multitude of origins including coal ash, eroded paint, burning old painted timber and, more recently, from vehicle exhaust emissions.

2.21. Soils in urban and industrial areas often have additional inputs of lead, in particular from current and past industrial activity. The most severe contamination occurs near premises producing lead emissions which find their way into dust. Lead concentrations of up to several thousand $\mu\text{g/g}$ can be found in soils close to major emitting premises. This has been illustrated by a recent survey of heavy metal contamination of soils in Walsall, where 47 per cent of sites were found to have concentrations above 100 $\mu\text{g/g}$, 1.5 per cent above 1,000 $\mu\text{g/g}$ and 0.25 per cent above 2,000 $\mu\text{g/g}$ ⁽⁵²⁾. A recent survey of soils in 10 towns in Great Britain⁽⁵³⁾ has shown an average soil lead concentration of 671 $\mu\text{g/g}$.

2.22 Systematic data on the regional distribution of soil lead concentrations throughout the UK are difficult to obtain directly because of problems in ensuring consistent sampling procedures and because local variation makes a large number of samples necessary. A survey of England and Wales, based on sampling of stream sediments (Figure 2.11), not only reveals the natural background concentrations of lead in the rocks and soils, but also demonstrates clearly the regions contaminated by lead mining and smelting activities and the 'haloes' around large industrial areas.

2.23. The distribution and behaviour of lead in soils depends on the properties of the soils and the chemical form of the lead. Soils vary greatly in physical and chemical composition and within a particular soil there are different layers with different properties. Most measurements of the concentration of lead in soils have involved analysis only of the total amount present and have not distinguished between the different chemical forms of lead or the different components of the soil with which they are associated. The lead may be associated with many components of the soil, for example the humus, the clay particles, or dissolved in the soil moisture. Different techniques can be used selectively to extract lead from these different soil fractions. In general it appears that only a small amount of lead present in soil is in a soluble form. For example in soils contaminated with lead from past mining activities in Shiphams (Somerset) and Wales the percentages of the total lead which were in solution were found to be 0.002 per cent and 1.1 per cent respectively⁽⁵⁴⁾. Most lead in soils is usually associated with the humus fraction and located in the top few centimetres.

2.24. Much of the lead in soil is not readily available for further circulation within the environment and soils can thus be considered as a 'sink' for lead. However, some of the lead in soils is in a chemical form such that it can be taken up by micro-organisms, plants or animals and hence enter food chains (see Chapter III). Some lead will be leached out in soil water and reach watercourses, and some will be transported as dust.



Figure 2.11
Distribution of lead in stream sediments in England and Wales

Source: Wolfson Geochemical Atlas of England and Wales

Lead in dust

2.25. Dust, both outdoors and within buildings, may contain appreciable amounts of lead, particularly in urban areas. Lead from many sources becomes incorporated in dust through a variety of pathways. Dust generally contains

lead from aerial deposition, soil and paint. Locally it may contain lead from the erosion of yellow road markings and contaminated dust may be blown from premises using lead or be carried out on vehicles or workers' clothes. In certain circumstances paint is an important source of lead in dust and this is considered further in Chapter VI. In older buildings in particular dust may contain appreciable amounts of lead from erosion of paint or from its removal by burning, scraping or sanding. It is at present not possible to identify how much lead in a particular sample of dust comes from each of the various sources, though some useful clues can be obtained by identifying components in the dust using a variety of techniques, some of them sophisticated.

2.26. There are considerable technical difficulties in the sampling and analysis of lead in dust, and in the absence of standard techniques the comparability of much of the published data is in doubt. To record only the concentration of lead in the dust, as is the usual practice, presents an incomplete picture unless some indication of the total amount of dust present is also given. The rate of lead deposition can also be measured, but again does not provide a measure of the total amount of lead present.

2.27. The concentration of lead in urban street dusts is typically in the range 500–5,000 $\mu\text{g/g}$. Higher values are usually found only in close proximity to 'hot spots' such as some premises which handle or process lead. Table 2.6 gives examples of the wide ranges of lead concentration that have been found in dust at different types of site in urban areas. There have been a number of studies of lead in the dust of school playgrounds, where the concentration is generally similar to that in dust in adjacent streets, though in some cases the playground dust lead concentration is raised by lead from old paint on school buildings⁽⁵⁶⁾.

2.28. The lead concentration of household dust is usually less than 1,000 $\mu\text{g/g}$, but concentrations up to several times this value can be found in places where the soil or outside dust lead concentration is particularly high or in

TABLE 2.6
Lead in dust in Great Britain

Site	Lead concentration ($\mu\text{g/g}$)		Number of samples
	Range	Mean	
Town centre streets*	840–4,530	2,100	13
Urban roads**	140–7,720	1,188	86
Main roads*	740–4,880	1,900	19
Rural roads*	410–870	570	4
Car parks*	950–51,900	12,900	20
Garage forecourts*	1,370–48,900	12,100	9
Urban playgrounds**	93–1,828	486	44
Residential areas*	620–1,240	850	7
Urban houses (indoors)**	39–30,060	1,263	977

*Lancaster, England (⁵⁵)

**Preliminary data from 10 towns as part of survey of 35 towns in Great Britain (⁵³)

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the homes of lead workers. There is evidence that where the soil lead concentration is low, the household dust lead concentration is higher, which would suggest contamination from other sources; but where the soil lead concentration is high, the household dust lead concentration is lower (though still above average), which would suggest dilution by other substances in the dust⁽⁵⁷⁾.

Conclusions

2.29. Man's activities, particularly during the last two centuries, have resulted in lead being distributed in the environment more widely and at greater concentrations than would occur through natural processes alone. Generalisations about concentrations of lead must be treated with caution because of limited data, the fact that the concentrations can vary considerably over short distances and periods of time, and problems of sampling and analysis. Our understanding of pathways of lead in the environment, notably through dust, is still far from complete.

CHAPTER III

LEAD IN PLANTS AND ANIMALS

Introduction

3.1. We considered in Chapter II how lead is present throughout the environment, frequently at raised concentrations as a result of man's activities. All living organisms therefore are likely to be exposed to lead. We believe it is important to consider the effects of lead on species other than man: lead may affect species in the food chain leading to man; there is concern that it may poison wild animals and plants; and its effects may be harmful to conservation and amenity.

Micro-organisms

3.2. The effects of lead on micro-organisms are important for three main reasons. There have been suggestions that some micro-organisms can convert inorganic lead compounds to organic ones, which are generally more toxic. Some micro-organisms scavenge for lead very effectively and so might be developed for use in the pollution control industry. Finally, micro-organisms are at the base of food chains and could be a vehicle for the entry of lead to plants and animals.

3.3. It has been known for some time that lead is toxic to micro-organisms under laboratory conditions and that tolerant strains can evolve. However, information on the effects of lead on micro-organisms in the field is scarce; other metals are usually also present in severely contaminated sites and it can be difficult to identify individual effects and any interactions between the different metals. Nevertheless, there is evidence that lead compounds will modify microbial activity and enzyme synthesis in the soil⁽⁵⁸⁾. But whilst some populations of micro-organisms in soil do develop tolerance to inorganic lead⁽⁵⁹⁾, the species diversity and abundance of microbial communities may be reduced. There is no convincing evidence of lead affecting nitrogen fixation by bacteria.

3.4. It is known that natural processes in the environment can convert some metals, for example mercury, from an inorganic to an organic form by methylation and it has been suggested that micro-organisms, particularly in aquatic environments, may play a part in this. However, while there is convincing evidence of chemical methylation of inorganic lead compounds in aquatic environments, and of biological methylation of lead that is already in organic form, there is no conclusive evidence that micro-organisms can bring about the methylation of inorganic lead compounds⁽⁶⁰⁾.

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3.5. Strains of bacteria and of fungi isolated from sites contaminated with inorganic lead have been shown in the laboratory to be able to accumulate up to 40 per cent of their dry weight as lead with little sign of toxic effects⁽⁶¹⁾. This causes some concern about the potential risks of lead accumulating in the food chain, but also some hope that suitable microbial strains can be used to remove inorganic lead from industrial wastes. In contrast organic lead compounds are generally far more toxic to micro-organisms and accumulate much less.

Plants

3.6. Lead reaches plants through uptake from the soil and through deposition on aerial surfaces both from the air and by soil splash. It is at present not possible to quantify the relative contributions made by these various routes: no reliable way has yet been found of measuring the proportion of lead which is typically absorbed through the plant surface, and when attempting to measure the amount of lead within the plant it may be difficult to ensure that all the surface lead is removed by washing (see Table 4.3).

3.7. It has already been mentioned (see paragraph 2.24) that not all the lead in soil is in a form available for uptake by plants. In comparison with other metals the availability of lead in soil is low and so even in moderately contaminated soils plants may be growing normally. There is no simple relationship between the concentration of lead in soil and the amount taken up by plants, although the higher the soil lead concentration the higher is likely to be the uptake by the plant. Factors which influence this relationship include the chemical and physical properties of the soil (such as phosphate status), the species (and cultivars) of plant and its rate of growth. Lead taken up from the soil is generally, but not always, found at a greater concentration in roots than in above-ground parts of the plant.

3.8. There have been many measurements of lead concentration in different parts of plants, and examples relating these to the soil lead concentration are shown in Table 3.1. The lead content of plants eaten by man has attracted particular interest, and the Ministry of Agriculture, Fisheries and Food (MAFF) has carried out analyses of the lead concentration in fruit and vegetable crops in the UK⁽⁶⁹⁾. The current general limit for lead in food intended for sale for human consumption, set by the Lead in Food Regulations 1979 (made under the Food and Drugs Act 1955), is 1 mg/kg (fresh weight). Table 3.2 shows 'background' values for the lead content of fruits and vegetables unaffected by any elevated concentration of lead in the air or soil. Similar values have been obtained for fruits and vegetables in France⁽⁷⁰⁾. MAFF has also analysed crops grown in areas of high soil lead and near lead smelters. In an area of high soil lead concentration (greater than 3,500 $\mu\text{g/g}$) the lead content of vegetables was elevated, more so for winter than for summer crops (Table 3.3). In contrast, analyses of vegetables grown at sites with a history of sewage sludge application showed relatively little increase in the lead content: for a soil with a lead concentration 25 times greater than the background concentration, the greatest increase in the lead concentration of vegetables was by a factor of

TABLE 3.1

Lead in soils and plants

Plant	Lead concentration in soil ($\mu\text{g/g}$)	Lead concentration in plant ($\mu\text{g/g}$ dry weight)	Reference
<i>Plants from uncontaminated sites</i>			
Potato (tubers)	13-175	0.8-3	(51)
Vegetation (above ground)	13-19	15-41	(62)
Vegetation (roots)	13-19	9-22	(62)
<i>Plants from sites with naturally elevated lead</i>			
Cowberry (leaves)	23,200	64	(63)
Wavyhair grass (leaves)	17,200	99	(63)
Australian <i>Gomphrena</i>	3,400	404	(64)
Australian <i>Polycarpaea</i>	3,200	1,044	(64)
<i>Plants from polluted sites</i>			
Potato (tubers)	100-512	2-4	(51)
Radish (roots)	10-2,636	1-57	(51)
Radish (leaves)	361-4,644	3-11	(65)
Radish (stems)	672-4,644	1-15	(65)
Lettuce (leaves)	361-4,644	4-12	(65)
Grass	39-403	21-60	(66)
Pasture	780-2,200	140-350	(67)
Vegetation (above ground)	52-128	118-979	(62)
Vegetation (roots)	52-128	132-309	(62)
Vegetation	90-2,976	30-100	(68)

TABLE 3.2

Lead in fresh fruit and vegetables

Food Crop	No. of samples	Mean (mg/kg fresh weight)	Range (mg/kg fresh weight)
Brussels sprout	16	0.05	<0.01-0.24
Cabbage	23	0.08	<0.01-0.51
Carrot	8	0.02	<0.01-0.04
Leek	4	0.06	0.04-0.07
Mushroom	6	0.06	0.03-0.13
Onion	11	0.06	<0.01-0.38
Pear	17	0.10	<0.01-0.23
Potato	19	0.04	<0.01-0.14
Plum	5	0.11	0.06-0.16
Rhubarb	5	0.07	0.04-0.15
Swede	8	0.02	<0.01-0.05
Tomato	10	0.06	0.01-0.14
Watercress	4	0.15	0.08-0.33

Source: Reference (68)

TABLE 3.3
Lead in fresh vegetables grown at Shipham, Somerset

Vegetable	Winter crops			Summer crops		
	No of samples	Mean (mg/kg fresh weight)	Range	No of samples	Mean (mg/kg fresh weight)	Range
Brussels sprout	30	1.07	0.12–3.60	11	0.09	0.02–0.19
Cabbage	14	1.47	0.45–4.47	59	0.24	0.02–0.77
Carrot	16	1.29	0.21–3.82	55	0.26	0.05–1.20
Kale	7	2.12	1.34–3.38	9	0.25	0.02–0.36
Leek	41	1.38	0.15–4.27	8	0.14	0.07–0.28
Parsnip	27	1.64	0.34–5.95	12	0.24	0.12–0.54
Spinach	8	2.79	0.12–7.50	12	0.29	0.02–0.76

Source: Reference (69)

two. The MAFF analyses also showed how fruit and vegetables which have not been thoroughly washed can carry additional lead as a result of aerial deposition or soil being splashed up by the rain⁽⁶⁹⁾.

3.9. It is generally considered that lead is toxic to the growth of plants and much is known about its effects on plant physiology⁽⁷¹⁾. This information comes mainly from laboratory studies, since in the field there are often problems in distinguishing between the effects of lead, other metal pollutants, and other environmental influences. Nevertheless it is clear that gross contamination of soils by lead causes some species to disappear and others to adapt.

3.10. Since the demonstration by Bradshaw in a common grass species thirty years ago of lead tolerant ecotypes⁽⁷²⁾, they have been demonstrated for many plant species growing on soils which contain a high natural concentration of lead or which have been contaminated by lead from mining, smelting or atmospheric fall-out. Lead tolerance in roadside populations of plants has been shown to fall off rapidly with distance from the road. Tolerance of lead is genetically determined and may be linked to morphological changes and also to tolerance of other metals.

3.11. The total amounts of lead in the different components of the vegetation of one particular woodland, studied over many years, are shown in Table 3.4. Contamination of this woodland was by aerial deposition of several metals, including lead, from a smelter, other industrial sources and a motorway. The highest concentration of lead was found in leaf litter and, as has been reported for many other areas contaminated with heavy metals, the soil was found to be the major site of accumulation of lead. Despite the heavy contamination there were no symptoms of plant toxicity, probably because most of the lead was present as relatively inert deposits on the surface of the soil. One observed effect was that fallen leaves decomposed more slowly than those on uncontaminated sites.

TABLE 3.4

Total amounts of lead in components of a cross section of contaminated woodland downwind of a primary smelter

Component of woodland	Lead (mg/m ²)	Percentage of lead burden
Trees		
Wood	Not detected	} 23
Bark	2,930	
Branches	7,180	
Leaves	30	
Shrubs		
Wood	Not detected	} <1
Bark	80	
Branches	100	
Leaves	<10	
Ground plants	30	<1
Plant litter	16,290	38
Soil	16,780	39
Total lead burden	43,430	100

Source: Reference (73)

Invertebrates

3.12. The effects of lead on organisms which inhabit the soil and leaf litter areas are of particular interest since these organisms are at or near the base of many food chains and because the soil is the principal 'sink' of lead in terrestrial ecosystems. Soil micro-organisms have already been considered in paragraph 3.3. There have been a number of suggestions that the reduced rate of litter decomposition that is observed when there is metal contamination is due to a decrease in the numbers of invertebrate animals feeding on the litter. In contrast to certain other metals (such as cadmium and zinc), lead does not appear to accumulate through ecological food chains (bioaccumulation)⁽⁷⁴⁾, although a high concentration may be found in particular organs within some animals. For example, in woodlice, an important component of the soil-litter fauna in deciduous woodland, lead concentrated in the digestive organ has been found to constitute as much as 7,500 µg/g (2.5 per cent of the dry weight) at heavily contaminated sites⁽⁷⁵⁾. It is not known what effects such concentrations of lead have on populations of invertebrates.

Vertebrates

3.13. There are numerous data on lead concentrations in wild animals, particularly mammals and birds. Studies both in the UK and overseas have compared the concentration of lead in the tissues of animals at contaminated and uncontaminated sites (see Tables 3.5 and 3.6). These have shown that animals grazing by main roads, at sites of former mining activity and at sewage farms may have elevated tissue lead concentration, sometimes associated with structural changes in the tissue. Work in New Zealand⁽⁷⁶⁾ has shown that

TABLE 3.5
Lead in blood and kidneys of vertebrate animals

<i>Animal</i>	<i>Site</i>	<i>Blood lead concentration (µg/dl)</i>	<i>Kidney lead concentration (µg/g dry wt)</i>	<i>Reference†</i>
Wood mouse (UK)	Derelict mine		47*	(77)
	Uncontaminated		13	
Field vole (UK)	Sewage farm		7	(78)
	Uncontaminated		6	
Deer mouse (USA)	Roadside		23	(79)
	Uncontaminated		1	
Brown rat (USA)	Urban	58	79	(80)
	Rural	18	4	
Squirrel (USA)	Urban schoolground		6	(81)
	Rural		1	
Dog (USA)	Boston (with symptoms)	120* **		(82)
	Boston (without symptoms)	19		
Sheep (NZ)	Roadside	90	154	(76)
	Uncontaminated	20	1	
Cattle (UK)	Derelict mine	21		(53)
	Uncontaminated	10		
Cattle (UK)	Farms with mine waste	140* **	137* **	(83)
	Uncontaminated	5-26	70	
Lizard (UK)	Mine spoil heap		18	(84)
	Roadside		8	
	Uncontaminated		2	
Swan (UK)	Water with fishing weights	375**	1,734**	(85)
	Uncontaminated	22	16	
Swan (UK)	Water with fishing weights		1,105**	(86)
	Uncontaminated		24	
Pigeon (UK)	Inner London	101*	321*	(87)
	Rural	19	4	

*Associated with some symptoms of lead poisoning.

**Associated with fatal lead poisoning.

†Some figures from the original papers have been converted from wet weight to dry weight.

TABLE 3.6
Lead in small animals from roadside, contaminated and control sites

<i>Animal</i>	<i>Whole body lead concentrations (µg/g fresh wt)</i>		
	<i>Uncontaminated site</i>	<i>Roadside</i>	<i>Other contaminated site</i>
Wood mouse	0.9-2.6	1.7	8.6-31.3
Mole shrew	1.6-2.6	6.6	
Bank vole	1.5-2.6	1.8	16.3-20.7
American vole	1.4	4.7	
Field vole	2.8	3.3	42.8-45.3
Deer mouse	0.8	2.0	
Deer mouse	0.4-2.7	1.4	
Shrew	0.9		11.2

Source: Reference (77)

elevated blood lead concentration in roadside sheep is a result both of ingestion of lead and of inhalation of airborne lead from vehicle emissions. The Central Veterinary Laboratory has encountered no cases of poisoning in the UK that were attributable to lead from motor vehicle emissions.

3.14. The presence of lead in vegetation and soil may pose a serious health hazard, particularly to farm and other domestic animals which obtain most of their food from grazing, and cases of frank poisoning have been reported. Grazing inevitably involves ingestion of soil: the Central Veterinary Laboratory has recorded four incidents of lead poisoning in sheep in old mining areas, and another study has shown that between 40 and 70 per cent of the lead intake of cattle comes not from contaminated vegetation but from ingested soil⁽⁸⁸⁾. Probably of greater importance is that young animals tend to lick or chew surfaces and leaded paint can thus be a hazard. Old lead mining waste has occasionally caused death in working farm dogs when used as hardcore on farm roads. During 1979–81 the Scottish Agricultural Colleges recorded lead poisoning, mostly fatal, in about 143 cattle, 9 sheep and 11 collie dogs. Studies on lead metabolism in sheep have shown that lead uptake and retention, and thus the hazard created by lead in the environment, are modified very substantially by the quality and quantity of the diet; this parallels the situation of man (see paragraph 4.30). We note that nearly all the reported farm deaths would have been avoided if simple precautions had been taken.

3.15. The most comprehensive studies of lead poisoning in wildlife have involved birds, particularly in aquatic habitats. There are many data on lead concentrations in the soft tissue of birds. Measurements of tissues from raptors and waders in the UK show that the concentration of lead is usually below 1 $\mu\text{g/g}$ (dry weight)^(89, 90). There are, however, several exceptions. Urban areas may be 'hot spots' for some birds: in central London some pigeons have been found with kidney lead concentrations over 300 $\mu\text{g/g}$ (dry weight) (Table 3.5) and showing symptoms of lead poisoning in the renal and blood-forming systems⁽⁸⁷⁾, including increased kidney weight, and altered structure and function of components in blood, liver and kidney cells.

3.16. Although lead shot which remains lodged in the muscle of a surviving bird is unlikely to produce lead poisoning, it has long been known that ingestion of lead from spent gun shot and from fishing weights can kill birds⁽⁹¹⁾. Many birds need to swallow grit to grind ingested plant material. Waterfowl gather this from mud, where spent shot may be relatively abundant, and are thus particularly liable to swallow shot and suffer from lead poisoning. Lead poisoning in waterfowl with ingested shotgun pellets has been demonstrated in 15 countries, including the UK⁽⁹¹⁾. A report to the British Association for Shooting and Conservation, the Royal Society for the Protection of Birds and the Wildfowl Trust on the poisoning of wildfowl in Great Britain by spent gun shot⁽⁹²⁾ estimated that about 8,000 mallard each year die of poisoning from this source of lead, although this figure is a very small proportion of the overwintering mallard population and small compared with the direct losses from wildfowling.

Chapter III

3.17. A particular problem in the UK is the ingestion of lead fishing weights by mute swans^(85, 86, 93). Swans affected by lead poisoning show progressive loss of weight and increased lead concentration in blood and other tissues (see Table 3.5), followed by severe liver and kidney damage and impaction of food in the digestive tract. Externally there is a characteristic drooping of the lower part of the neck due to muscle paralysis. A report by the Nature Conservancy Council⁽⁹³⁾ estimated that in England about 3,000 mute swans die each year from lead poisoning due to the ingestion of fishing weights. Other environmental factors may be involved and a correlation was noted between boating and swan deaths, but the NCC Report, after considering the evidence, specifically discounted emissions from petrol-engined boats as a source of ingested lead. The NCC Report estimated that 255 tonnes of lead were introduced into the environment each year in the form of fishing lead, although the National Anglers' Council, in its evidence to us, has estimated an annual figure of only 50 tonnes. Whichever figure is accepted, there can be no doubt that a substantial amount of lead from fishing weights reaches the environment and is a major cause of mortality among mute swans.

Poisoning of birds by organic lead

3.18. An incident of poisoning of birds by organic compounds of lead occurred during the last quarter of 1979 when an estimated 2,400 birds were found dead or dying in the middle reaches of the Mersey estuary, an important wintering area for estuarine birds⁽⁹⁴⁾. Although a number of species were affected, most of the dead birds were dunlin. Smaller numbers of deaths were reported in each subsequent year. A number of organisations collaborated in an investigation and concluded that the birds died from poisoning by tri-alkyl lead^(94, 95). Nearly all the dead birds analysed had a lead concentration in the liver in excess of 10 $\mu\text{g/g}$ (wet weight) with between 30 and 70 per cent of the lead in tri-alkyl form. Previous studies suggest that such a concentration is likely to be fatal.

3.19. Studies were also made of apparently healthy birds from the Mersey and other estuaries⁽⁹⁵⁾. Those from the Mersey were found to contain less lead than the dead birds but more than birds from elsewhere. Apparently healthy birds with a liver concentration of tri-alkyl lead above 0.5 $\mu\text{g/g}$ (wet weight) often had internal symptoms similar to those of the dead and dying birds. These findings were confirmed by experiments in which captive birds were dosed with tri-alkyl lead compounds. The results of these studies suggest that apparently healthy birds with a liver concentration of tri-alkyl lead above 0.5 $\mu\text{g/g}$ may be at risk, particularly if vulnerable to other environmental pressures such as disease or shortage of food⁽⁹⁵⁾.

3.20. The affected birds in the Mersey estuary are believed to have acquired the lead from their invertebrate prey, mainly a bivalve (baltic tellin) and polychaete worms. Analyses of these species showed tri-alkyl lead concentration of about 0.2 $\mu\text{g/g}$ (wet weight) in polychaetes and of about 1.0 $\mu\text{g/g}$ (wet weight) in the baltic tellin, which were high enough to account for the lead concentration found in the birds⁽⁹⁴⁾ and which may be compared with a

concentration in such invertebrates in the nearby Dee estuary of less than 0.1 $\mu\text{g/g}$ (wet weight).

3.21. It is known that alkyl lead compounds reach the Mersey estuary from industrial discharge, but it is not clear how these compounds are taken up by invertebrates or whether the environmental concentrations in 1979 were significantly different from those in earlier years. There is no evidence of any abnormal industrial discharge of alkyl lead compounds directly or indirectly into the Mersey at the time. It is therefore a matter for speculation why bird deaths should have occurred on such a scale when they did. It seems probable that other factors besides lead may have played a part. Since the original incident the biota and water have been extensively monitored. The detection of further bird deaths in each year, believed to be due to tri-alkyl lead poisoning, and the findings of effects in apparently healthy birds suggest that, although the problem is probably highly localised, there is cause for concern at the discharge of organic lead compounds in amounts which hitherto have been considered safe for wildlife.

Aquatic life

3.22. There is no evidence that plankton suffers adverse effects from the low concentration of lead present in sea and lake water. There are extensive data on the lead concentration of aquatic, especially marine, animals and particularly detailed studies have been made on the uptake, storage, detoxification and excretion of metals, including lead, in marine invertebrates, especially the mussel. The concentration of lead found in invertebrates in polluted estuaries can be considerable; the lead concentration in the animals is affected not only by the concentration in the water but by factors such as salinity and iron concentration. Studies in seals and porpoises from around the shores of the UK showed that lead was not present in sufficient quantity to permit detection by the techniques employed⁽⁹⁰⁾.

3.23. The concentration of lead at which water becomes toxic varies considerably from one species to another. The values shown in Figure 3.1 are based on laboratory experiments and may exaggerate the toxicity of lead in nature. There is little evidence of direct damage to marine organisms which accumulate lead at high concentration, but mussels and other marine invertebrates are components of food chains and may contribute substantially to the lead intakes of higher animals including, in certain circumstances, man. The Ministry of Agriculture, Fisheries and Food and the Department of Agriculture and Fisheries for Scotland monitor mussels for lead contamination to measure the impact of lead pollution in a species which is known to accumulate lead. Under the Lead in Food Regulations 1979 the maximum allowable concentration of lead in shellfish intended for sale for human consumption is 10 mg/kg (fresh weight); in practice the concentration of lead is usually considerably lower.

Conclusions

3.24. Since lead is now universally dispersed by man in the environment (see paragraph 2.3) it is to be expected that it is present in all plants and animals. There are many data on lead concentration in the biota though its

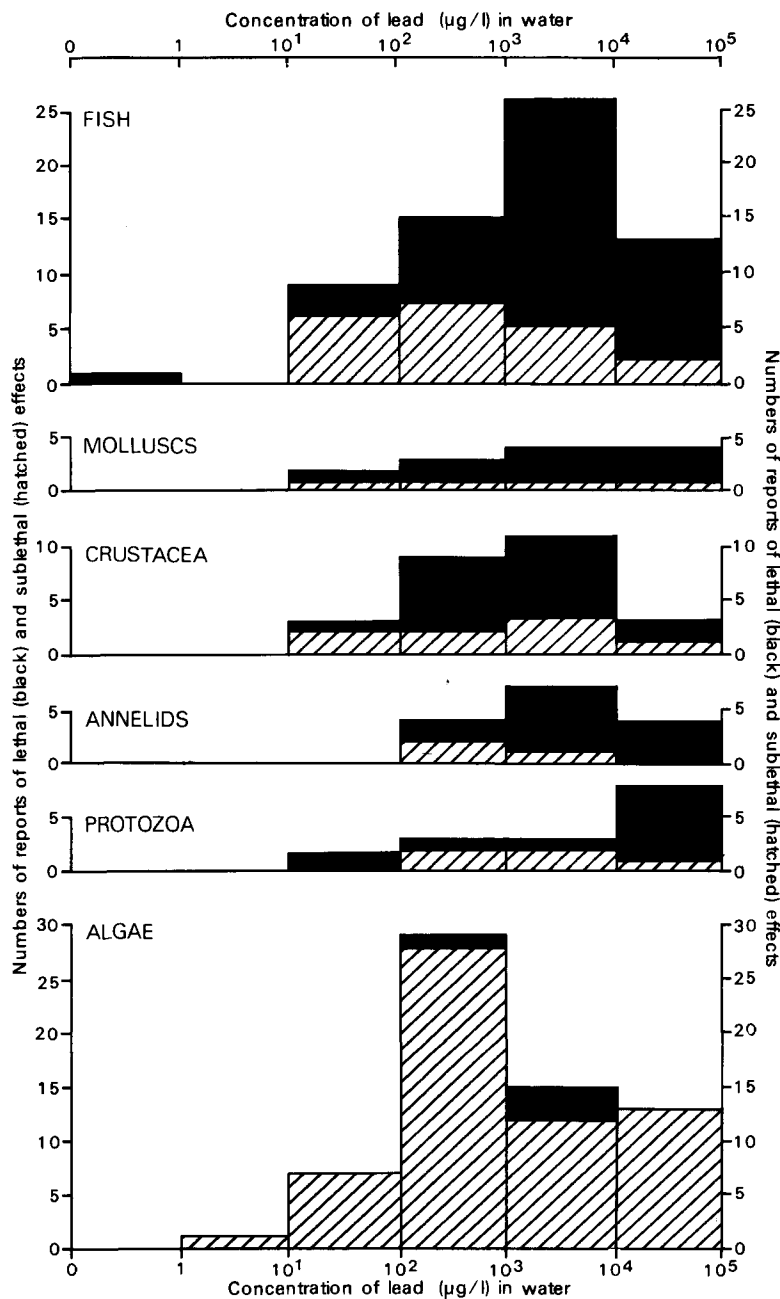


Figure 3.1
Lethal and sublethal concentrations of inorganic lead for aquatic (freshwater and marine) organisms

Source: Reference ⁽⁹⁶⁾

effects are often uncertain. A higher than average concentration of lead is found in plants and animals in the vicinity of major sources of lead such as main roads, mine wastes and industrial emissions (Tables, 3.1, 3.5 and 3.6).

3.25. Although lead from the soil is generally not readily taken up by plants there are now well documented examples of areas (including roadsides) where a high soil lead concentration is associated with changes in the genetic or species composition of vegetation. To this extent anthropogenic lead is having a direct effect on the vegetation. We do not, however, consider that on the present scale this in itself is a cause for concern, since naturally occurring lead may be present in a high enough concentration to have similar effects in some areas; moreover the total effect on the vegetation is very much less than that due to many other disturbances by man.

3.26. There is some evidence that lead may have detectable local effects on the dynamic processes of certain ecosystems near major sources of contamination, for example on the decomposition of leaf litter. However, there is generally little evidence that lead is accumulated to any great extent along food chains or that the animals at the top of food chains are at particular risk.

3.27. Each year instances of frank lead poisoning are reported in both wildlife and domestic animals, and other cases may of course go undetected. Most of the cases that we know of have specific sources, either localised (for example, industrial discharge) or widespread (for example, anglers' lead weights) and in Chapter VI we consider measures to reduce some of these.

3.28. The data displayed in Tables 3.5 and 3.6 show that whereas in most wild animals the tissue concentration of lead is well below that which causes death, at contaminated sites and roadsides it is above those found in more natural conditions, although even here the concentration may be raised by the ingestion of aeriaily deposited lead. From the data for birds and those for man given in Chapter V, it is clear that lead absorption may induce pathological changes in animals without producing external signs. Such animals may be at risk, particularly if subjected to additional stress. As with other poisons, the adverse effects of lead on wildlife may be greater than indicated by cases of lethal poisoning alone.

CHAPTER IV

LEAD IN MAN

Introduction

4.1. In this chapter we consider human exposure to and uptake of lead from the environment. We also examine the relative contribution of different sources and pathways to the body lead burden; knowledge of this is important when considering methods to reduce the body burden of lead, an issue which forms the basis of Chapters VI and VII.

4.2. There are two routes by which lead enters the body: by inhalation into the respiratory system and by ingestion into the alimentary system. (Absorption through the skin is significant only with some organic compounds of lead and hence intake by this route is usually negligible.) From each of these lead is absorbed into the bloodstream. It is important to distinguish between intake and uptake of lead: by *intake* is meant the amount of lead inhaled from the air or ingested in food and drink, while *uptake* refers to the amount subsequently absorbed into the bloodstream.

4.3. The amount of lead entering the respiratory system depends on its concentration in the air and on the volume of air inhaled. Not all lead inhaled reaches the lungs as some particles are trapped in the moist surface of the windpipe, and are eventually swallowed. Of the lead which reaches the lungs, some is absorbed and some exhaled (see paragraph 4.22). The amount of lead reaching the alimentary tract depends on the concentration in food and drink and the amount of food and drink consumed. Within the gut some lead is absorbed and the remainder passes directly to the faeces.

Lead within the body

4.4. The behaviour of lead in the body is affected by its chemical form, not its route of entry. Most of the inorganic lead taken up rapidly becomes attached to red blood cells (erythrocytes) before distribution to other tissues and organs throughout the body. Nearly all of it accumulates in the bones, which account for about 90 per cent of body lead in adults and 70 per cent in children. While lead in soft tissues and organs is potentially toxic, lead in bone is largely isolated in a metabolically inert form. There is considerable evidence, however, that there can be a slow movement of lead from bone to other compartments of the body. Organic lead, in contrast, concentrates in the liver⁽⁹⁷⁾. The main route of excretion of absorbed lead from the body is in urine, with smaller amounts in bile (excreted in the faeces), sweat and other minor excretion routes. The relationship between exposure to lead and the way in which lead moves about in and leaves the body is far from completely understood.

4.5. Although it is convenient to refer to 'body lead' the total amount of lead contained in the body cannot be measured directly. The lead content of certain tissues, such as blood and teeth, can be measured and the values obtained used as indices of the amount of lead in the body.

Measurement of body burden of lead

4.6. The measurement of lead at low concentration in biological materials is not easy. Many research reports provide no information on the precision and accuracy of the methodology used for this and it is impossible to assess whether differences in concentration are real, or due to sampling or analytical errors. It is also impossible, without such information, to compare one set of findings with another. Different inferences can be made from the concentration of lead in different tissues. The concentration in blood, for example, is influenced by exposure over the previous few weeks, while the concentration in bone and teeth reflects the accumulation of lead over a long period, perhaps throughout life.

4.7. The most widely used assessment of lead in the body is by the direct measurement of the concentration in venous or capillary blood. Great care to avoid contamination of the blood from collection onwards is essential and generally venous blood is preferred. Participation by analytical laboratories in quality assessment programmes is essential and, in population studies, samples of blood should be cross-checked by assay in a second laboratory.

4.8. A second, indirect method of assessing the concentration of lead in blood relies on the fact that lead interferes with the production of haemoglobin, a component of blood, resulting in the accumulation of one of its precursors, protoporphyrin. The protoporphyrin in red blood cells (erythrocytes) forms a complex with zinc (present as a trace element), which can be measured either directly by a haematofluorimeter or, after extraction from the blood, by spectrophotometry. As factors other than lead can result in accumulation of erythrocyte protoporphyrin (EPP), enhanced EPP is not by itself proof of enhanced blood lead concentration.

4.9. It has been proposed that EPP determination could be a useful screening tool to identify children with a high concentration of blood lead⁽⁹⁸⁾: it is a much simpler test than blood lead measurement, it can use capillary blood (which is easier than venous to sample), and it is not affected by contamination during sampling since protoporphyrin production ceases as soon as the sample is taken. Although the EPP concentration appears to vary logarithmically with the blood lead concentration, the correlation is not very good, particularly for children under 3 years old⁽⁹⁹⁾. EPP concentration is a measure of the metabolic effect of lead rather than of the blood lead concentration itself. If the purpose of a screening programme is to detect children suffering from metabolic effects of lead, the EPP analysis is probably adequate⁽⁹⁹⁾. If, however, the purpose is to detect children with a slightly raised blood lead concentration, as a precaution against possible damage, then direct measurement of blood lead is desirable.

Chapter IV

4.10. Lead also accumulates in other tissues where it can be measured. The collection of hair is convenient, but the measurement of its lead content is so fraught with problems of contamination and interpretation that it has not been used widely. A number of studies have measured lead in teeth (whole, crown, dentine) as a reflection of accumulation over a period of time. There are major problems concerned with the accuracy of tooth lead measurement so that it is difficult to compare measurements made by different laboratories. An additional problem is the variation in lead concentration with the position of the tooth in the mouth⁽¹⁰⁰⁾. Studies of tooth lead in the UK suggest lower levels of exposure than those in the USA⁽¹⁰⁰⁾.

Sources and pathways

4.11. To avoid confusion, it is important to distinguish between the *sources* of lead and its *pathways* to man. By the former we mean the matter from which the lead is first released to the environment, such as paint, solder, petrol or lead-bearing rock. In contrast sewage, food and air are not sources of lead but stages in pathways of lead already released to the environment.

4.12. Any attempt to represent diagrammatically the relationship between sources and pathways is either so simplified as to be misleading or so complex as to be confusing; we have therefore made no such attempt. For most people almost all inhaled lead is derived from petrol and industrial emissions, which are the main sources of lead in the air (see paragraph 2.4), though lead can also be inhaled from tobacco smoke and from resuspended dust, which in turn contains lead from a variety of sources. Lead which is ingested comes from many sources and by many pathways. All food and drink contain some lead but the concentrations are usually very low. Food crops are contaminated by deposition of airborne lead to leaf, shoot and fruit surfaces, and lead is also taken up from the soil (see paragraph 3.6.). Lead in the soil may be of natural origin or come from sewage sludge, other waste disposal, from former industrial activity, or aerial deposition. Lead in sewage sludge comes from a variety of sources (see paragraph 2.12). Canned foods may be contaminated by lead from solder (see paragraph 6.31). Lead in water may contaminate not only beverages but also foods cooked or prepared in water; this contamination may occur in the home or in factories processing food. Children, in particular, may swallow lead in dust or soil on their fingers or on objects, and lead from paint if they mouth painted items. Of less widespread importance, although serious when it occurs, is the compulsive habit, known as pica, of some children, where non-food matter such as paint and soil, both of which may contain lead, is actively eaten. There are other miscellaneous sources of ingested lead, including privately imported cosmetic and medicinal preparations and old pewter, which may be of significance in certain cases (see paragraph 6.46).

4.13. It is very difficult to evaluate the relative contributions to the body burden of different sources and pathways of lead. It is not generally possible to distinguish between lead from different sources. Experiments on the uptake of lead by people, and obtaining human tissues other than blood, teeth and hair for measurement of concentration, present major practical difficulties. When

making studies which are not being performed for the benefit of the individual child considerations of medical ethics are particularly important; the guidelines published by the British Paediatric Association⁽¹⁰¹⁾ are helpful.

4.14. However, there are data from several kinds of studies which allow at least a general picture to be built up of the exposure to lead in the UK from different sources and pathways and of the resulting blood lead concentration.

Exposure and blood lead concentration

4.15. There is now a considerable amount of information on the relationship between exposure to lead and blood lead concentration. Most of this comes from population surveys in which the blood lead concentration of individuals or groups is correlated with locally measured lead concentration in air and water; experiments in which volunteers are exposed to controlled air lead concentration and their blood lead concentration measured; and studies of the lead balance of individuals, estimating the contribution of air and measuring the intake of lead in food and drink.

4.16. Most of the earlier work involved inhaled lead, and the relationship between concentrations of lead in air and blood was often treated as linear (i.e. any increase in air lead concentration results in a proportionately similar increase in blood lead concentration). More recently it has become accepted that the relationship is curved^(13, 102), although its precise form is not clear. Several studies have shown a non-linear relationship between the concentration of lead in blood and in tap water^(103,104). There is also evidence for a similar form of relationship between blood lead concentration and dietary lead intake^(103, 105). These various studies indicate that the relationships between blood lead concentration and the concentration of lead in air, water and diet, though not linear, are each of broadly the same form, so that successive increments in intake or exposure result in progressively smaller contributions to blood lead concentration.

4.17. These similarities suggest that it may be possible to derive, for adults, a relationship between the blood lead concentration and the total amount of lead taken up by the body. There have been several attempts to do this using previously published data⁽¹⁰⁶⁾. The combined results of these studies are shown in Figure 4.1. The outcome is a curve, although it is not possible to describe an exact form. Figure 4.2 shows the range of interpretation possible from Figure 4.1. We believe that the relationship shown in Figure 4.2 is a useful one both in that it illustrates the degree of variability associated with the relationship and also because it can be used to predict the effects on blood lead concentration of changes in lead uptake and hence of measures designed to reduce exposure to lead. There are insufficient data to derive an equivalent relationship for children.

Intake and uptake

4.18. There have been several studies measuring the intake, uptake and metabolism of lead in volunteers, and balance schemes for lead have been

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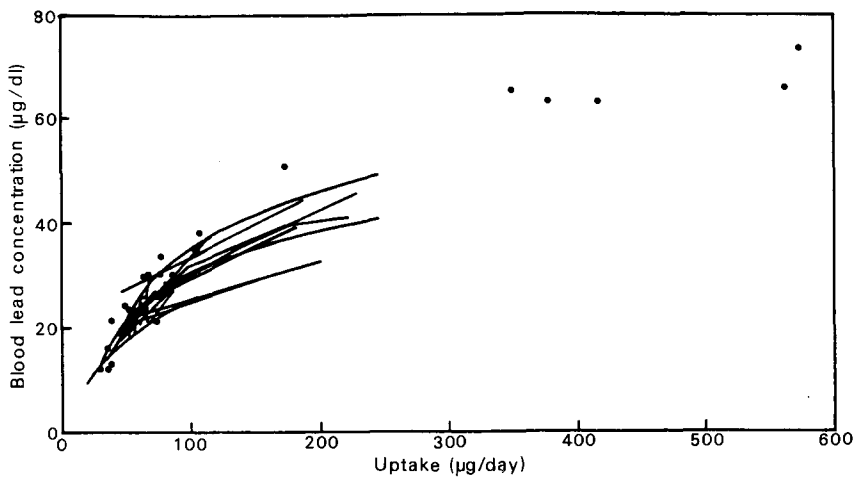


Figure 4.1
Relationship between blood lead concentration and total lead uptake for adults

Source: Reference ⁽¹⁰⁶⁾

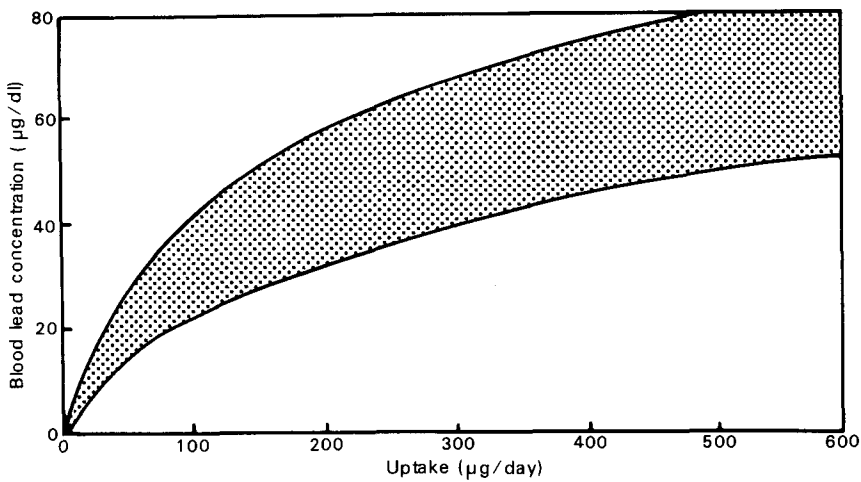


Figure 4.2
Relationship between blood lead concentration and total lead uptake for adults, showing the range of interpretation possible from Figure 4.1

constructed from the data^(28, 37, 107-109). These balance schemes are derived from limited data obtained under experimental conditions; they apply to average urban, adult males and are difficult to extrapolate to other groups of people.

4.19. It is also possible to construct balance schemes by making assumptions about lead intakes and about various metabolic factors. This approach has the disadvantage that the assumptions are based on the results of many separate pieces of research, but the advantage that, provided the data exist, the balance schemes can be constructed for different groups of people with different exposures to lead.

4.20. We have attempted to devise model balance schemes for various groups of people within the UK. The details of the data and calculations are set out in Appendix 4. It is important to recognise the limitations of this exercise, which involves many uncertainties and assumptions and which makes no attempt to quantify lead excreted by the body. The results, summarised in Table 4.1, give a broad outline of the actual and relative magnitudes of intakes and uptakes of lead by different pathways and from different sources. The groups of people considered in the model do not purport to include the whole UK population; they comprise groups with different exposures to lead, some of them extreme, in order to illustrate the variations in lead intake and uptake in different situations. We have found this approach valuable in identifying the sources and pathways of major concern, but we warn against uncritical use of the absolute figures.

4.21. Model balance schemes for nine groups of adults and two of two-year old children are given in Appendix 4. The adults include those in rural areas or small towns, in inner city areas, and those exposed to particularly high concentrations of lead in air, water or food. The effects of tobacco and alcohol are also considered. Some of the groups represent, as far as possible, typical cases (Columns A-G and L) and the others extreme cases (Columns H-K).

4.22. The calculation of intake of lead from air involves assumptions about the air lead concentration both indoors and outdoors, and about the amount of time spent indoors. These factors vary considerably between people living and working in different locations and with different activities. However, it is possible to make reasonable estimates. A more difficult assumption concerns the respiration rate; this is known to vary between people and to depend on the activity being undertaken at the time. There is a wide range of published estimates of the daily volume of air respired, thus introducing considerable uncertainty into the calculation of lead intake. Data are available on the lead content of cigarettes and it is believed that smoking increases the amount of lead inhaled; support for this belief comes from epidemiological data⁽¹¹⁰⁾ which show that heavy smoking adds significantly to the blood lead concentration. The percentage of inhaled lead which is absorbed depends on the size and shape of the lead particles and the single value (50 per cent) used in the calculations is therefore an estimate of the typical value. It is by no means certain that the same estimate is as valid for a smoker as for a non-smoker, or

TABLE 4.1
Summary of model balance schemes in Appendix 4

	RURAL/SMALL TOWN					INNER CITY					
	Adults	Adults (smoking)	Adults (drinking)	Adults (smoking/ drinking)	Children (2-yrs old)	Adults	Adults (smoking/ drinking)	EXTREME CASES			Children 2-yrs old)
								Adults (high water lead)	Adults (high air lead)	Adults (high food lead)	
Column in Appendix 4, Table 1	A	B	C	D	E	F	G	H	J	K	L
Total lead uptake from lungs (µg/day)	1.0	4.0	1.0	4.0	0.5	6.3	9.3	6.0	15	6.3	3.4
Total lead uptake from gut (µg/day)	11	11	14	14	70	11	14	38	11	22	102
Total lead uptake from lungs and gut (µg/day)	12	15	15	18	70	18	23	44	26	29	105
Percentage of daily lead uptake from inhalation	8	26	7	23	1	36	41	14	57	22	3
Percentage of daily lead uptake from ingestion	92	74	93	77	99	64	59	86	43	78	97
Lead uptake from petrol (µg/day)	2.0	2.0	2.0	2.0	3.3–45	6.8	6.8	6.5	15	17	5.9–80
Percentage of daily lead uptake from petrol	16	13	14	11	5–64	39	30	15	56	59	6–76
Predicted blood lead concentration (µg/dl)	7	9	9	11	—	11	13	20	14	15	—

All values are approximate and those below 100 are rounded to 2 significant figures. The cases do not purport to include all groups of people in the UK. By inner city is meant the inner areas of the larger conurbations. For details of calculations see Appendix 4.

for someone living in an area of high traffic density as for someone living in a rural area. In each case the spectrum of lead particle size and shape may be different. The estimates of percentage absorption in children are even more uncertain. Table 4.1 shows estimated daily lead uptakes from air ranging from 1 μg for adults in small towns or rural areas, to 15 μg for adults in areas of extremely high air lead concentration. Two-year old inner city children are estimated to have a daily uptake via the lungs of about 3 μg .

4.23. Estimating lead intakes and uptakes by ingestion involves further assumptions and uncertainties. Estimates of dietary lead intake come from measurements of the lead content of particular foodstuffs (Table 4.2) and the lead content of duplicates of actual diets. There is, of course, considerable variation between people and intakes will generally be lower for children than for adults. MAFF has calculated an average daily dietary intake of lead for the 'average' person for each year since 1975. The overall mean intake for 1975–81 has been estimated to be 100 $\mu\text{g/day}$ ⁽⁶⁹⁾. This figure is likely to be an overestimate since it was calculated by assuming that lead concentrations below the limit of detection were equal to that limit. Nevertheless the figure is considerably lower than those used in the past for the UK^(13, 28) and overseas⁽¹¹⁾. It is not clear whether the differences are attributable to differences in sampling and analysis or to a fall in the amount of lead in food.

TABLE 4.2
Lead concentration in components of the average diet

Food group	Daily consumption (kg)	Lead concentration Range (mg/kg)	Mean (mg/kg)	Daily lead intake (mg)
Bread & cereals	0.240	<0.050–0.050	<0.050	0.012
Meat & poultry	0.058	<0.050–0.050	<0.050	0.003
Offal	0.003	<0.050–0.500	<0.130	0.000
Meat products	0.077	<0.050–0.050	<0.050	0.004
Fish	0.015	0.050–0.150	0.080	0.001
Oils	0.090	<0.050–0.050	<0.050	0.005
Sugars & preserves	0.095	<0.050–0.100	<0.055	0.005
Green vegetables	0.046	<0.050–0.150	<0.065	0.003
Potatoes	0.159	<0.050–0.050	<0.050	0.008
Other vegetables	0.068	<0.050–0.050	<0.050	0.003
Canned vegetables	0.043	0.050–0.200	0.135	0.006
Fruit	0.060	<0.050–0.050	<0.050	0.003
Fruit products	0.024	0.050–0.250	0.155	0.004
Beverages	0.118	<0.010–0.040	<0.014	0.011
Milk	0.360	<0.020–0.020	<0.020	0.007
TOTAL	1.456			0.08

The figures are obtained from MAFF's Total Diet Study (1981) in which the daily consumption of each food group by the 'average' person is measured. The total dietary intake of lead shown is based on the analysis of 10 total diets prepared in 1981 using a revised methodology. The results are presented by way of example and the total is therefore not identical to the estimate used in Appendix 4.

Source: Reference ⁽⁶⁹⁾

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4.24. Canned foods make a substantial contribution to dietary lead intake because of widespread use of lead solder in can manufacture. (Cans used for baby foods and certain other foods, and cans made by some modern processes, do not contain lead—see paragraphs 6.31–6.32.) The presence of oxygen accelerates the dissolution of lead from the solder in the can, and storage of food in opened cans is therefore likely to result in an increase in the dissolved lead. In Appendix 4 we calculate that on average adults have a daily lead intake of about 15 μg from the solder in canned foods.

4.25. The remaining dietary lead (about 85 $\mu\text{g}/\text{day}$ for the average adult) is associated with the food itself. Food crops obtain lead from the soil and from the air. Lead in the soil may be of natural origin, from contaminated waste material such as sewage sludge or from aerial deposition (see paragraphs 2.15–2.21). It is extremely difficult to estimate, and a matter of some dispute, how much of the lead in food comes from each of these various sources and pathways. There is uncertainty about the lead content of food from atmospheric deposition. Lead can reach crop plants by direct or indirect (for example by splashing) deposition to the exposed surfaces of the plant, and by deposition on the soil followed by uptake through the roots. It is difficult to assess how much of the lead on the crop plant surface is removed during the preparation and cooking of food. There are data on the amount of lead deposited on particular crops and on its reduction during washing and preparation of food. These data are sparse and unsystematic with published values for the lead removed by washing from the surface of fruit and vegetables ranging from virtually nil to 100 per cent (Table 4.3), with 50 per cent generally taken as an average value^(69, 71). Another approach is to assume that the natural lead isotope ^{210}Pb (see paragraph 2.1) enters the diet in the same way and to the same extent as anthropogenic lead from the atmosphere. From measurements of the deposition of ^{210}Pb and total lead and their concentrations in food in the

TABLE 4.3

Some experimental values for the percentage of lead removed from crops by washing

<i>Crop</i>	<i>Lead removed by washing (per cent)</i>	<i>Reference</i>
Strawberry	21–44	(112)
Strawberry	0	(113)
Blackberry (wild)	19	(114)
Apple (peel)	3–84	(112)
Orange (peel)	≥ 50	(113)
Pear	11–47	(112)
Plum	16–38	(112)
Tomato	≥ 80	(113)
Lettuce	70	(115)
Lettuce (outer leaf)	19	(116)
Cabbage (outer leaf)	13	(116)
Brussels sprout	20	(116)
Curly kale	1	(116)
Grass	50*	(117)
Grass	35–55	(118)

*at roadside, decreasing with distance from road

UK it has been calculated that about 13 $\mu\text{g/day}$ of lead in the diet of the average urban adult is derived from atmospheric fallout⁽¹¹⁹⁾. As ^{210}Pb has a half-life of 22 years the estimate includes some atmospheric lead deposited on soil and taken up by plants and animals in the diet. The estimate of 13 $\mu\text{g/day}$ has an uncertainty as a significant proportion of the food in UK diets is grown overseas, where fallout rates of lead may well be different. We find it hard, however, to accept that all the remaining daily lead intake (up to 72 μg) is derived from natural sources, mine waste, sewage sludge and miscellaneous sources. We consider that the estimate of 13 $\mu\text{g/day}$ may well represent the contribution of current atmospheric deposition, but it does not fully take account of the cumulative deposition in the soil, which must go back many decades. Thus, if it were possible to identify the total proportion of the lead in our diet attributable to atmospheric fallout, it is likely that only a small part of it would initially be eliminated by a reduction in the air lead concentration to zero.

4.26. There are several categories of ingested lead additional to dietary lead intake. Water contributes to the ingestion of lead both through beverages and by absorption of lead by food during cooking. The median lead content of tap water in Great Britain is about 10 $\mu\text{g/l}$ ⁽⁴⁴⁾, but in areas of high plumbosolvency and lead plumbing the concentration may be 300 $\mu\text{g/l}$ or even higher. It is estimated that a tap water lead concentration of 10 $\mu\text{g/l}$ contributes about 9 μg to the daily lead intake of adults (Appendix 4). Infants from homes with a high concentration of lead in tap water will ingest less lead if they are breast-fed than if they are bottle-fed.

4.27. Another source of ingested lead is the glaze on ordinary crockery. It has been estimated that this generally contributes about 3 μg to the daily intake of lead⁽¹²⁰⁾.

4.28. There is epidemiological evidence of an association between alcohol consumption and increased blood lead concentration in men⁽¹¹⁰⁾. However, information on the lead content of alcoholic drinks in the UK is limited and shows a wide range of values⁽⁶⁹⁾. The estimates in Appendix 4 of lead intake from beer suggest no greater intake for most people than drinking an equal volume of beverage based on tap water, but are possibly low values⁽⁶⁹⁾.

4.29. Intake of lead from dust is extremely difficult to estimate, but it can be important for children, particularly in inner city areas⁽¹²¹⁾. It has been estimated that a two-year old urban child ingests about 0.1 g/day of soil and dust from the sucking of fingers and contaminated objects^(18, 122). The concentration of lead in dust in urban streets is typically in the range 500–5,000 $\mu\text{g/g}$ (see paragraph 2.27) and generally lower indoors (see paragraph 2.28). Although the limited data involve theoretical calculations we believe that the intake of lead from dust can be substantial for young children.

4.30. The percentage of ingested lead which is absorbed into the blood-stream depends on the physical and chemical form of the lead and on the other contents of the gut. Uptake is greater when the gut is empty and hence lead in

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beverages taken without food or early in the morning is likely to make a greater contribution to body burden. The mineral content of the diet is also known to affect the uptake⁽¹²³⁾ (both in man and animals) and population surveys have suggested that lead uptake is greater in areas of soft than of hard water⁽¹²⁴⁾. Published values of percentage absorption range from about 1 per cent to 35 per cent for adults and we have assumed an overall value of 10 per cent⁽¹³⁾. The value for children is considered to be much higher—about 53 per cent⁽¹²⁵⁾—although data are far fewer.

4.31. The main results of the balance schemes in Appendix 4 are summarised in Table 4.1. Estimates of the total daily lead uptake range from 12 μg for rural adults who neither smoke nor drink alcohol to 44 μg for the deliberately extreme case of inner city adults with very high concentration of lead in their tap water. We estimate that two-year old children might have a total daily lead uptake of about 105 μg in inner city areas and about 70 μg in rural areas. The estimate of the percentage of total lead uptake by inhalation ranges from less than 10 per cent for non-smoking rural adults to almost 60 per cent for the extreme case of inner city adults living very close to a major road. We have made tentative estimates of the daily lead uptake derived from lead in petrol, including the indirect pathway via food as measured by the ^{210}Pb technique (see paragraph 4.25). These range from 2 μg to 17 μg for adults and from 11 per cent to 59 per cent of total uptake of lead by both inhalation and ingestion. For the two-year old children we have expressed the figures as very wide ranges as we are not able to estimate the percentage of lead in dust deriving from petrol. If, in the absence of evidence, an arbitrary assumption is made that overall 50 per cent of dust lead is from petrol, then for the inner city children about 43 μg (41 per cent) of the daily lead uptake has petrol as the original source (see Table 2 of Appendix 4). It must be emphasised that these figures are derived from model balance schemes (see paragraph 1 of Appendix 4). They do not purport to be exact but are intended to illustrate the wide range of results when different groups of people are considered and the approximate magnitudes of the various pathways under these different circumstances.

4.32. From the estimates given in Table 4.1 of total daily lead uptake and from the mid-values of the relationship between lead uptake and blood lead concentration shown in Figure 4.2 we have estimated the approximate blood lead concentrations which would be predicted for the different cases. These predictions are generally lower than the concentrations found in population surveys (paragraphs 4.34–4.42) but, where particular cases in Table 4.1 can be compared with survey data, by a fairly constant factor. To the extent that the predictions are of the same order as the actual concentrations in the population they provide a measure of confirmation of the general validity of this approach.

4.33. In Table 4.4 we compare our balance scheme for inner city adults (Column F in Table 4.1) with balance schemes for urban adults published by other authors. These published schemes often make different assumptions and they do not all relate to the UK; they indicate greater uptakes of lead than are assumed in our calculations, but this is mainly because of our use of a lower

TABLE 4.4

Comparison of balance schemes for lead uptake of urban adults

<i>Source/Author(s)</i>	<i>Table 4.1 Column F</i>	<i>Bryce-Smith</i>	<i>Chamberlain et al.</i>	<i>Moore & Goldberg</i>	<i>Harrison & Laxen</i>	<i>Isotopic Lead Experiment, Turin</i>
Total lead uptake from lungs ($\mu\text{g/day}$)	6.3	12.6	7.5	7.5	9.0	15.0
Total lead uptake from gut ($\mu\text{g/day}$)	11	15.4	41.0	30.8	22.5	45.0
Total lead uptake from lungs and gut ($\mu\text{g/day}$)	18	28.0	48.5	38.3	31.5	60.0
Blood lead concentration as measured or predicted by authors ($\mu\text{g/dl}$)	11	—	22.0	22.0	13.6	22.5
Reference		(109)	(28)	(126)	(108)	(37)

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estimate of UK dietary lead intake (see paragraph 4.23). They show a higher blood lead concentration than do our predictions.

European Community surveys of blood lead concentration

4.34. There are no data on the blood concentration of lead in the UK from which it is possible to generalise about the population as a whole. We do, however, have some knowledge of the distribution of blood lead concentration among selected groups of the urban adult population and among children who may have been exposed to an above-average concentration of lead. This comes from two programmes of surveys recently carried out in accordance with European Community Directive 77/312/EEC⁽¹²⁷⁾. Under this Directive, Member States were required to undertake two screening surveys (known as 'campaigns') for lead, co-ordinated across the Community and separated by an interval of at least two years. For each million inhabitants at least 50 had to be included and three particular categories were specified: groups of at least 100 persons in major urban areas with a population above half a million; groups of at least 100 persons exposed to significant sources of lead pollution; and critical groups at special risk. People with occupational exposure were not to be included. The Directive defined 'reference levels' which, if exceeded, had to be reported and had to trigger action to identify and reduce the exposure. These 'reference levels' were that no more than 2 per cent of any group should have a blood lead concentration greater than 35 $\mu\text{g}/\text{dl}$; no more than 10 per cent greater than 30 $\mu\text{g}/\text{dl}$; and no more than 50 per cent above 20 $\mu\text{g}/\text{dl}$. Follow-up investigations were also expected for any individual with a blood lead concentration greater than 35 $\mu\text{g}/\text{dl}$.

4.35. The first survey was carried out in the UK between spring 1979 and spring 1980, and the second survey in spring and summer 1981. Detailed results of the two surveys* have been published by the Department of the Environment^(128, 129). The data have been analysed for the effects of a number of environmental and social factors⁽⁴³⁾. The first survey showed that the average adult blood lead concentration was higher in people residing in inner than in outer city areas, and lower in London than in northern cities (Table 4.5). Overall, the average inner city value was 12.8 $\mu\text{g}/\text{dl}$ and the outer city value 11.0 $\mu\text{g}/\text{dl}$. The distribution of blood lead concentration of adults in UK cities is shown in Table 4.6 and Figure 4.3: overall 3.1 per cent of the inner city population and 1.9 per cent of the outer city population were estimated to have a blood lead concentration greater than 25 $\mu\text{g}/\text{dl}$ ⁽¹²⁸⁾. The blood lead concentration was higher in men than in women, and higher in heavy smokers and in those living in pre-1940 housing⁽¹²⁸⁾. As the surveys concentrated on groups of people in urban areas, or otherwise exposed to particular sources of lead pollution, no measurements were made in rural areas other than near major emitting premises.

4.36. It is difficult to compare the results of the two surveys in the UK so far as adults are concerned. Where a particular local authority participated in both surveys, different localities were chosen and, in the case of the second survey, had particular sources of lead such as traffic on major roads or old housing. For

*Only preliminary results of the second survey were available in time for consideration by us.

TABLE 4.5

Blood lead concentration of adults in major UK cities from first European Community survey, 1979

	Inner city $\mu\text{g/dl}$	Outer city $\mu\text{g/dl}$	Difference $\mu\text{g/dl}$
Birmingham	13.6	11.1	2.5
Greater London	12.0	10.2	1.8
Leeds	15.6	13.3	2.3
Liverpool	14.2	13.8	0.4
Manchester	17.0	16.6	0.4
Sheffield	14.6	13.2	1.4
All cities	12.8	11.0	1.8

Figures are geometric means.

Source: Reference (128)

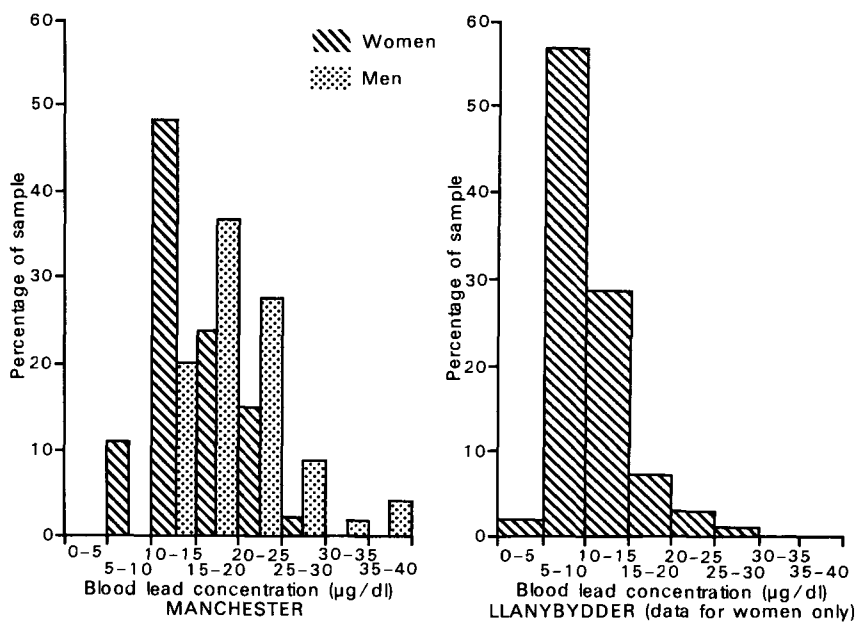


Figure 4.3

Frequency distribution of blood lead concentration in adults living in an inner city area (Manchester) and a small town (Llanybydder)

Sources: References (128, 130)

TABLE 4.6

Estimated distribution of blood lead concentration in adults in major UK cities in 1979

	Percentage of population with blood lead concentration ($\mu\text{g/dl}$) in range:							Percentage of population exceeding 25 $\mu\text{g/dl}$
	<5	5–10	10–15	15–20	20–25	25–30	>30	
Inner cities	0.5	30.7	38.4	21.1	6.2	1.6	1.5	3.1
Outer cities	2.4	42.2	37.9	11.7	3.9	1.5	0.4	1.9

Source: Reference (128)

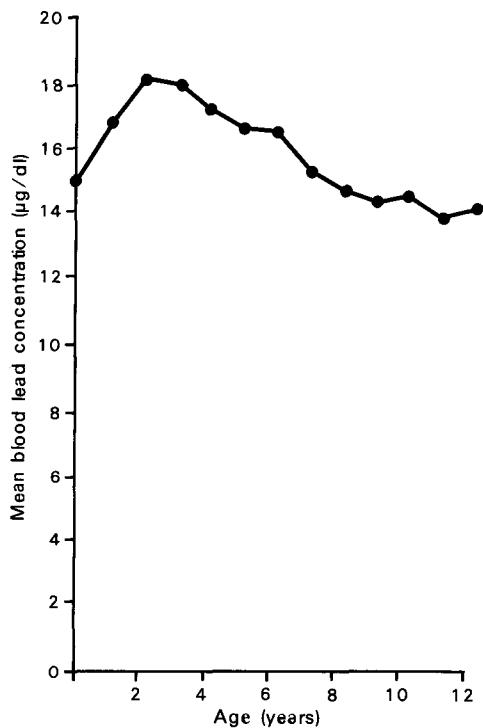


Figure 4.4
Blood lead concentration by age of UK children in the European Community blood lead survey, 1979

Source: Department of the Environment

the localities involving major roads, the blood lead concentrations in the second survey were generally equal to or lower than those in the first survey⁽⁴³⁾.

4.37. All the children included in the two surveys were selected as being exposed to particular sources of lead and it is not therefore possible to draw conclusions about the overall blood lead concentration in children in the UK. Nevertheless, the data for 1979 illustrate the general relationship between blood lead concentration and age (Figure 4.4): the blood lead concentration reaches a peak around the age of 2 or 3 years and subsequently declines. Some children were sampled in both surveys and an overall reduction of about 15 per cent was recorded in the second survey. Part of this reduction may have been due to increased awareness of the dangers of lead, action to reduce factory emissions and declining economic activity⁽⁴³⁾.

4.38. Most of the groups in the UK in the two surveys were below all three reference levels, generally by a wide margin. Some breaches of the reference levels were however found. In the first survey these were in Chester and Leeds (both in the vicinity of lead works) and in Glasgow (with a plumbosolvent water supply). Following remedial action there were no breaches of the reference levels in these three cities in the second survey. In the second survey the results from Ayr (with a plumbosolvent water supply) breached all three reference levels, while the upper (35 $\mu\text{g}/\text{dl}$) reference limit was breached by adults in Islington, London, and by children of leadworkers in Gravesend (Gravesham), Kent.

4.39. The results of the first European Community survey for the UK are compared with those from other Member States in Figure 4.5, which summarises the average blood lead concentration of different categories of adults and children in each Member State. Not all Member States, however, included each category in the survey. The UK, for example, included children only in the 'exposed' categories. Although the samples from different Member States are only strictly comparable where they were random, it appears nonetheless from these surveys that the blood lead concentrations in the UK lie towards the centre of the range for the European Community.

Other data for blood lead concentration in the British Isles

4.40. Data for the general population for the UK, and particularly for rural populations, are scarce. Since 1972 a number of surveys have been undertaken in Wales, based on samples of adult women in different areas. The results (Figure 4.6) show a current mean blood lead concentration of about 11 $\mu\text{g}/\text{dl}$ and a trend of decreasing values over the decade⁽¹³¹⁾. Values for adult women are also available from Dundee where the mean of mothers *post partum* (71 per cent of all births in Dundee from September 1980 to August 1981) was 6.4 $\mu\text{g}/\text{dl}$ ⁽¹³²⁾. A recent study of two villages in Somerset⁽¹³³⁾ showed mean adult blood lead concentrations of 10.2 $\mu\text{g}/\text{dl}$ and 10.7 $\mu\text{g}/\text{dl}$ respectively; the first village was Shipham, with a mean soil lead concentration of about 3,800 $\mu\text{g}/\text{dl}$ ⁽⁵⁷⁾ caused by contamination from past mining, and the second

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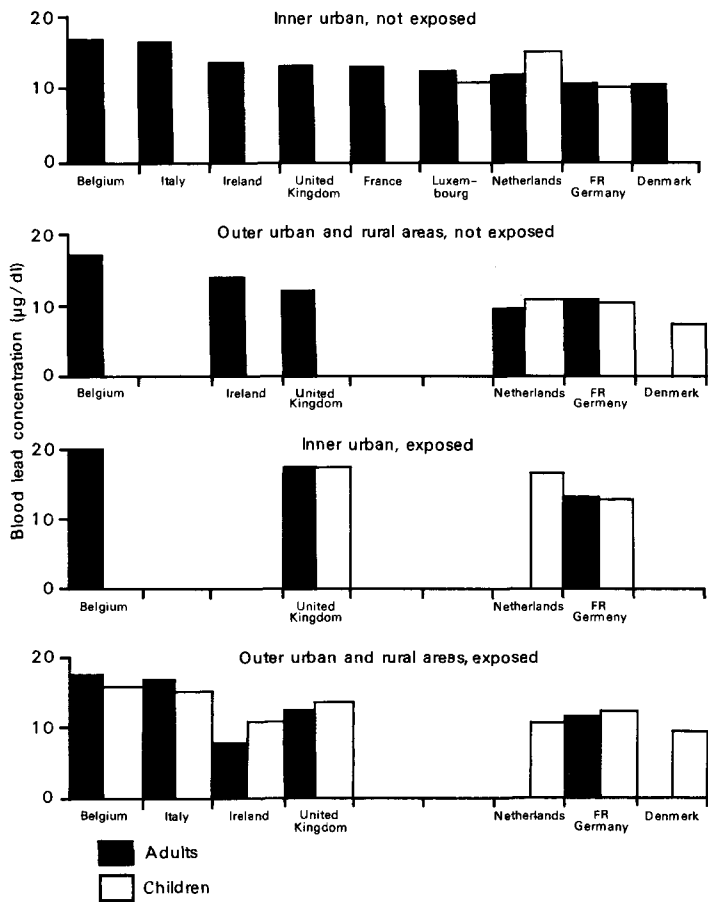


Figure 4.5
European Community blood lead survey, 1979: median blood level concentration in adults and children

Exposed/not exposed refers to the presence or absence of local industrial emissions of lead.
Sources: Department of the Environment; Commission of the European Communities

village, North Petherton, had a normal soil lead concentration (see paragraph 2.16). The mean blood lead concentration of the population of a small island, lying seven miles off the north west coast of Ireland and using no petrol, was found to be 8.9 µg/dl for adult men and 7.0 µg/dl for adult women⁽¹³⁰⁾, showing that populations remote from sources of air lead can have an appreciable blood lead concentration.

4.41. There are also data from several recent studies on the blood lead concentration in population samples of children. Between September 1980 and August 1981 data were obtained for 71 per cent of all newly born infants in Dundee⁽¹³²⁾; the mean blood concentration was 4.4 µg/dl. Young children

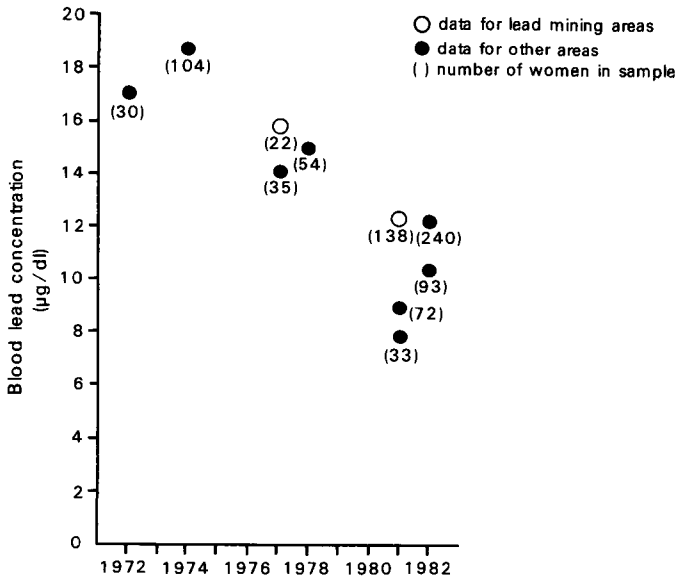


Figure 4.6
Blood lead concentration of groups of Welsh women, 1972–1982

Source: Reference (¹³¹)

(1–3 years) in an old lead mining area of Wales(¹³⁰) had a mean blood lead concentration of 23 $\mu\text{g/dl}$ compared with 18 $\mu\text{g/dl}$ in a control village. It is interesting to compare the Welsh data with those from Shiphams in Somerset(¹³³), where the mean blood lead concentration of children was 9.5 $\mu\text{g/dl}$, and from the Somerset control village, where the figure was 9.4 $\mu\text{g/dl}$. Children (up to 8 years) attending schools in County Wicklow(¹³⁴) had a mean blood lead concentration of 7.1 $\mu\text{g/dl}$; the comparable value for children attending schools in Dublin was 16 $\mu\text{g/dl}$. Another recent report(¹³⁵) has presented data on the blood lead concentration in pre-school children in Birmingham. The mean value for children from day centres and nursery schools was 20 $\mu\text{g/dl}$, and values in excess of 35 $\mu\text{g/dl}$ were found almost exclusively in children of Asian parents.

4.42. From the limited data available we do not find a clear and consistent picture of blood lead concentration in the UK. Values in inner city areas appear on the whole to be slightly higher than those in suburban areas and differences have similarly been found between urban and rural areas. However, there are regional differences within the UK which cannot be explained by population density or industrial activity alone, and lower values than expected have been found in some large towns.

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Other data for blood lead concentration overseas

4.43. There have been many studies in different countries which have measured the blood lead concentration likely to be typical of the whole population. Few studies have been on an international scale and the accuracy and comparability of the data are often questionable. The World Health Organisation has undertaken an international survey of blood lead and cadmium concentrations in urban teachers, using strict quality controls⁽¹³⁶⁾. Although the UK was not included in this survey, one European Community Member State, Belgium, did take part. The survey showed considerable variation between countries with the average blood lead concentration ranging from about 6 $\mu\text{g}/\text{dl}$ in Peking and Tokyo to between 10 and 20 $\mu\text{g}/\text{dl}$ in Brussels and Indian cities (Table 4.7). One of the lowest reported population blood lead concentrations is from Nepal, where an average value of 3.4 $\mu\text{g}/\text{dl}$ was found for a sample of adults and children⁽¹³⁷⁾.

4.44. There are also data available on the distribution of blood lead concentration in the population of the USA⁽¹³⁸⁾. As part of the second National Health and Nutrition Examination Survey (NHANES II), statistics have been gathered on the distribution of the blood lead concentration of people aged between 6 months and 74 years and analysed according to age, race, sex, family income and location. The mean blood lead concentration of the total sample (almost 10,000) was 13.9 $\mu\text{g}/\text{dl}$, with 1.9 per cent greater than 30 $\mu\text{g}/\text{dl}$. The mean blood lead concentration of young children increased with the degree of urbanisation of the area in which they lived⁽¹³⁹⁾. The survey was carried out between 1976 and 1980, and preliminary analysis of the data indicates that during this period there appears to have been overall a 37 per cent decrease in the mean blood lead concentration from 15.8 $\mu\text{g}/\text{dl}$ to 10.0 $\mu\text{g}/\text{dl}$. However, the survey was not designed to examine a trend during this period and this decrease must be treated with caution.

TABLE 4.7

Blood lead concentration of urban teachers in an international survey with strict quality control

Country—Town		Sample size	Median blood lead concentration ($\mu\text{g}/\text{dl}$)	90 percentile lead concentration ($\mu\text{g}/\text{dl}$)
Belgium	—Brussels	143	15.2	21.3
China	—Peking	240	6.4	10.2
India	—Ahmedabad	200	13.1	26.0
	—Bangalore	73	18.3	31.1
	—Calcutta	100	10.1	16.4
Israel	—Jerusalem	201	8.6	12.7
Japan	—Tokyo	200	6.0	8.9
Mexico	—Mexico City	85	22.0	34.6
Peru	—Lima	206	9.5	13.5
USA	—Baltimore	180	7.5	12.5
Yugoslavia	—Zagreb	192	9.0	16.9

Source: Reference ⁽¹³⁶⁾

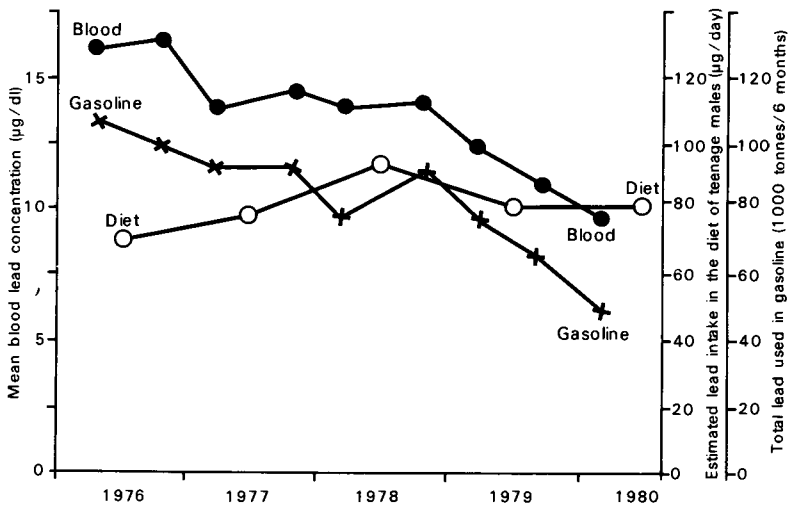


Figure 4.7
Trends in blood lead, gasoline lead and dietary lead in the USA, 1976–1980

Sources: References (39, 140)

4.45. This decrease, together with trends in the use of lead in gasoline and dietary lead (expressed as the estimated dietary lead intake of teenage males), is shown in Figure 4.7. Over the period 1976–80 dietary lead has shown a slight increase, making it unlikely to have been responsible for the reduction in blood lead concentration. If a decrease in exposure to lead in paint was a major factor it would be expected that the blood lead concentration of young children (who ingest more dust, including paint dust) would be reduced to a greater extent than those of other ages. This did not happen. It has been suggested that the most plausible interpretation of the data is that the reduction in gasoline lead was the primary cause of the fall in blood lead concentration⁽¹⁴¹⁾. Some support for this interpretation comes from a recent demonstration of a close correlation between the lead content of all gasoline sold in Massachusetts between April 1979 and April 1981 and the concentration of lead in umbilical cord blood from births at a Boston hospital⁽¹⁴²⁾.

The Isotopic Lead Experiment

4.46. Some further information on the contribution of petrol lead to the body burden has come from the preliminary results of the Isotopic Lead Experiment (ILE)⁽³⁷⁾. In the area around Turin, in the northern Italian region of Piedmont, the lead added to all petrol distributed between 1975 and 1980 had an isotopic ratio distinct from that used beforehand and afterwards (see box on following page). During the period of the experiment measurements of the concentration and isotopic ratio of lead in human tissues and the environment enabled estimates to be made of the pathways taken by petrol lead in the

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environment and of the contribution of petrol lead to the body burden. Unfortunately, because of limitations in the experimental design and sampling programmes, the results have to be treated with caution and great care must be taken in extrapolating the findings to the situation in the UK.

THE ISOTOPIC LEAD EXPERIMENT

Natural lead in rocks is composed of four different stable isotopic forms: ^{204}Pb , ^{206}Pb , ^{207}Pb and ^{208}Pb . Three of these are the final products of the radioactive decay of isotopes of uranium and thorium. The proportions of the four isotopes vary between different deposits of lead-containing ores, depending upon the age of the deposits and the relative abundance of the uranium and thorium parents. The ratio of the isotopes ^{206}Pb : ^{207}Pb ranges from 0.89 in parts of South Africa to 2.11 in parts of Outer Mongolia⁽³⁷⁾. In the area around Turin, before the start of the Isotopic Lead Experiment, lead in petrol, soil, vegetation and blood had a ratio ^{206}Pb : ^{207}Pb in the range 1.16–1.20. From 1975–1979 the lead in petrol was from the Broken Hill mine in Australia and had a ratio ^{206}Pb : ^{207}Pb of 1.04. After a period of transition the isotopic ratio in retail petrol fell to around 1.06 between 1977 and 1979. The use of Australian lead was phased out from the beginning of 1980, and the isotopic ratio has since been moving towards its original value. During the period of the experiment measurement of the ratio ^{206}Pb : ^{207}Pb of lead in man and the environment, in the area around Turin, provided direct evidence of the amount of lead derived from petrol.

4.47. During the experiment the average lead concentration in petrol was about 0.6 g/l; the present UK figure is about 0.38 g/l. A calculated value of the average air lead concentration experienced by residents of Turin was about $2\text{ }\mu\text{g}/\text{m}^3$ compared with $0.56\text{ }\mu\text{g}/\text{m}^3$ in a radius of 25 km from Turin and $0.33\text{ }\mu\text{g}/\text{m}^3$ in the countryside further away. The average adult male blood lead concentration of the samples was $22.5\text{ }\mu\text{g}/\text{dl}$ in Turin and $26.9\text{ }\mu\text{g}/\text{dl}$ and $29.6\text{ }\mu\text{g}/\text{dl}$ respectively in the two countryside zones. The higher blood lead concentration values for the rural populations were unexpected and difficult to explain; it is possible that they were due to dietary factors. A Turin adult had an estimated daily lead uptake of about $60\text{ }\mu\text{g}$; the relationship of this uptake to the average blood lead concentration ($22.5\text{ }\mu\text{g}/\text{dl}$) is consistent with Figure 4.2.

4.48. Calculations based on measurements of the isotopic ratios of lead have been used to estimate the percentage of lead uptake derived from petrol of the low isotopic ratio. For the adults sampled in Turin the estimate is 24 per cent, and in the two countryside zones 12 per cent and 11 per cent respectively. However, as the samples were not random it is not possible to generalise for the whole populations. The final results of the ILE, when they are available, should provide information on the contribution of petrol lead to the lead content of vegetation and of urban dust.

Conclusions

4.49. The body burden of lead is derived from many sources, via several pathways, and there are major gaps in our knowledge, such as the sources of lead in dust and its significance for children's lead intake and uptake and the relative contributions to lead in food. Therefore we do not place great confidence in the details of particular calculations or consider these to represent the 'average for the population'. Certainly as further information becomes available the details summarised in Table 4.1 will need to be modified, but the general consistency of the various results is such that we consider it unlikely that these modifications will invalidate our general conclusions.

4.50. The relative importance of different sources and pathways of lead may differ markedly between groups of people. For example, where there is a very high lead concentration in tap water, lead in water forms the largest element of total lead uptake. In certain areas of very high air lead concentration, air lead forms the largest uptake element. It is clear that social factors can have a marked effect on the amount of lead uptake. For example, it seems that a variety of factors (such as home and personal cleanliness, the age and condition of paintwork in the home, playing in the street and eating with fingers) are often associated in socially disadvantaged children, thereby increasing their intake of lead from dust. Heavy smoking and drinking may increase the uptake of lead by about 50 per cent.

4.51. The contribution that petrol makes to the uptake of lead has been a matter of particular concern. While the results of our calculations (Table 4.1) have considerable margins of error, we believe that most *adults* derive up to 20 per cent of blood lead from petrol, but the figure may be considerably higher for particular groups of people. Recent data from the USA (the NHANES II survey) and from Italy (the ILE) tend to reinforce our view, although differences in habits and in the concentration of lead in the environment make the extrapolation of results from one location to another uncertain.

4.52. It is extremely difficult to draw equivalent conclusions for *children*. The situations for infants and children of various ages are likely to be different. We believe that dust may be the most important pathway of lead to many young children and we would like to see more research directed at establishing the lead concentration in such dust and the sources of that lead (see paragraph 6.38). It is most likely, though not yet confirmed by experiment, that petrol, paint and in certain circumstances industrial emissions are major sources of lead in dust, although we expect that there are significant differences between urban and rural areas and between outdoors and indoors.

4.53. It follows from these conclusions that predictions can be made about the effects on lead uptake and body burden of various measures to reduce exposure to lead. For those parts of the UK with a very high tap water lead concentration, reduction of this concentration to the median UK value could result in a halving of the lead uptake of adults. A decrease in the lead content of canned food from solder could reduce the lead uptake of both adults and children by up to one tenth. It is reasonable to assume that individuals could

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appreciably reduce their blood lead concentration by reducing their smoking and consumption of alcohol. A reduction in the lead content of dust, from whatever sources, would probably make the greatest overall contribution to reducing the lead uptake of young children.

4.54. Reducing the lead content of petrol would reduce the lead uptake of the whole population but there are inadequate data to calculate, with much confidence, by how much. We can make some estimates for particular groups of the population but would caution against attaching too much reliance on the details. If, for example, petrol lead is found to make a larger contribution to lead in food than that currently assumed (see paragraph 4.25), these will be underestimates. Present government policy is that the maximum lead content of petrol will fall to 0.15 g/l by the end of 1985. We would expect this to result in a reduction of the average urban daily adult lead uptake by around 3–4 μg and by greater amounts for some people. If unleaded petrol were introduced for all vehicles then the equivalent expected reduction would be about 5–6 μg ranging to over 12 μg for some. In an extreme case, the blood lead concentration of adults living by a very busy urban road may be predicted to fall from around 14 $\mu\text{g}/\text{dl}$ to about half this value. It should be noted, however, that all lead, including lead from petrol, is persistent (Table 1.1) and therefore cumulative and likely to remain in man's environment, though not normally airborne, for many years after the source has disappeared.

4.55. It is important that measures designed to reduce further the release of lead to the environment (see Chapters VI and VII) are accompanied by a well designed programme to monitor the body burden of man. We understand that the Government is planning such a programme and we **recommend** that it is undertaken in consultation with the Medical Research Council and started as soon as possible so that adequate baseline data are obtained.

CHAPTER V

EFFECTS OF LEAD ON MAN AND ANIMALS

Introduction

5.1. Lead in substantial amounts is toxic to most if not all forms of life. It is possible that minute concentrations, as of some other metals, are necessary for life but the evidence for this is unconvincing and it is doubtful whether lead performs any essential biological function in man or in other animals.

5.2. The clinical manifestations of lead poisoning have been well known for centuries. However, the effects of exposure to lead at lower concentrations are still disputed, particularly in children, and have been considered in a number of recent reviews^(13,17-21). We do not attempt here to cover all this ground again by reviewing in detail this wide field, but aim to outline developments since publication of the Report of the Lawther Working Party⁽¹³⁾ and to identify what we consider to be the key areas.

5.3. There is considerable variation in the body burden of lead at which particular effects are manifested. It is therefore not possible to give a simple indication of the effects that lead has at any particular blood lead concentration or other measure of the body burden of lead.

Frank* poisoning

5.4. The clinical manifestations of frank lead poisoning in human adults include anaemia, alimentary symptoms such as constipation and colic, wrist and foot drop, renal damage and occasionally encephalopathy. In children symptoms include irritability, loss of appetite, occasional vomiting, intermittent abdominal pain and constipation. If the poisoning is unchecked vomiting becomes more persistent, muscle co-ordination is affected and there may be impairment of consciousness leading to coma. Cases of acute poisoning in children can usually be traced to particular sources such as old paint or certain privately imported cosmetics, mainly from the orient.

5.5. Clinical signs of lead poisoning, generally similar to those in man, have been described in animals, particularly in birds and in farm and domestic stock. In the particular case of birds poisoned by organic lead compounds (see paragraphs 3.18-3.21), many of the abnormalities described, such as tremor and lack of co-ordination, resemble those of poisoning by organic lead in man.

*The words *frank*, *acute*, *classic* and *clinical* have often been variously used in the literature to describe lead poisoning with definite signs and symptoms in the individual. Strictly speaking *frank* means unmistakable, *clinical* recognisable by a medically trained person and *classic* as described in a textbook. *Chronic* poisoning is the result of sustained exposure while *acute* poisoning arises suddenly and may be superimposed on a chronic condition.

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5.6. It would be misleading to state a blood lead concentration below which the features of frank lead poisoning are not usually found, or above which such symptoms are normally present in man. For both adults and children there appears to be considerable variation. In industrial practice screening occasionally reveals men with a blood lead concentration in excess of $150\text{ }\mu\text{g/dl}$ and with no obvious clinical symptoms. However, symptoms are occasionally encountered with a blood lead concentration of $60\text{ }\mu\text{g/dl}$ and even perhaps below $50\text{ }\mu\text{g/dl}$ ⁽¹⁴³⁾.

Effects at low blood concentration

5.7. The Lawther Working Party⁽¹³⁾ concluded, from its interpretation of the available evidence, that there was uncertainty about the effects of lead at low blood lead concentrations even in the range $35\text{--}80\text{ }\mu\text{g/dl}$. Opinion would now generally consider such concentrations as high enough to cause concern, as illustrated by the European Community's reference levels (see paragraph 4.34) and the recent advice by the Government that where a person, particularly a child, has a blood lead concentration greater than $25\text{ }\mu\text{g/dl}$ as a result of environmental exposure steps should be taken to reduce exposure⁽¹⁵⁾. An approved code of practice for the control of lead in work places⁽¹⁴⁴⁾, introduced in 1980, states that a worker should be suspended from work with lead if his blood lead exceeds $80\text{ }\mu\text{g/dl}$, whereas this course of action was previously recommended at a blood lead concentration of $100\text{ }\mu\text{g/dl}$. The code of practice provides that women of reproductive age should be suspended from work exposing them to lead when their blood lead exceeds $40\text{ }\mu\text{g/dl}$; this is in order to safeguard any developing foetus. In Sweden a value of $70\text{ }\mu\text{g/dl}$ is unacceptable and a value of $50\text{--}70\text{ }\mu\text{g/dl}$ is acceptable only with precautions⁽¹⁴⁵⁾. In the USA⁽¹⁴⁶⁾ a worker is suspended from his work if his blood lead exceeds $50\text{ }\mu\text{g/dl}$. A World Health Organisation Study Group⁽¹⁴⁷⁾ has recommended an exposure limit of $40\text{ }\mu\text{g/dl}$ for men and for women over the reproductive age, and of $30\text{ }\mu\text{g/dl}$ for women in the reproductive age.

5.8. There has been a considerable debate concerning the occurrence of effects associated with a blood lead concentration lower than about $35\text{ }\mu\text{g/dl}$ and whether there is a threshold level below which damage does not occur. There is particular concern about the possible effects of small quantities of lead on the behaviour and intelligence of children. The information relevant to these issues comes largely from population surveys of children and from research on animal behaviour and cellular processes.

Population surveys of children

5.9. The Lawther Working Party⁽¹³⁾ was unable to come to definite conclusions about the effects that small amounts of lead may have on the intelligence, behaviour and performance of children in the general population. This was because of the paucity of studies, reservations about experimental design and execution, and the consequent lack of reliable evidence. The results of several new studies, which have a direct bearing on this subject, have subsequently been published⁽¹⁴⁸⁻¹⁵¹⁾ and the field has been reviewed by Rutter⁽¹⁵²⁾. As we explained in Chapter I, we did not feel it would be profitable to go over this ground again in detail, but we felt it important to consider these new findings.

We are aware that the US Environmental Protection Agency⁽²²⁾ has recently taken the view that the likelihood of a causal relationship between low concentrations of lead and neuropsychological effects in children may justify giving renewed impetus to the phasedown of lead in gasoline.

5.10. The relationship between children's behaviour and performance and their body burden of lead has been investigated through the use of population surveys. Even when precautions have been taken to avoid experimental bias, and the measurement both of the body burden of lead and of the indices of behaviour and performance are as accurate as possible, there remain difficulties in interpreting the meaning of an association of higher lead concentration with intellectual impairment and behavioural disturbances. This is because of so-called confounding factors: these are other factors which are causes of the condition (for example, lowered IQ) but which are associated with the other measured variable (i.e. the body burden of lead). To illustrate the nature of confounding factors it may be helpful to give another example. Although there appears to be an association between lung cancer and taking alcoholic drinks this does not prove that alcoholic drinks cause lung cancer⁽¹⁵³⁾. Heavy alcohol drinking is often associated with heavy smoking but it is the smoking which causes the lung cancer. In this case smoking is a confounding factor associated with one variable (taking alcoholic drinks) and the cause of the other (lung cancer). The situation is often complicated by the number of associated factors that may contribute to a condition.

5.11. One of the first large surveys relating psychometric indices to lead concentration used tooth lead and was made in the United States⁽¹⁵⁴⁾. More recent studies, also using tooth lead, have been carried out in the Federal Republic of Germany⁽¹⁴⁹⁾ and in England⁽¹⁵⁰⁾ and both have shown a link between lead concentration and measures of intelligence, the higher lead groups performing worse. However these measures of intelligence are known to be determined by various social factors (i.e. confounding factors) which are also linked with the lead concentration. Such social factors, many of them linked to one another, include parental IQ, housing condition (such as the nature of paintwork) and home cleanliness. In the two studies^(149, 150), after careful attempts had been made to allow for known confounding factors, the IQ differences between the groups of children with lower and higher tooth lead concentrations were small and fell short of conventional statistical significance as assessed by the tests applied. Most of the other recent studies measured blood lead concentration and, taken together, do not present a straightforward picture of associations between the body burden of lead and psychometric indices⁽¹⁴⁸⁾. Many studies have indicated that socially disadvantaged children tend to have a greater body burden of lead and a recent UK study has suggested that neuropsychological effects of lead may be greater in, or largely confined to, such children⁽¹⁵⁵⁾.

5.12. In our view the accumulated evidence may indicate a causal association between the body burden of lead and psychometric indices, or the effects of confounding factors, or both. On present evidence we do not consider it possible to distinguish between these possibilities. We consider it unlikely that

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population surveys alone will settle the issue in the near future, particularly as the effect of lead on behaviour and intelligence, as suggested by the studies mentioned above, is at the most small at the concentrations found in the general population.

5.13. Studies have also been made of the relationship between blood lead concentration in children and electrophysiological measurements in the brain⁽¹⁵¹⁾ and have shown effects at blood lead concentrations usually encountered. The techniques used are not yet well established, little information is available on normal children and the authors of the work themselves admit to uncertainties in the interpretation of their data, which they regard as provisional. The functional significance of the measurements made are unknown, other than that they reflect some aspect of brain activity. Thus, while work in this field is interesting, we do not consider that the results represent reliable evidence of effects of small amounts of lead on the brain function of children.

Research on animal behaviour

5.14. Practical and ethical problems severely restrict the administration of lead to humans for experimental purposes and rule it out entirely in the case of children. Hence there are formidable difficulties in the way of any direct attempt to resolve the uncertainties surrounding the effects of small amounts of lead on man. Experiments on the effects of lead on the behaviour of animals have the advantage that it is possible to eliminate the influence of confounding factors as animals can be genetically identical and live in a controlled environment. Such experiments, however, have proved to be far from straightforward. Of particular importance is that in few studies have precautions been taken to prevent observer bias. It is well established that if the observer is aware which animals have been treated and which are the untreated controls this can affect the conduct and outcome of the measurements. Both the types of behavioural test employed and the time of administration of lead have varied greatly between experiments. Until recently most of the experiments involved blood lead concentrations that in man would be expected to produce frank poisoning. Body burdens of lead were not monitored throughout the experiment and in many cases were not measured at all. Most of the studies used rodents; very few used primates, from which behavioural results can be extrapolated to man with more confidence. In the light of these problems it is hardly surprising that the large and growing literature includes many contradictory results.

5.15. We note that several of the better-performed studies (with rats and sheep) have demonstrated apparent behavioural effects of lead at blood lead concentrations of about 50–60 $\mu\text{g}/\text{dl}$ and lower, using measures of activity, learning, memory and the timing and patterning of responses⁽¹⁵⁶⁾. We have to conclude that this field of experimentation has so far proved disappointing and we agree with the US National Academy of Sciences⁽¹⁸⁾, which found the results of such studies to be only of limited help in assessing the hazards posed to man by small amounts of lead in the body.

Cellular processes

5.16. A number of fundamental processes in the cells of animals (including man) are known to be affected by lead. The body is often able to withstand minor biochemical perturbations and it does not necessarily follow that these effects are harmful to health; but they may be, and they are also important in providing information on the ways in which lead exerts its effects and on issues such as whether there is a threshold concentration below which lead has no effect.

5.17. Most is known about the effects of lead on the biochemical pathways leading to the formation of blood. Lead inhibits several stages of the synthesis of haem (a precursor of haemoglobin, which is the oxygen-carrier in red blood cells). It is likely that lead acts by blocking particular chemical sites (thiol groups) on the enzymes. One particular enzyme (ALA dehydratase) appears to be especially sensitive and its activity in blood falls when the blood lead concentration rises to around 20–40 $\mu\text{g/dl}$. Animal studies have shown a commensurate fall in the activity of this enzyme in both blood and brain, but the significance to man of these findings is not clear.

5.18. Recent research has suggested that lead may interfere in the production of neurotransmitters, chemicals which are necessary for the proper functioning of the nervous system⁽¹⁵⁷⁾. Lead irreversibly inhibits the activity of the enzyme dihydropteridine reductase, which is essential for the formation of several neurotransmitters, and so causes the accumulation of plasma biopterins (Figure 5.1). Plasma biopterins in man have been shown to increase significantly with increasing blood lead concentration, although it is not known whether this occurs with a blood lead concentration below 15 $\mu\text{g/dl}$. Somewhat similar findings occur in the rare, inherited disease phenylketonuria, in which the nervous system is damaged and the IQ scores are reduced. Although the results with lead and phenylketonuria cannot be related directly to one another, a reduction in neurotransmitters could provide a biochemical mechanism for the effects of lead on the nervous system and hence on behaviour. It is unfortunate that there are few data on the concentration of lead in central nervous system tissue.

5.19. It has been known for some time that lead can destabilise the structure of nucleic acids, which form the genetic material of living organisms. In particular, lead salts in dilute solution are extremely efficient at cleaving molecules of ribonucleic acid (RNA)^(158, 159). Although many metal salts can cleave RNA, lead is unusual in doing this at the conditions of pH and temperature found in living cells. The concentration of lead which can effect this *in vitro* is as low as about 20 $\mu\text{g/dl}$ for messenger RNA (m-RNA)⁽¹⁵⁸⁾, and about 100 $\mu\text{g/dl}$ for transfer RNA (t-RNA)⁽¹⁵⁹⁾. Recent research⁽¹⁶⁰⁾ on the mechanism of the action of lead on t-RNA, which plays a key role in assembling amino acids for protein synthesis, suggests that there is no reason to expect a threshold concentration of lead below which cleavage would not occur *in vitro*. Lead may also affect deoxyribonucleic acid (DNA) and hence chromosomes which carry the organism's genetic information and of which DNA is a major component.

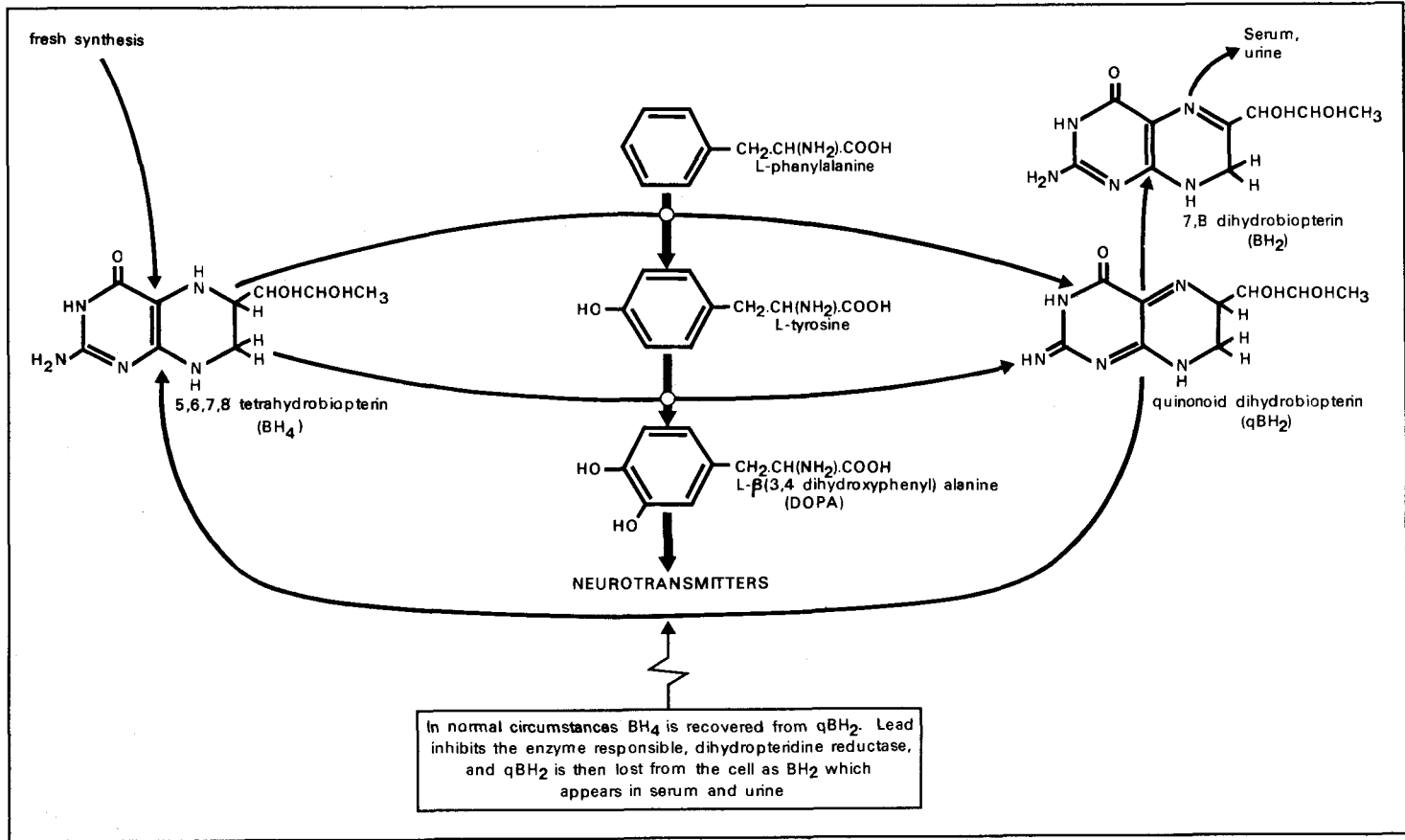


Figure 5.1
Synthesis of neurotransmitters

However, studies of people who have been occupationally exposed to lead have given conflicting results on whether there are chromosomal changes associated with lead exposure⁽¹⁶¹⁾.

Reproduction

5.20. It is well established that when pregnant women are exposed to large doses of lead as, for example, occurred in the past from employment in some industries, an increased incidence in abortion, still-birth and other ill effects to the foetus may occur⁽¹⁶²⁾. Prenatal toxicity and abortions have also been reported in a number of experiments in animals following the administration of lead and lead salts. Lead has been shown, in numerous reports, to cross the placenta and close correlations have been reported between maternal and foetal blood lead values. There have been claims that low levels of exposure may have similar effects, and also of effects on fertility in both women and men⁽¹⁶³⁾, though most of the evidence for this comes from experiments on animals and there is a lack of supporting clinical data for man. We do not consider that there is yet convincing evidence that lead, at concentrations currently found in the general population, presents a hazard to unborn children. Nevertheless we consider that it is prudent to consider pregnant women as a sector of the population particularly susceptible to the effects of lead.

Carcinogenicity

5.21. A number of studies have shown that lead acetate, lead subacetate and lead phosphate can produce cancer when fed to rats and that lead subacetate can also produce cancer in mice⁽¹⁶¹⁾. The lead salts administered have usually comprised between 0.1 and 1.5 per cent of the daily diet. The tumours produced are benign and malignant neoplasms of the kidney, and cerebral gliomas. Insufficient data are available to evaluate the carcinogenicity of metallic lead powder fed to experimental animals. Little evidence is available about the long-term risk of cancer in industrial workers exposed to metallic lead and none relating to exposure to lead salts. One large study showed a slight excess (not statistically significant) of certain categories of malignant neoplasms in smelter workers but not in battery workers. The results do not support the view that there is a strong carcinogenic effect of lead in man, but we **recommend** that further long-term studies of persons exposed to lead and lead salts in industry should be undertaken.

Thresholds and safety margins

5.22. There has been considerable discussion of whether there is a threshold concentration of lead in the body below which there are no harmful effects. We believe that here the concept of a threshold concentration is a misleading one. Experimental studies, particularly those at cellular level which shed light on possible mechanisms of the action of lead, suggest that a threshold concentration would not be expected for at least some effects. However, when the body is exposed to small amounts of lead it does not follow that any of these necessarily reach the target cells where the effect occurs. Even if a threshold concentration is postulated on theoretical grounds, there is enough evidence of variation

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between individuals of the body lead concentration at which a particular effect occurs to show that it is not possible to give a meaningful value for the threshold concentration.

5.23. The average blood lead concentration in the population is about one quarter of that at which symptoms of frank poisoning may occasionally occur. We find this disturbing. We do not know of any other toxic substance which is both so widely distributed in human and animal populations and present at concentrations greater than even one tenth of those at which frank symptoms may occur. We consider this reason enough to seek to reduce the exposure of the general population to lead; we have noted that the Government accepts that the present safety margin may be too small in some circumstances and should be increased wherever practicable⁽¹⁵⁾.

Conclusions

5.24. It is well established that lead at high doses has adverse effects on man and animals. These effects occur at body lead concentrations rarely found in the general population. There is continuing uncertainty about the effects of lead at low concentration, particularly on children. We **recommend** that research into this subject should continue. We also **recommend** that the Medical Research Council should encourage experimental studies on the effects of low concentrations of lead on the behaviour of animals, particular attention being paid to careful experimental design.

5.25. We consider that the safety margin between the blood lead concentrations in the general population and those at which adverse effects have been proven is too small, particularly in view of the great variation in the response of individuals to lead. It is our view that it would be prudent to take steps to increase the safety margin of the population as a whole. When this is viewed against the background of the universal occurrence of lead and of its accumulation in the environment, which we described in earlier chapters, we are convinced that it would be prudent to reduce further its anthropogenic dispersal and man's exposure to it and we so **recommend**. In the two following chapters we therefore consider what measures can be taken to this end.

CHAPTER VI

REDUCTION OF EXPOSURE TO LEAD FROM WATER, FOOD AND LOCALISED SOURCES

Introduction

6.1. We concluded Chapter V by recommending that it would be prudent to seek to reduce the burden of lead in the environment and in man. In this chapter and the next we consider what is already being done to reduce exposure to lead, what more could be done, and what we believe should be done, taking into account our earlier discussion of the relative significance of different sources and pathways. In doing so we take account also of the recommendations of the Lawther Working Party for reducing exposure to lead⁽¹³⁾, and consider the adequacy of the measures announced and advice given by the Government in its response⁽¹⁴⁾ to the Working Party's Report and, subsequently, in documents such as the Circular issued jointly by the Department of the Environment and the Welsh Office in September 1982 to local authorities in England and Wales⁽¹⁵⁾. A parallel Circular for Scotland is due to be issued late in March 1983⁽¹⁶⁾.

6.2. In this chapter we consider the reduction of exposure to localised lead, by which we mean exposure to lead from sources or in pathways that are still largely under the control of individuals or public authorities rather than subject to dispersal and degradation by the physical and chemical processes of the wider environment. In Chapter VII we deal with lead in petrol, which accounts for about 90 per cent of airborne lead and stands apart from other sources in that exposure to it is virtually unavoidable by the individual and reduction can be achieved only by central decision.

Lead in tap water

6.3. Raw water abstracted for treatment for public supply in the UK seldom contains lead at a concentration above 10 $\mu\text{g/l}$, which is well below the limit of 50 $\mu\text{g/l}$ prescribed in European Community Directive 75/440/EEC⁽¹⁶⁴⁾ on the quality required of surface water intended for the abstraction of drinking water. The few ground water reserves with an unusually high concentration—arising, for example, from natural lead deposits or old mine workings—are avoided as sources for public supplies. If lead is present at a higher concentration at a consumer's tap it will normally have entered the water during distribution. Contamination may be caused by material dissolved or dislodged directly from the pipe itself, by deposits which may have built up in the pipe, or by stray solder from joints in copper pipes. It has been estimated⁽¹⁵⁾ that about 45 per cent of households in Great Britain use water which has at some stage passed through lead pipes, usually in the domestic plumbing system.

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In some parts of Scotland water for drinking may also pass through lead-lined storage tanks.

6.4. Contact with lead during distribution does not, however, necessarily result in contamination of water. The physical and chemical characteristics of the water—for example acidity, hardness and temperature—determine its ability to dissolve lead. Soft, acid water generally shows the greatest plumbosolvency, though recently some hard alkaline waters have been found to be plumbosolvent, the reasons for this being not yet fully understood. The lead content of water at the tap depends on the particular combination of circumstances prevailing before and during each drawing of a sample. Given the number of variables involved—for example pipe length and condition, time for which water has been standing, and water flow rate—it is not surprising that the lead content of random samples taken at the same tap can vary considerably. Wide variations in the amount of water drunk and consumed indirectly by different people also make it difficult to estimate to what extent lead in tap water contributes to an average individual's total intake of lead, though we have estimated (see paragraph 4.26) that an adult's intake from tap water beverages and cooking water is usually about $10\text{ }\mu\text{g/day}$, and possibly 30 times this amount in an area where plumbosolvency is a problem. Moreover, the significance of any lead in drinking water needs to be assessed in relation to the other constituents of that water since, for example, the body's uptake of lead from hard water is less than that from soft water with the same lead concentration⁽¹²⁴⁾. The potential dangers from lead plumbing are, therefore, especially severe in areas with soft, plumbosolvent water. Likewise whilst the setting of a statutory maximum for the permissible concentration of lead in drinking water is the only practicable method of protecting the public, the use of a single limit to cover all circumstances will actually provide a lesser degree of protection in some areas than others.

6.5. A survey carried out in 1975–76 by the Department of the Environment and the Scottish and Welsh Offices⁽⁴⁴⁾, in collaboration with the water authorities, found that 7.8 per cent of random daytime samples of domestic tap water in England and Wales contained lead concentrations above $50\text{ }\mu\text{g/l}$, and 2.6 per cent above $100\text{ }\mu\text{g/l}$; in Scotland the figures were 34.4 per cent and 21 per cent respectively (see Table 2.5). A more recent study in Northern Ireland found figures of 3 per cent and 1 per cent respectively. Remedial action has subsequently been taken to reduce these percentages, particularly in the light of the requirements of Directive 80/778/EEC⁽¹⁶⁵⁾ on the quality of water intended for human consumption. This Directive specifies $50\text{ }\mu\text{g/l}$ as the maximum admissible lead concentration and, when the distribution system includes lead pipes, applies to a sample taken after flushing. It also specifies $100\text{ }\mu\text{g/l}$ as the concentration which, if exceeded regularly or to an appreciable extent in samples taken at any time, should trigger official action to reduce the consumer's exposure to lead. The DOE and Welsh Office Circular⁽¹⁵⁾ reports that, in practice, detailed investigations and appropriate remedial action should be triggered when more than $2\frac{1}{2}$ per cent of random daytime samples of tap water in any supply zone contain lead in excess of $100\text{ }\mu\text{g/l}$.

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6.6. The most decisive way to eliminate lead from tap water is to replace the lead pipes or tanks that are the source of the contamination. To encourage such action in appropriate cases the Government extended the home improvement and repair grant system in 1982⁽¹⁶⁶⁾ to cover the removal of lead pipes and the provision of other pipes for the supply of domestic drinking water. The normal rules on eligibility for grants have been extended to empower local authorities to accept applications for grants towards the cost of replacing lead plumbing in more modern homes (those built or converted after 2 October 1961 in England and Wales and after 15 June 1964 in Scotland) that do not otherwise qualify for grants. In Scotland, alteration and replacement of lead plumbing has also been made one of the items for which repairs grants can be given without any test of the applicant's financial means or of the rateable value of the property concerned. In England and Wales, however, it should be noted that grants for owner-occupiers are subject to the same rateable value limits (not above £400 in London or £225 elsewhere, other than in housing action areas) that apply to improvement and repair grants for other purposes, not all of which have a direct bearing on public health. The retention of this limitation means that many older, larger houses, including some that may be used for child care or as day nurseries and where long lengths of lead piping might be expected to be found, are not covered by the new grant arrangements. We regard this as a serious omission and, accordingly, we **recommend** that the Government should reconsider the criteria for grants for the replacement of lead pipes to ensure that all owners are given sufficient incentive to expedite pipe replacement in appropriate cases. In the course of this review the Government should bear in mind not only the problems of properties with high rateable values but also the need for publicity to encourage the take-up of grant, particularly in respect of tenanted property and property in multiple occupation, where the incentive for initiating action is not always clear. The need to encourage any necessary pipe replacement in other privately owned buildings, such as private residential homes for the elderly, that are not eligible for home improvement grants as such should also be considered.

6.7. It follows that the Government should also ensure that financial constraints are not allowed to hamper the pipe replacement programme. Local authorities operate the grant systems and we note that, in October 1982, the Government removed all constraints on their spending on home improvement and repair grants for the remainder of 1982/3. For 1983/4 the Government has notified each local authority in England and Wales of a figure for expenditure on grants and has said that approval for further spending will be available to any authority whose expenditure on grants exceeds its notified figure but which has no funds remaining for transfer from elsewhere in its overall allocation for capital expenditure on housing. In Scotland, increased allocations will be available if local authorities spend on grants over 80 per cent of the total allocation from which grants are funded. Grants are currently payable at rates of up to 90 per cent of approved expenditure.

6.8. In 1981 the National Water Council⁽¹⁶⁷⁾ estimated that the average cost of pipe replacement was about £600 per dwelling, of which about £400 might

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be for pipes that were the householder's responsibility. Replacement of a lead-lined tank might cost a further £150. We note that water supply authorities are generally prepared to replace any lead communication pipes for which they are responsible, when the consumer replaces lead pipes in his own plumbing system. It has been found that, after removal of lead pipes, residents' blood lead concentrations fall over about 6 months to values close to those of people living in areas with lead-free water⁽¹⁶⁸⁾.

6.9. The Government's advice to the water industry and local authorities is that, because of expense both to the householder and to public funds by way of grants, wholesale pipe replacement should be considered only if other options have been found inadequate or inappropriate for households with lead pipes and plumbosolvent supplies. Water authorities and water companies have, therefore, been urged to press ahead with their surveys, already well advanced in many areas, to identify which of their water supply zones present difficulties and, for each of these, to determine the most appropriate remedy, including pipe replacement if other remedies are not suitable. We find it surprising that, apparently, there are still some limited areas of the UK where the existence or extent of any problems associated with plumbosolvency is not yet fully defined. The harmful effects of plumbosolvent water flowing through lead pipes have been fully recognised, increasingly understood, and readily treatable for generations⁽¹⁶⁹⁾, but until recently a sense of urgency has been largely lacking. We **recommend** that the Government should now set an early and firm target date for completion of all surveys and investigations relating to plumbosolvency and of remedial work found necessary. When this is substantially completed throughout the country, a report of the findings and the remedial action taken should be published to set alongside the report of the 1975–76 survey.

6.10. Where plumbosolvency is found to be a problem and alternative, less plumbosolvent, sources are not available, the main course open to a supply authority is to treat the water entering the distribution system to reduce its ability or opportunity to dissolve lead. Since soft, acid water is generally the most plumbosolvent, addition of an alkali to raise the pH is one option. Lime and caustic soda have been used successfully for this, for example for supplies in Glasgow and the North West of England respectively, and lime dosing plants are expected to be in operation for all plumbosolvent supplies in Northern Ireland by 1984. Adjusting the pH has brought about an 80 per cent reduction in the concentration of lead in water supplied through lead pipes in Ayr⁽¹⁰³⁾. The addition of an orthophosphate salt can, at some acidity levels, also significantly reduce the uptake of lead by a plumbosolvent supply by forming a protective coating of a sparingly soluble lead phosphate on the internal surface of lead supply pipes. Such treatment may be used in addition to pH control in soft water areas, or as an alternative in hard water areas. We note, for example, that since early 1981 the Severn-Trent Water Authority, which takes its supplies from the very soft surface waters of the Elan Valley, has been experimentally dosing water from its Warley Service Reservoir with disodium hydrogen phosphate, achieving initially 0.4 µg/l (measured as phosphorus) at the tap and more recently 0.6 µg/l⁽¹⁷⁰⁾. The reservoir in question serves about

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10,000 houses in Handsworth and Edgbaston and initial results show encouraging reductions in lead concentration without excessive levels of phosphate at the tap. Addition of phosphate was stopped in October 1982 so that a further, more detailed assessment of its benefits could be made by examining the rate of return to the previous condition. We note also that, in joint trials by the Water Research Centre and the East Anglian Water Company, orthophosphate has been used to treat the particularly alkaline supply from Ormesby to Great Yarmouth and that the method there is considered generally proven and to have potential for wider application⁽¹⁷¹⁾.

6.11. Lead solder is commonly used for joining copper pipes in modern plumbing systems and if it is not carefully applied it may come into contact with the water and lead may enter solution by electrolytic action. A study commissioned by the Department of the Environment and undertaken by the Water Research Centre concluded that this problem was sufficiently serious to justify phasing out lead solder for use on pipes carrying drinking water⁽¹⁷²⁾. However, this view was disputed by the Department⁽¹⁷³⁾, though their Circular⁽¹⁵⁾ did encourage local authorities to promote high standards of workmanship in their own properties so that solder did not escape from joints. Although we accept that contamination of water by lead from solder is a minor and generally transient matter compared with the chronic problems that can be presented by lead piping in combination with plumbosolvent water, we nevertheless think it regrettable, and disquieting for the public, that there should be an apparent difference of opinion on the significance of the data in the WRC report. The Department have told us that they are continuing to examine the extent of the problem. We **recommend** that those concerned should reach a definitive view for public information and discussion as soon as possible.

Lead in paint

6.12. Modern paint has three major components—solvent, binder and pigment. The solvent—which is water for most emulsion paints—is a volatile liquid which assists the application of the paint by brush, roller and spray. The binder is a polymeric resin which forms a thin, coherent film when the solvent evaporates. The pigment is a fine powder, suspended in the solvent, which gives the paint its colour. White and red lead pigments were once common. Most paint also contains minor components and in oil-based paint the most important of these is a drier, normally an organic lead or other metal compound, which speeds the reaction of the binder with oxygen to form a dry film and without which the paint would take days rather than hours to dry. Water-based paint dries by evaporation of water; thus there is no reaction with oxygen and so no need for driers. Most paint currently used for domestic purposes is decorative emulsion paint. Any lead in this arises from adventitious contamination or from traces which may be present in the pigments or mineral extenders.

6.13. Technological progress and increasing awareness of the hazards of lead have substantially diminished the use of white and red lead pigments in paints since 1945. Today they are recommended only for purposes such as the protection of outdoor woodwork and to combat corrosion on steel surfaces, though even in such applications hazards will arise in connection with the

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disposal of structures coated with leaded paint, for example in ship breaking yards. Lead chromate pigment has also largely been replaced, by organic dyestuffs, though it continues to be used for yellow road markings. In general, though, we understand that there are no uses for which a lead compound *must* be included in paint, though in many cases the available alternative pigments or additives function less well, may cost more, and sometimes present potential hazards of their own—as, for example, with cadmium sulphate, which could be an alternative to lead chromate for road markings.

6.14. The use of lead-based paint in factories has been controlled by statute for some years—by the Lead Paint Regulations of 1927, as incorporated in the Factories Act 1961 and thereby in the Health and Safety at Work etc Act 1974. However, the lead content and use of paint and related materials available to the general public is not controlled by statute and the public has to rely on a voluntary agreement between the Paintmakers' Association and the Government, first made in 1963 and revised in 1974, under which paints which yield more than 1 per cent total lead in the dry film (broadly equivalent to 0.5 per cent in the liquid paint) carry a warning that they should not be used on surfaces accessible to children. In practice, most manufacturers have reformulated paints by excluding lead pigments so as not to require this warning to appear. However, the agreement cannot be forced on non-members of the Association, including foreign manufacturers and distributors, who can sell their products legally in the UK without any warning. We note that even 1 per cent of lead, equivalent to 10,000 $\mu\text{g/g}$, is a high level compared for example with those typically found in street and household dusts (see paragraphs 2.27 and 2.28) and that even such 'low lead' paint can be harmful if ingested in large quantities. British Standard 4310 specifies 0.5 per cent as the proportion of total lead above which a paint cannot claim to be 'low lead'.

6.15. The voluntary agreement is, however, shortly to be supplemented by Regulations stemming from European Community Directive 77/728/EEC⁽¹⁷⁴⁾, as amended, which concerns the classification, packaging and labelling of paints, primers, varnishes, printing inks, adhesives and similar products sold in the course of trade. The Directive—due to be implemented in the UK in mid-1983—classifies many substances as toxic, harmful, corrosive or irritant and prescribes prominent warning symbols and labels accordingly. For lead, compounds containing over 1 per cent of lead soluble in 0.07 N hydrochloric acid (a rough approximation to conditions found in the gut) are classified as 'harmful' and packages containing over 125ml must be clearly labelled to show the particular risks involved. Paints and varnishes containing more than 0.5 per cent of lead in the liquid preparation are required, in addition, to carry the warning:

CONTAINS LEAD

Should not be used on
surfaces liable to be
chewed or sucked by
children

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The Directive prescribes minimum dimensions for warning labels; for example, on packages containing up to 3 litres of paint or varnish the label should normally be at least 52 × 74 mm; on very small packages, containing less than 125 ml, the warning about lead can simply say 'WARNING: contains lead'.

6.16. Although the forthcoming Regulations should bring about more consistent and reliable labelling of paint and related materials containing lead, they will neither directly affect the ease with which leaded paint can be bought nor control the uses to which such materials are put. The continuing growth of do-it-yourself activities means that products intended primarily for use by professional decorators and painters will be increasingly in demand by members of the general public with no expertise in their use. The lead content of some paints currently manufactured by members of the Paintmakers' Association is shown in Table 6.1. Although the Lawther Working Party estimated that lead-based paints accounted for less than 3 per cent of the current market, we have been unable to ascertain the quantities of the various types sold in Britain and thus assess the effectiveness of the existing, voluntary warnings in reducing their use. We feel that it is important for information to be available on the extent to which leaded paint is still used and, accordingly, we **recommend** that the Department of Trade should, in collaboration with the paint industry, apprise itself of the situation and ensure, through publicity to supplement precautionary labelling, that users and potential users of leaded paints are aware of the dangers and the alternatives.

6.17. The lead content of paint on toys and pencils has, however, been controlled for some time. The Toys (Safety) Regulations 1974 reduced from 0.5 per cent to 0.25 per cent of the dry paint film the maximum permitted total lead in paints for toys; and the Pencils and Graphic Instruments (Safety) Regulations 1974 set 0.025 per cent as the maximum for the soluble lead in paint for pencils. The Report of the Lawther Working Party recommended maximum vigilance for items for sale in breach of these Regulations and, in the light of that Report, the Department of Trade in 1980⁽¹⁷⁵⁾ reminded local authorities of their duty to police these Regulations thoroughly.

TABLE 6.1
Lead content of some paints on sale in the UK

<i>Paint</i>	<i>Total lead in dry paint film (µg/g)</i>
Toy paint	<50
Modern decorative gloss	2,500-3,000
White lead gloss	44,000
White lead undercoat	71,000
White lead primer	448,000
Pink primer	476,000
Red lead paint	661,000

Source: Paintmakers' Association of Great Britain Limited

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6.18. Yellow markings are applied extensively, thickly and repeatedly to roads in urban areas, in and around school buildings and in residential areas. The material used is either a thermoplastic formulation which is spread or sprayed hot on to the road or a liquid paint applied by brush or spray. The thermoplastic material is governed by British Standard 3262, which makes no reference to any required lead content. The liquid paint is governed by British Standard 6044, which requires that any lead chromate pigment shall be in a low solubility form so that the paint is not 'lead paint' within the meaning of the Factories Act 1961. The Department of Transport's specification for road and bridge works at present requires there to be a minimum of 6 per cent lead chromate in such paint. However, the specification is in the process of revision and in due course is expected to refer only to the requirements of the paint in terms of its performance (for example, luminance and colour) rather than its composition.

6.19. Nevertheless, since large quantities of road marking paint can be seen everywhere and are regularly being renewed or added to, and since there is some uncertainty about how much ingested lead chromate is absorbed by the body, we thought we should establish the extent to which lead chromate, as normally mixed with a thermoplastic base for application to roads, was available for uptake by man following degradation of the road markings and their incorporation in dust or water. Accordingly, we arranged for the Laboratory of the Government Chemist to apply samples of road paint in the recommended manner, to abrade them to powder, and then to apply the test prescribed for lead in paint on toys—agitation with 0.07N hydrochloric acid for 2 hours—to determine the amount of lead potentially available for uptake by man. Analyses of total lead were also undertaken. The results are shown in Table 6.2.

6.20. These results suggest that, although road paint can make an appreciable contribution to the total burden of lead in dust, only a small proportion (between 1 per cent and 2.5 per cent in our samples) is likely to be available for uptake by man and is not, by itself, a cause for concern. However, in line with our view that, over the longer term, all contributions to the total input of lead to the environment should be reduced or eliminated where practicable, we **recommend** that research should continue to lower further the amount of lead necessary for a satisfactory road paint and that the use of paint containing the least practicable amount of lead at any given time should be mandatory.

TABLE 6.2
Lead analyses of yellow road paint

Sample	Total lead (percentage by weight)	Soluble lead (µg/g)
powdered paint	2.1	20
lumps } samples from	1.4	150
lumps } different sources	1.0	250

Soluble lead was determined by the method specified in the Toys (Safety) Regulations 1974.
Source: Laboratory of the Government Chemist

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6.21. Thus considerable progress has already been made in devising paints for many purposes which contain low or only trace amounts of lead. We note that in the United States, where the extent of lead poisoning from paint in old houses has made people particularly aware of the dangers of lead in paint, the Lead-based Paint Poisoning Prevention Act places a limit of 0.06 per cent on the level of soluble lead in paint accessible to children. We **recommend** that it should be the policy of Government and manufacturers in the UK to work towards reducing to a comparable level the maximum permitted concentration of lead in paint for household use and that, in the meantime, the Government should extend the labelling Regulations to bring all paint containing lead above this concentration within their scope. We also **recommend** that research on the formulation of paints should be directed towards further reducing the range of applications for which there are genuine grounds, whether technical or financial, for preferring leaded paints. The ultimate aim of these measures should be to eliminate the need for paint containing significant quantities of lead.

6.22. The dangers of lead in old paint have, perhaps, received more widespread attention than those of lead in modern, mostly 'low lead' paints. The contribution of leaded paint to dust in older buildings was referred to in paragraph 2.25, and the particular risks faced by children with pica were mentioned in paragraph 4.12. The Report of the Lawther Working Party⁽¹³⁾ identified old paint as the most important adventitious source of lead, especially for children. Pre-1930 paint films are liable to contain substantial amounts of white lead (a basic lead carbonate), and lead sulphate, lead chromate and their chemical complexes may also be present in pigments. From the 1950s, primers based on calcium plumbate were often used on galvanised metal window frames. Thus the date of application of paint is a fairly good indicator of its likely lead content.

6.23. The DOE and Welsh Office Circular⁽¹⁵⁾ invites local authorities to consider the possible extent of old leaded paint in their own properties, including housing as well as schools, playgrounds and other places used by young children. The Circular also stresses that it is important for teachers, social workers and others to be fully informed of the hazards of pica and that authorities should respond positively, with a full investigation of the possible causes, when a child is found to suffer from it.

6.24. Local authorities would be helped in their investigations by the availability of a simple *in situ* method for detecting and measuring lead in paint. Even a method that gave approximate results would be most useful for screening. Techniques that involve taking samples of paint and dust and subjecting them to traditional 'wet' chemical analysis can be costly and time-consuming. A portable X-ray fluorescence instrument is in use in the United States and this enables enforcement agencies to take rapid measurements of lead in paint, reliably and without any damage to the paintwork being investigated. While such instruments are not cheap, neither are chemical analyses. We therefore believe that local authorities would find it useful to review the techniques and equipment currently available for the detection of lead in paintwork and accordingly we **recommend** that they undertake such a review. Investment in

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modern equipment could well repay itself in terms of both staff time saved and the quality of services that environmental health departments can offer.

6.25. Once lead paintwork is detected, however, it does not necessarily follow that it needs to be removed. Indeed, as the DOE and Welsh Office Circular points out, wholesale removal is generally neither feasible nor cost-effective and, if not done with scrupulous care, will probably make matters worse by releasing lead dust and particles around the premises to be inhaled and ingested. When paintwork is sound, and children are not exposed to it, it is unlikely to present any hazard, whatever its lead content, if it is left alone or simply covered with modern paint in the course of normal redecoration.

6.26. Where, however, leaded paint is flaking or crumbling, or needs to be removed for some other reason, there are a number of precautions which should be taken by both professional and amateur decorators. Dry-sanding, whether for surface preparation or complete removal of the paint, is hazardous, particularly when power tools are used. The large quantities of dust released may be directly breathed in and, in occupied houses, may settle in carpets, curtains and furniture and contribute to high indoor lead concentrations for extended periods. We believe the hazards fully justify the advice that dry-sanding should never be performed indoors for the removal of leaded paint and that preparation of existing paintwork for redecorating should preferably be done by hand, with glasspaper. Burning or other stripping methods using heat can generate lead-rich fumes which may be dangerous to the decorator if exposed for long periods, although presenting fewer risks to other occupants provided that they keep out of the room and the debris is properly cleared up. Wet-sanding avoids the hazards of both dry-sanding and burning, but is slow for large areas and messy for normal domestic purposes. For the amateur decorator probably the most convenient safe method of stripping large areas, if it has to be done, is to use a hot-air tool of the kind now widely available. This softens the paint without generating fumes, provided that the temperature is below 500°C, and allows it to be scraped off and disposed of safely. Similarly, chemical paint strippers will give satisfactory results, but they are expensive, caustic to the skin and give off fumes which are hazardous if breathed to excess.

6.27. The DOE and the Welsh Office have jointly made available, through local authorities, a detailed leaflet on lead paintwork and safety precautions to take when dealing with it⁽¹⁷⁶⁾. We warmly welcome this leaflet and a number of others produced by environmental health departments and other local groups designed to publicise the dangers of lead in paintwork. Such leaflets will, of course, only be effective if they reach their target audience, including those for whom English is not the first language. We therefore **recommend** that local authorities should be particularly diligent in ensuring that the message gets through and that no opportunity is lost to publicise the hazards and remedies.

6.28. We say something more about health education and publicity generally later in this chapter. With specific reference to the dangers of lead in paintwork we have considered whether to recommend the compulsory inclusion of warning notices on decorating materials and equipment not within the

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scope of the packaging and labelling regulations (see paragraphs 6.15 and 6.16). We decided that this would not be justified, but we see much scope for constructive voluntary action in this field on the part of manufacturers and their associations, retailers and public authorities. For example, advice printed on paint tins about surface preparation should include the kind of safety warnings we have referred to, and similar warnings should be included with the instruction leaflets for power tools and on packets of sanding sheets or discs. Paint and tool manufacturers should consider providing suitable posters for display in hardware shops and drawing attention to the existence of other safety information, such as the DOE and Welsh Office leaflet mentioned above, in their promotional literature. The role of the media, particularly the various 'DIY' journals, is most important. We **recommend** that the Government conducts an early campaign in the press, TV and radio to reinforce the message of the DOE and Welsh Office leaflet, and that there should be periodic reminders to the public to ensure that the lessons are not forgotten.

Lead in food and drink

6.29. Food, like water, though not a primary source of lead, is a most important pathway for the transport of lead from a multiplicity of sources, the individual identity and relative significance of which are not always easy to establish. However, as for water, we have attempted in Chapter IV to illustrate the range of exposure that may be found in practice. In addition to any lead that the edible parts of plants may take up from the soil whilst growing (which, in turn, may come from a variety of sources, including sewage sludge—see paragraph 2.18), lead ingested with food may be deposited from the air on to growing food plants and not be wholly removed by washing; it may come from cooking water or the glaze on tableware; and it may find its way into food from packaging, especially cans.

6.30. As we have shown in Chapter IV, and as the Lawther Working Party also concluded, most adults in the UK derive the major part of their lead uptake from food. Reduction in exposure to lead from this pathway in the longer term must come from concerted action to reduce the contamination of food by lead from all sources; inability to reduce this exposure significantly and directly in the shorter term provides all the more reason for seeking to reduce exposure to and uptake from those sources which can be identified and avoided. This argument applies especially to small children, whose rate of absorption of ingested lead is believed to be much higher than that of adults (see paragraph 4.30).

6.31. We discussed many of the sources of dietary lead in connection with our model balance schemes in Chapter IV and pointed to the uncertainties that still exist over the origins of much of the lead in food. One component of the diet where the origin of the lead can be identified, however, is canned foods, in which the prime source of lead is the solder used in the cans. This causes the lead content of the food to rise for about six months after canning, though the process is accelerated by the presence of air, either in a punctured can or when food is stored in an open can. The figures we quote in Appendix 4 (paragraph 9) suggest average lead concentrations of 0.06 mg/kg and 0.22 mg/kg in

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uncanned and canned foods respectively, though the difference between these should not be attributed wholly to the can since the average lead content of foods commonly put in cans may well differ from that of food packaged in other ways. The current maximum permitted concentration of lead in most canned food intended for sale for human consumption by adults is 2 mg/kg; in foods specially intended for infants and young children the limit is 0.2 mg/kg. However, the Food Additives and Contaminants Committee (an independent group advising Ministers) has recently recommended that, by 1985, the statutory limits for lead in canned foods should be reduced in line with the limits now applicable to corresponding foods not contained in cans and that, where there is no uncanned equivalent, the current general limit of 1 mg/kg for uncanned food (see paragraph 3.8) should apply also to canned food⁽¹⁷⁷⁾.

6.32. Much of the lead in canned food derives from solder particles deposited on the internal surface whilst the can is in the vicinity of the soldering equipment. Considerable efforts have been made by can makers to reduce contamination, but the makers themselves admit that improvements are not always consistent or significant and that the rigorous quality control needed is not easy to maintain. Alternative methods have therefore been examined and include the application of an internal coating to the can to reduce the scope for contact between lead solder and the contents of the can, the widespread use of pure tin solder (already used on cans for products which must meet very low statutory limits or which tend to dissolve lead particularly readily), or the use of manufacturing techniques which produce cans of the type already widely used for drinks, with either welded or no side seams.

6.33. The Metal Box Company, which is the major manufacturer of cans in the UK, told us that they had carefully studied all the options available for reducing the contamination of canned foods by lead. Further use of coatings was considered impracticable and of limited value. The use of tin solder would be very expensive, and would not have the scope for economies in new materials or production that the 2-piece or welded can making techniques could bring. Thus Metal Box concluded that ultimately the solution must be to produce cans which do not use solder and in November 1982 they announced their decision to phase out the use of lead solder in can making by 1985. We welcome the Company's decision and expect its action to result in a significant reduction in the average lead concentration found in canned foods on the UK market. Continuing monitoring work by the Ministry of Agriculture, Fisheries and Food and by environmental health departments should register this decline, as well as policing the lead concentrations in cans from manufacturers and importers who continue to use lead solder. Details of UK canned food consumption and the proportions of various canned foods that are imported are given in Table 6.3.

6.34. We note that in America the Nutrition Foundation's Expert Advisory Committee has recently completed an assessment of the safety of lead and lead salts in food⁽¹⁰⁵⁾. That Committee concluded that, although environmental and industrial sources were the major origins of lead in food, the contribution from canned foods to the lead intake of young children was between 17 per cent and

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28 per cent of dietary lead and should be reduced. We endorse this view for the UK and **recommend** that there should be a continuing effort to gain better understanding of the various pathways and mechanisms by which food is contaminated with lead.

6.35. We have already noted (paragraph 4.28) a shortage of data on the lead content of a possible further source of ingested lead, namely some alcoholic drinks. Accordingly, we **recommend** that more data are obtained on the lead content of alcoholic drinks and that where drink passes through a delivery system, for example a beer engine drawing beer from a cellar, the measurements should be taken at the point at which the drink enters the glass.

6.36. A further identifiable source of lead in some food is sewage sludge spread on agricultural land. The joint DOE/National Water Council Standing Committee on the Disposal of Sewage Sludge recommended⁽¹⁷⁸⁾ that for application to grassland, where sludge may accumulate on the grass or soil surface and be consumed by grazing animals, the lead content of applied sewage sludges should not exceed 2,000 $\mu\text{g/g}$ (dry solid). For other agricultural uses, where sludge is mixed with soil, a total limit over 30 years or more of 10⁵mg/m² (1,000 kg/ha) was recommended, corresponding to about 450 $\mu\text{g/g}$ in soil 200 mm deep. The Commission of the European Communities has proposed a Directive on the use of sewage sludge in agriculture with more stringent limits⁽¹⁷⁹⁾. It envisages a mandatory limit of lead concentration in sludge of 1,000 $\mu\text{g/g}$ (dry solid) with a recommended figure of 750 $\mu\text{g/g}$; an annual application limit (based on a ten-year average) of lead in sludge of 1,500 mg/m² (15 kg/ha) with a recommended figure of 1,000 mg/m²; and a limit of 100 $\mu\text{g/g}$ (dry solid) on the lead concentration in the agricultural soil on which sludge is spread, with a recommended figure of 50 $\mu\text{g/g}$. We welcome the intention behind this proposed Directive and note that it is consistent with Recommendations 63 and 64 of our Seventh Report⁽⁴⁸⁾ that there should be greater efforts to reduce contamination of sewage by toxic metals and that there should be regular monitoring and recording of sludge applications to land.

TABLE 6.3
UK canned food consumption, 1979

	Total consumption (million cans)	Percentage imported
Fruit	740	83
Vegetables	1,580	34
Hot meats	210	0
Cold meats	280	93
Fish	290	94
Soup	680	1
Milk products	600	3
Baby food	130	—
Beans and pasta	1,140	1

Source: Metal Box plc

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Lead in Dust

6.37. We have already indicated the importance of dust as a pathway for intake of lead (paragraph 4.29). Young children, who can ingest dust by sucking dirty fingers, toys and other objects, are particularly at risk, but all age groups will inhale dust if it becomes airborne. The traditional methods of street sweeping may well serve to increase airborne dust. The possible contribution of yellow road marking paint to the lead burden of urban dust was mentioned in paragraph 6.20, and crumbling old paintwork and the use of inappropriate techniques to remove old paint also contribute to lead in dust both indoors and in places such as school playgrounds (see paragraph 6.25). Soil, which itself may contain lead from a variety of sources, can also contribute to dust.

6.38. We have noted that some local authorities, as a result of monitoring, have found concentrations of lead in dust over 1,000 $\mu\text{g/g}$ in school playgrounds and classrooms. Concentration peaks are usually associated with old paintwork in poor condition both indoors and outside but there is also evidence that the concentration of lead in playground dust decreases with distance from the road, suggesting some contribution from fallout from vehicle emissions⁽¹⁸⁰⁾. Remedial measures include vacuum cleaning and washing, and removal of paint. In 1981 the Greater London Council reduced from 5,000 $\mu\text{g/g}$ to 500 $\mu\text{g/g}$ its recommended safety limit for lead in dust and, along with the Inner London Education Authority, is undertaking further work on the level of sampling necessary to obtain a reliable picture of lead contamination at any school and on the origins of the lead in playground dust. We are pleased also to note that the Department of the Environment is sponsoring a survey of lead in urban dust in a number of towns in Great Britain (see Table 2.6). However, in view of the very limited data yet available on the relative contributions that different sources and pathways can make to lead in dust (see paragraph 2.25), we **recommend** priority is given to research in this area.

6.39. Reduction of exposure to lead in dust can be brought about by reducing both the concentration of lead in the dust and the amount of dust ingested, particularly by children. The former should follow over a period of time from some of the measures now in hand or recommended by the Government and local authorities, but the latter is very much a matter of health education and hygiene, in which parental attitudes clearly have an important part to play. We have already noted that the body burden of lead in children may be related to social factors such as behaviour and home cleanliness (paragraph 5.11).

Industrial emissions

6.40. Dust containing lead, as well as lead fumes (i.e. fine airborne particles), can also be released from premises where lead or its compounds are stored, smelted or used, and from other activities such as scrap metal and car battery recovery and the burning of waste engine oil. Industrial emissions themselves can contain lead, and dust may be blown from stockpiles or roadways or carried out on vehicle tyres or on workers' clothing and footwear. Responsibility for controlling such emissions rests largely with the Industrial

Reduction of Exposure to Lead from Water, Food and Localised Sources

Air Pollution Inspectorate (formerly the Alkali and Clean Air Inspectorate) and the Factory Inspectorate in England and Wales and with the Industrial Pollution Inspectorate in Scotland. We note that these authorities well recognise the need to apply high standards to both controlled and uncontrolled dispersal of lead dust from industrial premises and that, in particular, the Industrial Air Pollution Inspectorate has been carrying out a general review of the best practicable means (BPM) for controlling emissions from lead works⁽¹⁸¹⁾. We understand that major factors in achieving proper standards include care in works and process design to reduce handling to a minimum, cover or containment of stored materials, separation of routes for delivery and on-site vehicles, the use of mist wetting to reduce dust generation and minimise its spread, wet vacuum cleaning of roadways and other areas, and the use of a properly designed and sited vehicle washer. The Inspectorate is also hoping to develop a methodology for assessing the total amounts of lead leaving a works and the contributions of individual sources to that total. Such a methodology would permit a more systematic and cost-effective approach to control of low level sources, which currently depends largely on subjective assessments, and might also be applicable to other industries.

6.41. In the light of our general conclusions on the need to reduce the dispersal of lead in the environment, we **recommend** that the Industrial Pollution Inspectorates should give careful attention to the scope for reducing the BPM emission limits currently applicable to scheduled lead processes⁽¹⁸¹⁾. We note that, if demand for lead and its compounds is reduced by some of the action we recommend elsewhere in this and other chapters, there will be a related reduction in the processing and handling of lead in industry and scope for a consequential fall in emissions to the environment even with existing control standards.

Lead shot

6.42. The effects of spent lead shot on water birds and lead fishing weights on swans have been described in paragraphs 3.16 and 3.17. We know of little evidence of harmful effects of such lead on man, though the habit of some anglers, including young boys, of closing split shot weights between the teeth could add marginally to the intake of lead.

6.43. Various actions are already in progress to reduce exposure of wildlife to lead shot. The British Association for Shooting and Conservation is preparing a code of practice to reduce the deposition of lead in wildfowl areas and is also investigating the possibility of marketing alternatives to lead for shot gun pellets. The sole UK manufacturer of shotgun cartridges (the Eley division of Imperial Metal Industries, Birmingham) is currently studying American experience of the problems of quality control and reliability involved in the production of steel shot. These problems have evidently already been overcome in America, where the Department of the Interior has progressively introduced regulations requiring hunters to use non-toxic steel shot in specific areas. By 1979, 32 such areas, covering regions where about 22 per cent of the total US waterfowl catch has occurred in recent years, had been established⁽⁸¹⁾.

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The aim of the programme is to reduce by 75 per cent the number of waterfowl with elevated levels of lead in their blood and body tissues, and control zones are selected on the basis of the percentage of waterfowl found with ingested shot. The programme has apparently been so successful that in some areas over 60 per cent of the pellets found ingested by waterfowl are steel ones.

6.44. The National Anglers' Council has drawn up a code of practice on the use of lead shot fishing weights and the angling trade is aiming to eliminate spillage-prone packaging. It has been put to us that there is as yet no acceptable substitute for split lead shot and that its function of weighting a fishing line is so crucial to the angler that any attempt to restrict its use, in the absence of a suitable replacement, would constitute a damaging interference with anglers' rights to practise their sport. The Nature Conservancy Council Report on lead poisoning in swans⁽⁹³⁾ recognised the difficulties, but considered that both tungsten putty and steel had potential for development as substitutes for lead, though both would be more expensive than lead. The NCC Report recommended that urgent efforts should be made to develop alternatives to split lead shot and that the use of the latter should be phased out within five years.

6.45. We **recommend** likewise, and apply our recommendation also to lead used in shotgun pellets. We believe that it ought to be possible for adequate, though perhaps somewhat more expensive, substitutes to be developed for use in the UK within a very few years and we **recommend** that, as soon as substitutes are available, the Government should legislate to ban any further use of lead shot and fishing weights by hunters and anglers in circumstances where they are irretrievably dispersed in the environment.

Pewter, cosmetics and other miscellaneous sources

6.46. The traditional pewter vessels of Britain are alloys based on tin. Some of them, especially older ones, contain lead and if used for acidic food or beverages could contribute to lead intake. The problem is greater if the acidic food or drink is stored in such vessels. Certain cosmetics of Asian origin, principally some kohls and surmas, contain a large proportion of lead. The risks associated with these were described in detail in the Report of the Lawther Working Party; we believe that these risks are now more widely appreciated and that alternative preparations, not containing lead, are being introduced. We welcome the Department of Trade's further publicity campaign on this subject, drawing attention to the fact that the importation of such products for sale (but not for personal use) is now illegal. With these traditional consumer products, and others such as pottery with a lead glaze (see paragraph 4.27), public education and awareness rather than further legislation are the best preventative measures.

Conclusions

6.47. Most of the sources and pathways reviewed in this chapter are essentially local and, with the exception of industrial sources, road dust and (to a limited extent) food, exposure to them may be controlled or reduced by the

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action of individuals in their own homes and gardens. Local authorities have a dual role: to serve as a source of information and advice and to provide financial assistance for the removal of lead plumbing. We are glad to note the clarification of these responsibilities in Government circulars although we also note that expenditure (other than on home improvement grants) and manpower needs are to be met by a re-ordering of priorities. We well recognise the constraints under which local authorities must work, but **recommend** that they accord a high priority to the monitoring and other work necessary to establish the extent of human exposure to lead in their areas and to reassure the public that any necessary remedial action is being taken without delay. The protection of public health ought not to be a cyclical activity dependent on the prevailing financial climate.

6.48. We have seen, and welcome, a growing number of leaflets published by local authorities and others drawing attention to the risks associated with exposure to lead, and advising on how to avoid or minimise them. We note that the Scottish Health Education Group produced a leaflet⁽¹⁸²⁾ that was distributed to all households in Scotland earlier this year, with accompanying publicity in local newspapers and on local radio stations. We **recommend** other bodies to consider the scope for similar action. Having examined the issues in detail we consider that public information and education have the major role to play in enabling people to reduce their own exposure to lead from localised sources.

CHAPTER VII

LEAD IN PETROL

Introduction

7.1. In the previous chapter we discussed various sources of lead to which it is possible to avoid or reduce exposure, to a greater or lesser extent, by local or individual action. By contrast, lead emitted to the atmosphere by petrol engines, as we have seen in Chapter II, is dispersed very widely and affects the whole population. Directly and indirectly it currently accounts for up to 20 per cent of the body burden of lead of most adults (Chapter IV) and in inner city areas its contribution can be appreciably higher. When added to other background sources of lead, it can be seen as reducing the margin of safety where there is additional exposure to localised sources. Since there is no reliable criterion for setting a threshold or 'safety level' for human uptake of lead (Chapter V), prudence dictates that levels of lead in the environment should continue to be reduced by all practicable means.

7.2. Lead in petrol is a source which the individual can do little to avoid. It is not a 'point source' pollution problem, the solution to which depends on local initiatives or enforcement of the law by local agencies. Nor is it a problem which can be contained and steadily reduced by vigilance, good housekeeping, or public education programmes. On the other hand, general reduction or elimination of lead in petrol can be achieved with comparative ease. It requires a central decision, to be taken nationally if not internationally; it may depend on developments outside the control of the UK Government and domestic industry; it involves 'step changes' rather than gradual phasing down; and certain economic and technical consequences flow from it, some of which have international implications. In these respects lead in petrol is uniquely different from the other sources and pathways which we consider in this Report. It is also fair to say that, provided the constraining factors are recognised, the largest single controllable source of lead for the population as a whole is lead in petrol.

7.3. In this chapter we consider the role of lead as a petrol additive, the steps which are already being taken to reduce its use and emissions, and the technical and economic implications of further reduction, including elimination altogether. When the case for removing lead from petrol is discussed, we have found that it is frequently asserted that the costs—to industry, to the consumer and the nation—are considerable and quite out of proportion to the assumed health benefits. We therefore felt it was important to examine these issues with some care and to set them in the context of the general conclusions we have drawn at the end of Chapter V and elsewhere in this Report.

7.4. In the sections which follow our objective has been to highlight those features which we consider to be essential to the argument, without necessarily presenting an exhaustive account of the technical background. Inevitably we have had to compress and to some extent select from the very large amount of evidence and other information we received as a result of our decision to look at this aspect of lead in the environment. In some areas there is a lack of agreement on commercial or technical issues, which it would have been beyond our competence to attempt to resolve. We have had to rely on our judgement of the evidence as presented to us, with the valuable assistance of our independent consultant. We believe however that our analysis will prove to be helpful in placing this hotly debated subject in perspective.

The internal combustion engine

7.5. During the 20th century two main forms of internal combustion engine, the petrol engine and the diesel engine, have assumed a dominant position as the means of power for land transport. This is largely because two suitable liquid fuels—petrol (otherwise known as gasoline or motor spirit) and diesel (gas oil or Derv)—have been widely and consistently available. The physical and chemical qualities of these fuels have influenced the way in which the two engine groups have developed into their present forms. Vehicle pollution regulations coupled with the energy crisis have added further impetus to developments since the mid-1960s.

7.6. The most significant difference between the petrol and diesel engine (and the aspect with which we are principally concerned in this chapter) lies in the combustion system—i.e. the means by which air and fuel are mixed, burned in the combustion chamber and expelled as exhaust—rather than in the propulsion system which converts the energy into motion. Figure 7.1 illustrates this difference in relation to conventional cylinder and piston engines.* In the petrol engine the fuel and air are pre-mixed using a carburettor or a fuel injector. These ensure that by the time the piston has compressed the mixture, and the spark has fired across the sparking plug electrodes, the mixture in the combustion chamber (i.e. the cylinder) is homogeneous. Pre-mixed combustion, as this is called, takes place progressively across the chamber, starting from the spark plug.

7.7. Diesel engines differ from petrol engines in two important respects (Figure 7.1). Firstly only air is compressed by the piston, and is brought to a temperature higher than that at which spontaneous ignition of diesel fuel occurs. The fuel is then injected in the form of a fine spray at about the same time as the spark would occur in a petrol engine. A flame starts inside the spray and travels rapidly through it. The mixture is heterogeneous and combustion, unlike the case in the petrol engine, has no definite starting or finishing point.

*Wankel rotary petrol engines differ from conventional engines in not having cylinders and pistons, but the same combustion principles apply.

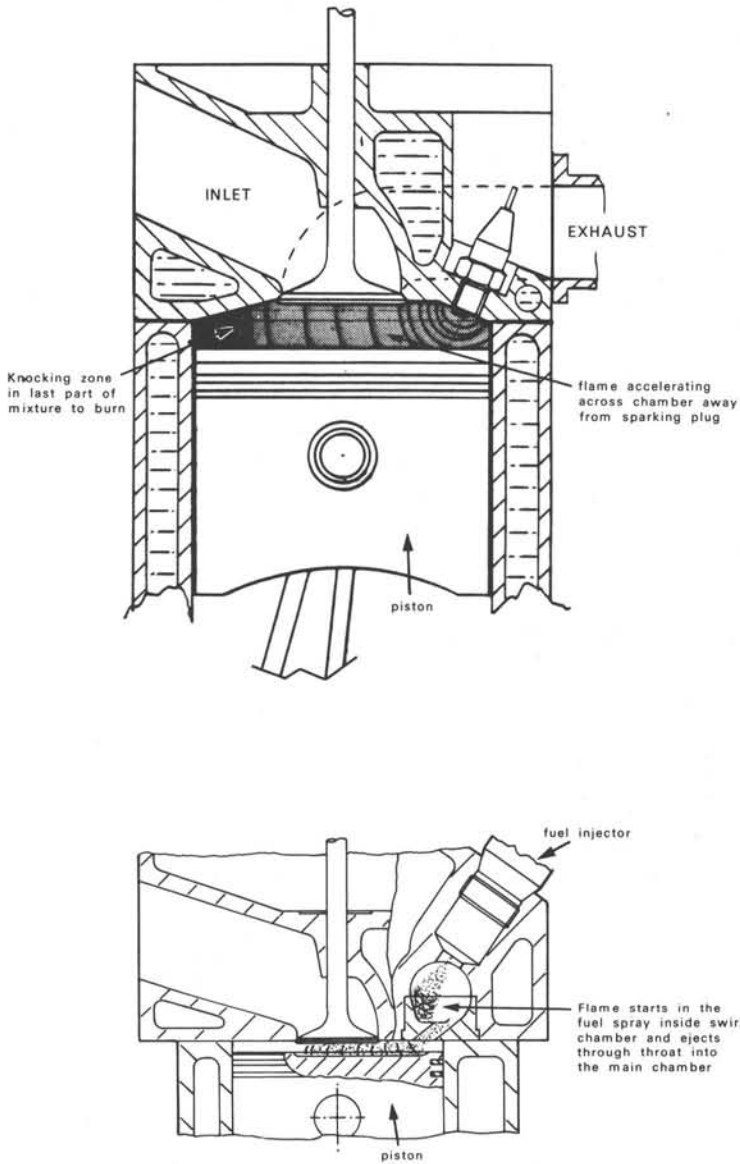


Figure 7.1
Petrol and diesel combustion systems

Upper drawing shows cross section of typical petrol engine cylinder; lower drawing shows corresponding cross section of a cylinder from a high speed diesel engine (Ricardo Comet type) for cars.

7.8. These important differences between the petrol and diesel combustion processes are essential to an understanding of why the petrol engine 'knocks' and the diesel does not, which we discuss below.

7.9. Petrol engines have always been the favoured power unit for cars and other light duty vehicles because at equivalent levels of performance they are cheaper, easier to start and lighter than diesels, and will function without high precision parts such as the diesel fuel injection equipment. Diesel engines, on the other hand, tend to be more reliable and durable than petrol engines and over high mileages show savings in fuel consumption and other operating costs, which offset the higher initial capital cost. Efforts by the car industry to improve performance in acceleration and sustained high speed driving have had the effect of making petrol engines more robust, with stronger crank assemblies, cylinder blocks and crankcases. In some cases robustness is now comparable to light duty diesel engine standards and this has enabled Volkswagen, for example, to make use of many petrol engine parts in their small diesel car, thus demonstrating that the diesel car is now able to benefit from some of the economies of scale enjoyed by petrol engine production.

Compression ratio and engine knock

7.10. An important determinant of the efficiency of any given design of internal combustion engine is its compression ratio, i.e. the ratio of the maximum to the minimum volume of the cylinder, or the extent to which the fuel and air mixture is compressed. Within certain overriding limits (for example, friction and other energy losses and the requirements of gaseous emission control standards), which vary according to engine design, the higher the compression ratio the greater the power obtained and the better the fuel economy. For practical purposes the optimum ratio lies between 12:1 and 16:1, depending on design, although this is the subject of controversy among automobile engineers.

7.11. In the petrol engine, however, the benefit from higher compression is generally limited by the phenomenon known as engine knock. Unlike the diesel engine (where the heterogeneous mixture of fuel spray and air in the cylinder ignites spontaneously), there is a progressive burning of the pre-mixed fuel and air mixture in the cylinder. When the spark plug ignites the petrol a flame front occurs which steadily spreads, consuming mixture, until it finally dies out in the furthest corner of the cylinder away from the spark plug (Figure 7.1). The mixture in this corner (known as the end-gas) is subject to heating and compression for longer than in any other location, particularly when the engine is working hard. Under these conditions the engine 'knocks', because the mixture in this corner (the end-gas zone) is brought to an abnormal state of partial oxidation and ignites spontaneously at great speed. This emits the vibrations which we hear as the familiar 'pinking' noise and which are referred to as acceleration knock (or spark knock). Light acceleration knock is relatively harmless, but in a heavier and more persistent form it not only reduces the efficiency and power output of the engine but can also cause serious damage to the pistons and cylinder head, leading eventually to engine failure.

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7.12. Acceleration knock occurs at relatively low engine revolutions and is audible when the mechanical engine noise is unobtrusive. However, there is another variety of knock known as high speed knock, which occurs at 4,000–6,000 revolutions per minute. This phenomenon is normally inaudible to the driver above the engine and road noise, but can be measured with special sensors. High speed knock is the most dangerous form of knock because it may occur very rapidly in motorway cruising conditions with the driver unaware until the point where the pistons melt and the engine may seize up.

7.13. An engine's propensity to knock is determined by engineering factors such as the design of the combustion system, the fuel and air mixture preparation, the temperature within the combustion chamber, and the engine load and speed; by manufacturing quality (see paragraphs 7.98–7.99); and by the quality and chemical composition of the fuel.

Petrol quality and octane number

7.14. For a given design of engine, the presence or absence of knock is determined by the combustion quality or 'octane number' of the petrol used (see box). Normally petrol is graded according to the so-called Research Octane Number (RON), but for some purposes the Motor Octane Number (MON) is also important. The higher the RON value, the higher the compression ratio at which the engine can be run without knocking. In the British Standard for petrol (BS 4040) 4 star petrol is a minimum of 97 RON, and in practice varies between 97 and 98.5 RON. With the virtual disappearance of 5 star this is now the highest octane quality generally available in most countries of the world, although some refineries in the Federal Republic of Germany are able to produce values as high as 99.8 RON.

7.15. In the UK some 80 per cent of the present car population requires 4 star petrol for satisfactory operation, at compression ratios typically in the range 9:1–10:1. BS 4040 sets the minimum RON for 3 star (now little used) and 2 star at respectively 94 and 90. Typical compression ratios suitable for 90 RON are between 8:1 and 9:1.

Why lead is added to petrol

7.16. Octane quality may be increased by intensive refining to increase the proportion of certain hydrocarbons, but this adds to refining costs (and hence to the price of petrol) and produces less petrol from a given quantity of crude oil. Some sixty years ago it was discovered that adding organic lead compounds (lead alkyls) was a convenient and cheap method of boosting the octane quality of petrol. The presence of lead in the fuel has the effect of delaying the abnormal state of partial oxidation in which the end-gas ignites (see Figure 7.1 and paragraph 7.11) and hence allows engines to operate at higher compression ratios and under greater loads before knocking occurs.

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The degree to which petrol resists knock is defined by reference to an artificial scale of *octane numbers*. The scale is derived from the knock resistance of a mixture, in varying proportions, of two pure hydrocarbons—n-heptane (which has a very low knock resistance) and iso-octane (which has a very high resistance). The percentage of iso-octane in the mixture is the octane number, with iso-octane by definition having on its own an octane number of 100 and n-heptane an octane number of 0.

To determine the octane number of a petrol, it is used to fuel a standard single-cylinder test engine, with a facility for varying the compression ratio whilst it is running. The compression ratio is increased until the point where knocking occurs, and the octane number is accordingly that of the corresponding mixture of n-heptane and iso-octane which produces the same result. Thus 97 octane petrol will start to knock in the test engine at the same point as a mixture of 3 per cent n-heptane and 97 per cent iso-octane.

The basic *octane requirement* of an engine at any given compression ratio can be determined by establishing the octane number at which knocking starts.

In fact two main tests are used to determine octane number. The first simulates acceleration from low speed—the condition in which audible knock occurs. The octane number given by this test is known as the *Research Octane Number*, or RON. The second test simulates driving at high and constant speed—a condition in which high temperature causes the performance of some fuels to degrade more than others and which can lead to high speed knock. This more severe test gives a lower octane number, which is known as the *Motor Octane Number*, or MON.

The difference between RON and MON is called the *sensitivity* of the fuel to temperature, and with most commercial fuels is in the range of 4 to 12 octane numbers. For marketing purposes it is usual only to state the RON of petrol, although sometimes the average of RON + MON is quoted. The British Standard specification for 4 star (premium) petrol is a minimum of 97 RON/86 MON and for 2 star (regular) it is a minimum of 90 RON/80 MON.

In conditions of rapid acceleration with sudden throttle opening the presence or absence of knock may depend on the 'front end octane', i.e. the RON value of the fraction of the petrol which vaporises and forms a mixture first. For this purpose the fraction which boils at a temperature of up to 100°C is taken. RON (100°C) is typically some 8 or 10 octane numbers below RON (whole fuel). Since tetramethyl lead (TML) boils at 110°C it is particularly useful for dealing with acceleration knock, whereas tetraethyl lead (TEL) does not boil until 200°C.

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7.17. For a long time only tetraethyl lead (TEL) was used to increase octane, but in the course of developing petrol with higher octane numbers it was found that for some purposes tetramethyl lead (TML) offered greater advantages, particularly in dealing with acceleration knock (see box on previous page). Both TEL and TML are used in current motor fuels.

7.18. The end-gas knocking zone in fact occupies only about 2–10 per cent of the total combustion space, so it follows that only this proportion of the lead actually functions as an anti-knock agent. It is, however, not possible to reduce the lead accordingly and obtain the same results.

7.19. Despite intensive research, to this day no cost-effective alternative to lead as an anti-knock additive (as distinct from the use of oxygenates, discussed in paragraphs 7.62–7.67) has been discovered, apart from a manganese compound, methyl cyclopentadienyl manganese tri-carbonyl (MMT)*, which is a toxic organo-metallic substance converted to a relatively non-toxic oxide (Mn_3O_4) in engine exhaust. MMT is banned in the USA because this oxide clogs up and inactivates catalytic converters (paragraph 7.29 and box on page 96). There are also, in the Government's judgement, sufficient grounds for concern about possible health effects for an assurance to have been obtained from the United Kingdom Petroleum Industry Association that member companies will not use MMT without prior consultation with the Department of Transport.

7.20. The amount of lead that needs to be added to petrol to bring it up to the required octane number will depend on the quality of the basestock petrol (i.e. the normal refinery product before the addition of lead), which in turn depends on the amount of additional refining to which it has been subjected in order to increase the proportion of high octane hydrocarbons. As we discuss later (paragraphs 7.56–7.69) there are practical and financial constraints to the amount of octane quality that can be obtained from refining. The upper and lower limits for lead in petrol of 0.4 and 0.15 g/l set by European Community Directive 78/611/EEC⁽¹⁸³⁾ (see paragraphs 7.113–7.127 and Appendix 6) represent a compromise between a number of factors applicable to Western Europe generally, notably health objectives, efficient use of energy (both in vehicles and refineries), current engine technology and performance requirements, whilst avoiding obstacles to trade and freedom of movement. Countries which have introduced or plan to introduce unleaded petrol have reduced octane quality rather than incur increasing refinery costs. For practical purposes 0.15 g/l is the lowest level of lead at which present Western European octane quality can be maintained.

Other properties of lead in petrol

7.21. Besides boosting octane quality, lead in petrol serves to protect hot engine parts from excessive wear by providing a protective and lubricating film. This is particularly significant in preventing 'valve recession', or erosion of valve seats, leading to loss of compression through leakage of combustion

*Methylaniline has also been found effective in suppressing knock, but is now discounted because of its adverse effect on nitrogen oxide emissions and its toxicity.

gases. The petrol engine has a long history of this problem (Figure 7.2). Older motorists will remember the regular valve-grinding that had to be carried out every few thousand miles. This was made necessary by the attrition of soft cast-iron cylinder heads by the steel valve heads. The valves themselves were also made of relatively soft steel which tended to erode and pit at a high temperature.

7.22. The use of leaded petrol has alleviated this problem in two ways. Firstly it has led to a general rise in compression ratios, with the result that exhaust gases, and hence valves, have become cooler at any given speed and load. Secondly it interposes a soft layer of lead compounds between the valve seats, which lubricates them and reduces frictional wear.

7.23. Modern valves, although highly stressed by high speeds, strong valve springs and fierce cams, often last the life of the engine without attention. Many modern engines have aluminium cylinder heads, and in some cases, particularly in high performance engines, both the valve seat inserts and the valves themselves are made from special hard material. These function without any problems on unleaded petrol.

7.24. Many family cars, however, for the sake of cheapness continue to have cast-iron cylinder heads with valve seats cut directly into the cast-iron. The presence of lead in petrol allows a fairly high performance valve operation without wear of the soft valve seat. With certain engines the recession problem will begin to occur if lead content drops below 0.12 g/l, but for most engines 0.05 g/l is adequate to prevent it and for this reason BS 4040 currently specifies that as the minimum lead content for petrol. In the absence of lead the valve seat must be hardened by a simple process of local heating (by direct flame or, more commonly, by electric induction) and quenching; this, coupled with a slightly superior valve material, is entirely adequate for preventing wear, and adds a negligible amount to manufacturing costs.

7.25. In contrast to its positive effects on engine performance, lead in petrol indirectly has some adverse effects on the durability of certain components of the car. The combustion products of lead alkyls (mainly lead oxides) tend to accumulate in the combustion chamber and cause fouling of spark plugs; to counteract this, ethylene dihalide 'scavengers' (ethylene dichloride and ethylene dibromide) are included with the lead compounds. These convert the non-volatile combustion products into more volatile chlorides and bromides of lead, which are more readily exhausted from the combustion chamber. Despite the use of scavengers, spark plugs may not last as long on leaded petrol as they do on unleaded petrol; and car owners who fail to change plugs at recommended intervals are liable to waste fuel.

7.26. On combustion ethylene dihalide scavengers generate hydrochloric and hydrobromic acids, which have a powerful corrosive effect on iron and steel. Mild steel exhaust systems are particularly vulnerable, and maintenance savings are thus possible on unleaded petrol, although external corrosion may for some cars be a more significant factor. Chlorides and bromides also collect in the lubricating oil, where they may cause corrosion of engine parts.

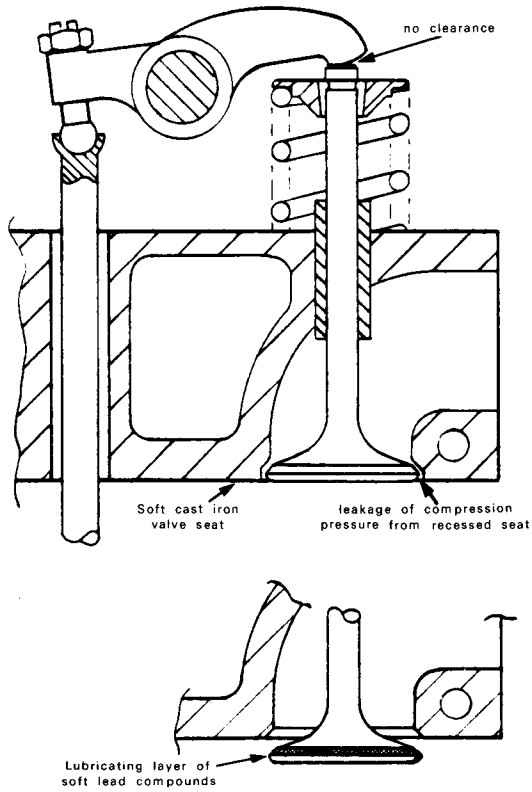


Figure 7.2
Valve seat recession (see paragraphs 7.21–7.24)

Upper drawing shows the effects of using unleaded petrol in an engine with a cast-iron cylinder head and unhardened valve seats. The lower drawing illustrates the lubricating effect of lead additives.

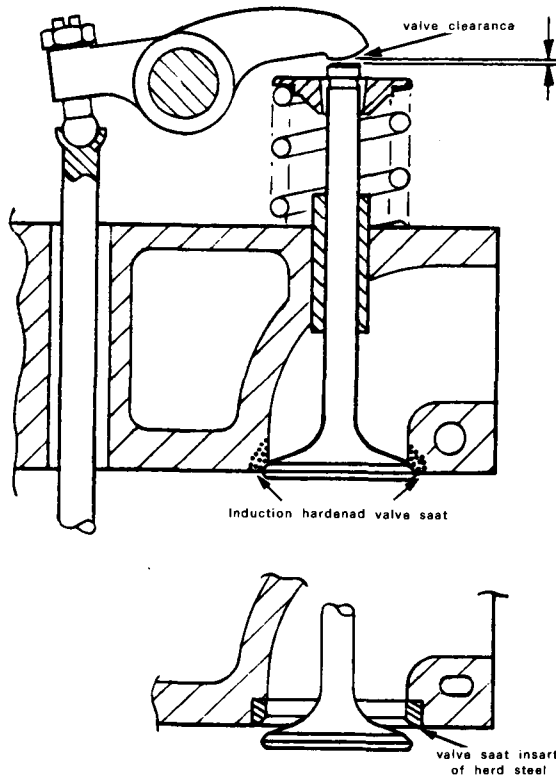


Figure 7.2 continued

Upper drawing shows an engine with a cast-iron cylinder head designed to run on unleaded petrol. The lower drawing illustrates valve seat inserts, as commonly used in aluminium cylinder heads, which can be used for converting existing cast-iron heads for running on unleaded petrol (see also paragraph 7.74).

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TABLE 7.1

Maximum permitted lead content of petrol in different countries, February 1983

<i>Europe</i> ¹	<i>lead content (g/l)</i>	
(a) EC Member States		
Belgium	0.4	
Denmark	0.4 premium 0.15 regular (0.15 premium from July 1984)	
France	0.4	
FR Germany	0.15	
Greece ²	0.4	
Ireland	0.4	
Italy	0.4	
Luxembourg ³	0.4	
Netherlands	0.4 (0.15 from 1986)	
UK	0.4 (0.15 from January 1986)	
(b) Other countries		
Austria	0.4 premium 0.15 regular (0.15 premium from July 1983)	
Finland	0.4	
Norway	0.4 premium 0.15 regular (0.15 premium from September 1983)	
Portugal	0.635	
Spain	0.65 98 RON 0.6 96 RON 0.48 90 RON	
Sweden	0.15	
Switzerland	0.15	
Yugoslavia	0.6	
<i>Rest of World</i>		<i>Status</i>
Australia ⁴	0.84	commercial practice
except:		
(i) Sydney, Newcastle and Wollongong		
Districts of NSW	0.4	} legal requirements
(ii) Victoria	0.3	
(iii) Tasmania	0.45	
Canada ⁵	0.77	legal requirement
Japan	0.31 premium 0.02 regular unleaded	advisory
New Zealand	0.84 (0.45 from 1984)	commercial practice (advisory)
South Africa	0.84	advisory
USA	0.29 ⁶ 0.013 unleaded	legal requirement

Source: The Associated Octel Co. Ltd.

Notes to Table 7.1

¹All European limits are legal requirements.

²There is currently a proposal for a reduction to 0.15 g/l from June 1983, probably applicable only to Athens.

³Since Luxembourg has no refining industry, no domestic legislative measures have been taken; but petrol sold in that country conforms to the EC permitted maximum.

⁴Unleaded petrol (91.5 RON) to be available from July 1985.

⁵Unleaded petrol is available commercially in Canada for use in cars built to US specifications.

⁶General Federal standard: see paragraph 7.31 for further details.

International action to reduce levels of lead in petrol

7.27. Table 7.1 contains the latest available information on maximum permitted levels of lead in petrol currently applied or proposed in countries where lead content is regulated, whether by law or by administrative action. These include all countries in Western Europe, Yugoslavia, Canada, the USA, Australia, New Zealand, South Africa and Japan. According to the Associated Octel Company Ltd, which manufactures anti-knock lead additives in this country, no restrictions other than commercial limits apply in Eastern Europe (apart from Yugoslavia and, to a limited extent, the Soviet Union*), Latin America, the Middle East, Africa (apart from South Africa) and Asia (apart from Japan).

7.28. Two factors lie behind the actions which various countries have taken to reduce or eliminate lead in petrol—the concern about the direct effects on health of airborne lead, and the control of other gaseous emissions through the use of catalytic devices which do not function properly with leaded petrol. Countries which have reduced but not eliminated lead have been motivated by the first factor; those which require unleaded petrol to be available (and no country so far has banned leaded petrol altogether) have been influenced primarily by the second.

7.29. Geography and climate make certain major cities, notably Los Angeles and Tokyo, particularly prone to ‘smog’ caused by photo-chemical reaction of certain gaseous emissions from motor vehicles (mainly hydrocarbons and oxides of nitrogen). Gaseous emissions generally are the subject of controls, for health reasons, in most of the countries which also seek to control lead emissions, and we intend to consider them in more detail in our next report. For normal purposes controls are achieved through regulation of engine design and operation, but to meet the more stringent standards necessary to minimise the formation of smog most cars require exhaust catalysts, or catalytic converters (see box overleaf), to be fitted in their exhaust systems. These devices are deactivated by lead, and this is the principal reason why unleaded petrol is required to be available by law in the USA and Japan, as it will shortly be in Australia, and is available commercially in Canada.

*We understand that unleaded premium and regular petrol (95 and 76 RON respectively) are sold in ‘capital cities and health resorts’ in the USSR in addition to normal leaded (0.4 g/l) grades (98 and 93 RON). No information is available on relative sales volume.

EXHAUST CATALYSTS

The combustion of fuel mixture in an engine is never complete. Some of the fuel escapes from the flames into crevices and cool areas, while some burns incompletely and leaves carbon monoxide instead of burning right through to carbon dioxide.

The flame in an engine can reach a temperature of $2,200^{\circ}\text{C}$, at which the oxygen and nitrogen of the air will combine to give nitrogen oxides. As a result the exhaust gases contain hydrocarbons, carbon monoxide, and nitrogen oxides in potentially toxic concentrations.

Exhaust emissions of carbon monoxide, hydrocarbons and nitrogen oxides can be reduced to a certain extent by modifications to the engine combustion, as is done in Europe. Any further reduction is usually effected (notably in the USA) by passing the hot exhaust through an exhaust catalyst, otherwise known as a catalytic converter, which can be of two main types.

The simplest type, called an oxidation catalyst, is a canister filled with a porous ceramic element which is coated with a thin layer of platinum, palladium or other noble metals of the platinum group. The exhaust gas is mixed with a little air from a small pump at a point just before it enters the canister. The platinum catalyses the reaction of carbon monoxide and hydrocarbons with air to give harmless carbon dioxide and water vapour. This type of catalyst however does not affect nitrogen oxides.

The second and more complex type of catalyst is called a three-way catalyst, because simultaneously it removes all three pollutants. Its construction is similar to the oxidation catalyst except that it uses a different mixture of platinum metals, has no air pump, and requires a special mixture strength.

The engine has to be electronically controlled to give a fixed level of oxygen in its exhaust. This is detected with a special sensor in the exhaust manifold. With the exhaust gas thus controlled the catalyst causes a reaction between oxygen and nitrogen oxides on the one hand and carbon monoxide and hydrocarbons on the other. Nitrogen oxides are reduced to harmless nitrogen, and the carbon monoxide and hydrocarbons are oxidised to carbon dioxide and water as before.

Lead compounds in the exhaust gases inhibit these reactions. They are said to 'poison' the catalyst, a metaphor which is more apt than might be supposed since other toxic metals such as arsenic have the same effect on platinum catalysts. The catalysts work by possessing active centres at which the gases are energized into reactions which would otherwise be very slow. The 'poison' operates by deactivating the centres, which consequently cannot promote the reaction. Leaded petrol (at 0.4 g/l) also physically plugs the gas passages in the catalysts.

The accidental use of a gallon or so of leaded petrol will reduce the activity of a catalyst, but it will partially recover on returning to unleaded petrol. With the three way catalyst, not only the catalyst but also the oxygen control sensor are poisoned by lead.

7.30. In the USA oil companies have been obliged since July 1974 to make available an unleaded grade of petrol (which in practice is usually about 92 RON) at all service stations for use in vehicles fitted with exhaust catalysts. The need for this arose originally from Californian emission control standards, later applied federally under the Clean Air Act 1970. In promulgating the regulations in January 1973, however, the Environmental Protection Agency proposed a separate set of regulations requiring progressive reductions—on health grounds—in the average lead content of petrol. The final regulations were promulgated in December 1973 and since then EPA has regarded the unleaded gasoline regulations and the lead in gasoline phasedown regulations (which were made under the same section of the Act) as complementary to each other.^(18, 22).

7.31. The phasedown programme was designed to achieve a 60–65 per cent reduction from 1971 levels of lead in the air, and required major refineries to maintain the quarterly average lead content of their gasoline output below a progressively reducing ceiling—initially 1.7 g/US gallon (0.45 g/l) and latterly (from October 1980) 0.5 g/US gallon (0.13 g/l). Small refineries were allowed an extra 2 years to meet the final standard. By the beginning of 1982 unleaded grades were estimated to account for 52 per cent of total gasoline sales, and in February 1982 the EPA (responding to pressures from industry and the White House) published a notice of proposed rulemaking which explored various options for the future handling of the phasedown programme, including rescission of the 0.5 g/US gallon (0.13 g/l) standard altogether. As a result of public reactions to that document, and further reviews of the health evidence, the EPA announced in August 1982 that it now believed the case for the phasedown programme to be as strong as ever. It also proposed that instead of regulating the average amount of lead in all gasoline it should in future set a maximum lead content for leaded gasoline only. The average standard was now having the undesirable effect of enabling refiners to add increasing proportions of lead to their declining output of leaded gasoline as their unleaded output went up⁽²²⁾. The new proposal represented a significant tightening of the programme, and under the final rule promulgated in November 1982⁽¹⁸⁴⁾ major refiners, and importers, may now not add more than 1.1 g/US gallon (0.29 g/l) of lead (California has been given a waiver until April 1983). Small refiners were to be allowed to add up to 1.9 g/US gallon (0.5 g/l) until July 1983, when they had to conform to the general standard, but this has been under review following a successful challenge by the refiners before the US Court of Appeals. We understand that California will be introducing a state limit of 0.8 g/US gallon (0.21 g/l) from October 1984.

7.32. Forecasts prepared for the EPA⁽¹⁸⁴⁾ indicate that by 1990 the demand for leaded gasoline will have declined (from 48 per cent) to 19 per cent. This might seem to support the argument that the phasedown programme could now be left to market forces. The EPA has made it clear, however, that it is concerned about the health effects of locally high levels of emission, particularly in urban areas. It has also noted that development of lead-tolerant exhaust catalysts (see paragraph 7.37) could mean that overall restriction of lead additive usage would have to be considered⁽²²⁾.

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7.33. In **Japan** an advisory limit of 0.02 g/l lead for regular petrol has been in operation since 1975. Premium grade petrol has a maximum lead content of 0.31 g/l. Since the market shares of premium and regular petrol in Japan are about 5 per cent and 95 per cent respectively, the average lead content is 0.03 g/l. This is the lowest for any of the developed countries. Unleaded regular grade petrol in Japan is around 90 RON.

7.34. **Australia** is currently going through a period of transition. At present the oil industry observes a voluntary limit of 0.84 g/l, but State Governments (who have the primary responsibility for control of vehicle emissions) apply lower limits in Victoria (0.3 g/l), Tasmania (0.45 g/l) and major urban areas of New South Wales (0.4 g/l). Studies carried out in 1979–80 for the Australian Environment Council and the Australian Transport Advisory Council indicated that in order to meet standards relating to airborne lead and photochemical smog recommended by the National Health and Medical Research Council, the optimum course of action, having regard to energy conservation, economic, environmental and health considerations, would be to adopt US emission control standards, involving the introduction of exhaust catalysts and unleaded petrol*^(19, 185). In July 1980 the New South Wales State Government announced its intention to introduce legislation requiring all retail petrol outlets to have 92 RON unleaded petrol for sale from July 1984 and requiring all new cars sold in the State and manufactured after January 1985 to be designed to run on that grade and to meet US emission control standards. It was recognised that a unilateral move by NSW would have serious adverse effects on industry, consumers and government administration⁽¹⁸⁵⁾, and in February 1981 the Federal and State Governments agreed on a common policy that from July 1985 91.5 RON unleaded petrol was to be available at a significant number of retail petrol outlets and that from January 1986 all new cars manufactured for sale in Australia must be designed to operate on unleaded petrol and meet the equivalent of the US Federal 1975 exhaust emission standards. Leaded petrol will continue to be sold for use in vehicles built prior to January 1986. It is likely to be available in diminishing quantities for 12 to 15 years or more.

7.35. The majority of countries in **Western Europe** including the UK, whether or not they are members of the European Community, base their lead legislation on Directive 78/611/EEC (text at Appendix 6), which since January 1981 has set upper and lower limits of 0.4 and 0.15 g/l respectively. We refer to this in more detail in paragraphs 7.40 and 7.113 *et seq.* Since 1976 the Federal Republic of Germany has set a maximum limit of 0.15 g/l and this has been or will be followed by Denmark, Greece, Netherlands, UK, Austria, Norway, Sweden and Switzerland. Table 7.2 compares the progress made by EC Member States in implementing the Directive.

7.36. No Western European country has unleaded petrol commercially available in the market place and none has so far stated any intention of

*The studies also indicated that if airborne lead were the only consideration, a reduction in the lead content of petrol to 0.15 g/l would be sufficient to meet the NHMRC's recommended lead in air standard of not more than 1.5 µg/m³, averaged over 3 months, which is equivalent to the United States standard—see paragraph 2.7.

requiring an unleaded grade in the future. In all countries the actual lead levels in commercial petrols are close to the legal maxima. Gaseous emissions regulations currently in force in Western Europe, including agreed plans for tighter limits, do not require the use of exhaust catalysts. However, there has been pressure from some countries (notably the Federal Republic, Sweden and Switzerland) for even more stringent controls, which for at least some European car models would require the use of catalysts, with unleaded petrol. The matter is currently under study under the auspices of the Commission of the European Communities (see paragraphs 7.124–7.125).

7.37. In the context of these developments, some interest has been expressed in the possible development of lead-tolerant catalysts. We are aware that this has been the subject of much research, for example by the Johnson Matthey Group, which claims that a lead-tolerant catalyst it has designed has considerable durability in road use⁽¹⁸⁶⁾. According to the Department of Industry, however, 'lead-tolerant catalysts so far developed do not have good records for durability in terms of operational corrosion, efficiency or total blockage'. It seems therefore that in the current state of knowledge unleaded petrol would become a necessity in Europe if emission controls were further tightened to any significant extent.

Action in the United Kingdom

7.38. Concern about the level of lead in the environment in the early 1970s led the then Government to announce towards the end of 1972⁽¹⁸⁷⁾ a phased

TABLE 7.2

Progress by European Community Member States in implementing Directive 78/611/EEC on the lead content of petrol

	Lead content (g/l)	Effective date		Lead content (g/l)	Effective date
Belgium	0.84 ¹		Ireland ⁴	0.64 ¹	
	0.55	Jan. 1978		0.4	Sept. 1982
	0.45	Oct. 1978	Italy	0.635 (Prem)	Apr. 1964
	0.4	July 1981		0.635 (Reg)	Dec. 1967
Denmark ²	0.7 ¹			0.4	July 1981
	0.4	Jan. 1978	Luxembourg ⁵	0.4	Jan. 1981
	0.15 (Reg)	July 1982		0.84 ¹	
	0.15 (Prem)	July 1984	Netherlands	0.4	Jan. 1978
France	0.64	Dec. 1966		0.15	1986
	0.55	Apr. 1976	United Kingdom	0.64	Jan. 1973
	0.5	Jan. 1979		0.55	Nov. 1974
	0.4	Jan. 1981		0.5	Dec. 1976
FR Germany	0.4	Jan. 1972		0.45	Jan. 1978
	0.15	Jan. 1976		0.4	Jan. 1981
Greece ³	0.84	Apr. 1966		0.15	Jan. 1986
	0.63	March 1979			
	0.5	Feb. 1980			
	0.4	Jan. 1981			

Source: The Associated Octel Co. Ltd.

¹Previous commercial practice. ²Excludes Faroes and Greenland. ³See note (2) to Table 7.1.

⁴Directive contained derogation for Ireland of up to 5 years. ⁵See note (3) to Table 7.1.

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programme of reductions in the maximum permitted lead content of petrol, which then stood at 0.84 g/l. Although this programme, which was to be achieved by voluntary agreement with the oil industry, was expected to result in some fall in overall lead emissions from motor vehicles, the primary objective was to ensure that emissions were brought back to the 1971 level (7,300 tonnes per annum) and held at that level. The planned reductions in the maximum permitted lead content were therefore the amounts which it was estimated would be sufficient to offset the projected growth in car ownership and vehicle mileage.

7.39. The first reduction, to 0.64 g/l in January 1973, was purely notional in its effect, in that commercial factors were already holding lead content well below that level, and it was not sufficient to prevent emissions rising to an all time high of 8,400 tonnes (see Figure 2.7). The further reduction to 0.55 g/l planned for January 1974 was then postponed by nearly a year because of the difficulties faced by refiners in maintaining octane quality during the world oil crisis, and in the aftermath of the crisis there were problems in achieving further reductions by voluntary agreement alone. From 1976 onwards, starting with the reduction to 0.5 g/l, it has been necessary for the Government to prescribe statutory limits by regulations made under section 75 of the Control of Pollution Act 1974. Table 7.3 compares the trends in vehicle lead emissions and total petrol consumption between 1971 and 1981 and shows how the combined effects of reduced demand after the oil crisis and the progressive reductions of lead content* have served to keep emissions close to their 1971 level during the period 1974–1980.

TABLE 7.3
Trends in UK vehicle lead emissions and petrol consumption, 1971–1982

	<i>Maximum lead content (g/l)</i>	<i>Index of UK vehicle lead emissions¹ (1971=100)</i>	<i>Index of UK petrol consumption² (1971=100)</i>
1971	0.84	100	100
1972	0.84	111	106
1973	0.64	115	113
1974	0.64/0.55	109	110
1975	0.55	101	108
1976	0.55/0.5	104	113
1977	0.5	101	116
1978	0.45	100	123
1979	0.45	100	125
1980	0.45	103	128
1981	0.4	92	125
1982	0.4	95	129

1982 data are provisional

Sources: ¹Department of the Environment (from data in Figure 2.7)

²Department of Energy, Digest of Energy Statistics (from data on total inland deliveries of motor spirit)

*Since the introduction of statutory limits, the average amounts of lead in petrol, according to information in *Petroleum Review*, have been:

1976 0.48 g/l 1977 0.45 g/l 1978 0.42 g/l 1979–80 0.41 g/l 1981 0.38 g/l

7.40. It was not until 1981, however, that lead emissions fell to a level below that of 1971. As long ago as December 1973, the Commission of the European Communities had proposed, in response to moves in the Federal Republic, a draft Directive laying down a maximum permitted lead level for the Community of 0.4 g/l, to take effect from January 1976, with a further reduction to 0.15 g/l in the case of regular petrol from January 1978. The Government had earlier claimed⁽¹⁸⁸⁾ that 0.45 g/l marked a critical point for the oil and motor industries, and had planned no reductions below that level, although some contingency planning had been set in train⁽¹⁸⁷⁾. The Directive (which we discuss in more detail in paragraphs 7.113–7.127) was eventually approved in June 1978. Table 7.4 compares the progress of lead reductions in the UK, as originally put forward and as actually achieved, with those proposed for the Community. We have already drawn attention to the fact that progress in the Community has, in the event, been slower than was expected at the time when we last reported on this subject (paragraph 1.13).

7.41. In parallel to the Lawther Working Party⁽¹³⁾, the Department of Transport set up in December 1978 a Working Party on Lead in Petrol (WOPLIP), consisting of government officials and specialists from the oil and motor industries, to assess the feasibility, effectiveness and costs of various options for reducing lead emissions from vehicles, taking the EC maximum lead content (0.4 g/l) as the starting point. The Working Party reported in July 1979⁽¹⁸⁹⁾ with a detailed analysis of five options. Of these, the most important for present purposes were:

- (i) fitting lead filters in the exhaust systems of new cars;
- (ii) reducing lead content to the lowest practicable level (0.15 g/l) consistent with maintaining octane quality; and
- (iii) requiring new cars to be designed to operate on unleaded 92 RON petrol while allowing existing cars to continue using existing grades of petrol with lead at 0.4 g/l.

7.42. The principal quantitative findings of WOPLIP, in relation to these options, are summarised in Table 7.5. The estimated overall energy penalties (2nd row of figures) were broadly consistent with the conclusions of the European oil industry's 'RUFIT' study^(190, 191), which was still in progress, although WOPLIP was able through its oil industry membership to take some preliminary account of it. We refer to that study in more detail in paragraph 7.82 *et seq.*

7.43. Of the options considered by WOPLIP, reduction of lead content to 0.15 g/l without loss of octane numbers was the most expensive in terms of cumulative costs and the second most expensive (after 92 RON unleaded petrol) in terms of annual costs. The Government however decided, in the light of the Lawther Working Party's recommendations, that the balance of advantage lay in reducing the maximum permitted lead content to 0.15 g/l. In announcing the Government's decisions on the Lawther Report to the House of Commons on 11 May 1981⁽¹⁴⁾, Mr. Tom King, MP, explained that 0.15 g/l was the lowest lead level consistent with the continued use of car engines of

TABLE 7.4

UK lead in petrol reduction programme—progress against original targets and European Community proposals

Lead content (g/l)	UK lead reduction programme			EC proposal December 1973	EC Directive 78/611/EEC 29 June 1978
	Dates proposed in August 1972 for introduction	Dates on which implemented			
	(Advisory)	(Advisory)	(Statutory)		
0.64	January 1973	January 1973			
0.55	January 1974	November 1974			
0.5	—		December 1976		
0.45	January 1976		January 1978		
0.4	—		January 1981	January 1976	January 1981
0.15	—		January 1986 (planned)	January 1978 (regular grade only)	—

present design; that the move would reduce lead emissions by about two-thirds; and that this reduction would be achieved some 10 years earlier than by any other practicable method.

7.44. Mr. King's statement also announced the Government's acceptance of the Lawther Working Party's recommendation that measures should be taken to keep the annual mean concentration of lead in air to less than 2 $\mu\text{g}/\text{m}^3$ in

TABLE 7.5
WOPLIP—summary of main quantitative findings
(at 1978 prices)¹

	<i>Option i</i> 97 RON 0.4 g/l + filters	<i>Option ii</i> 97 RON 0.15 g/l	<i>Option iii</i> 92 RON unleaded
Additional annual ² crude oil requirement (million tonnes)	nil	0.5	1.15
Annual overall energy penalty ³ compared with 97 RON/0.4 g/l	nil	2½%	5%
Additional annual petrol production costs, including amortised investment ⁴	nil	£90m	£106m
Car manufacturers' initial capital costs:			
domestic	£33m	nil	£30m
importers	£167m	nil	£111m
total	£200m	nil	£141m
Additional annual motor manufacturing costs (including imports)	£45m	nil	£3.7m
Net present value of total additional costs, capital and recurring, for period 1978–1998: ⁵			
energy costs ³	nil	£844m	£754m
motor manufacturing	£414m	nil	£72m
total	£414m	£844m	£826m
Total additional annual costs in 1998 ⁵ , including manufacturers' return on capital	£72m ⁶	£124m	£199m
Extra annual cost to motorist	£5–9	£7–8	£17–18
Forecast lead emissions as percentage of 1971 emission level:			
in 1986	% 91	% 35	% 80
in 1990	73	36	41
in 1998	55	38	0

Notes

¹It is not possible to update prices to 1983 values without reworking some of the underlying calculations, but as a rough guide energy and motoring costs may be doubled and manufacturing costs multiplied by a factor of 1.8.

²All annual figures represent position after full implementation of options.

³Including effect of higher fuel consumption at lower compression ratios.

⁴The information made available to WOPLIP did not permit refinery investment to be identified separately from operating costs.

⁵Calculation assumes 3.9% per annum real increase in energy costs over period 1978–1998.

⁶Excludes the additional £4–5m estimated to be needed to cover the costs of used filter disposal.

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places where people were liable to be continuously exposed for long periods—a standard also proposed in a draft EC Directive which has since been adopted (82/884/EEC)⁽³²⁾—see paragraph 2.7. In the paper which accompanied the statement the Government indicated that the action being taken to reduce emissions from vehicles and industry was expected to ensure that the proposed lead in air standard could be met, although the situation in 1986, after action on lead in petrol had taken effect, might need special monitoring to identify any continuing hot-spots. The need and scope for additional monitoring (see paragraph 4.55) would be discussed with the local authority associations.

Options for achieving further reductions in lead emissions from petrol

7.45. If the planned UK position of lead at 0.15 g/l is taken as the starting point, there are three main options for achieving further reductions in lead emissions. Lead filters (lead traps) could be fitted in car exhaust systems, where they would serve a dual purpose as silencers and in trapping lead particles in the exhaust; steps could be taken to encourage greater use of diesel and other alternative fuels; and lead could be phased out (with or without a reduction in octane quality).

7.46. Further reductions in petrol lead content which stop short of zero are, in our view, not a practical proposition. At levels below 0.15 g/l the value of lead as an octane booster is only marginal and many existing car engines would begin to develop valve recession problems (see paragraph 7.24). It also becomes prohibitively expensive to maintain present octane values (see paragraphs 7.56–7.69). We therefore consider there would be little sense, on economic grounds, in opting for an intermediate reduction below 0.15 g/l—a view which is shared by the WOPLIP Report, where the cost of this option (assuming a reduction in octane to 92 RON) is estimated as broadly similar to that of opting for unleaded petrol. Our conclusion therefore is that if there is a case for further reduction of lead in petrol, it must entail total elimination.

7.47. Lead filters have been the subject of much development work and trials in recent years, but have not been applied commercially. They consist of chambers filled with chemically impregnated alumina-coated tangled steel thread, through which the exhaust gases pass, as through conventional silencers. In normal driving conditions a substantial proportion of the lead in the gases is deposited and retained. With lead at 0.4 g/l, filters need to be larger than ordinary silencers, and would require design changes (mainly in the floor pan) in many models of car. Not surprisingly (as the Department of Industry has confirmed to us) the motor industry has tended to be unenthusiastic about them for this reason. Of the various options considered by WOPLIP (paragraph 7.41), filters were found on most calculations to be the cheapest (although much the most expensive in terms of initial capital costs), and the only one not involving a energy penalty (ignoring additional manufacturing inputs). The option ranked worst on lead emission reducing potential, and difficulties were noted in connection with the disposal of used filters. It was also noted that a statutory requirement for lead filters would need prior notification to the EC and would run counter to current moves towards harmonisation of

emission controls and type-approval standards (a potential objection which we feel has some force).

7.48. The latest research and development work by Associated Octel and by AERE Harwell⁽¹⁹²⁾ suggests that with petrol lead at 0.15 g/l it is possible to fit most cars with filters of the same dimensions as the standard silencers (although we understand that there have been some minor difficulties with the Mini Metro, which has a particularly compact silencer). Thus the bulk problem would in most cases no longer apply, although there would still be cost penalties in more elaborate materials and manufacturing processes and in the greater weight of filters compared with silencers. Engine manufacturers would also need to be assured that back-pressure and increased exhaust valve temperature were not likely to cause problems. On the basis of the trials at Harwell it is claimed that filters of the latest design will effectively trap all sizes of particulate emission and that as much as 75 per cent or more of the lead is caught. It is also claimed that with stainless steel casing filters could have a useful life of at least 50,000 miles (compared with 15,000–20,000 miles for ordinary mild steel silencers).

7.49. The efficiency of lead filters progressively deteriorates, however, and the Department of Transport, in its evidence to us, has assumed (conservatively) an average efficiency of 50 per cent. Efficiency also varies according to driving conditions. We understand that if a car fitted with a filter accelerates to a high speed after a period of urban driving there is a strong 'purging' effect as the increased gas pressure dislodges some of the lead which has hitherto been trapped, although efficiency is largely restored after a period of driving at the higher speed. We consider this a distinctly adverse feature of the filter, as currently developed, in that these temporary surges in lead emission would be likely to be concentrated at the entry points to motorways and other arterial roads radiating from or circling urban areas, where population densities will be relatively high.

7.50. Our main concern, however, (which is shared by the Automobile Association) is over the disposal problem and the risk that use of filters would to some extent merely substitute one pollution pathway for another. Research commissioned by Associated Octel⁽¹⁹³⁾ has suggested that, given suitable commercial incentives, the stainless steel or lead smelting industry could recover (through existing motor trade and car breaking channels) and safely recycle, at a profit, lead from the vast majority of used filters*. Our reaction to these findings was somewhat sceptical, given the traditional characteristics of the metal recovery trade, and we have since heard that our scepticism is shared by parts of the lead industry. We suspect that to the extent that old filters are not simply dumped intact, much of the lead in them will end up being burned in the local iron foundry or scattered on waste ground. For this reason, principally, we would not favour the adoption of lead filters as a long-term measure, although we do not dispute the fact that they are capable of reducing lead emission by at least 50 per cent. We would also argue that if it is possible for a

*By contrast, WOPLIP estimated that a disposal scheme would cost £4–5 million per annum.

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pollutant to be reduced or removed at source this is intrinsically more attractive, both technically and environmentally, than the use of an 'add-on' device to mitigate its effects. Nevertheless, since filters can be fitted to existing cars, they could (as the UK Petroleum Industry Association has suggested) be considered as an interim measure to reduce emissions during a transition to unleaded petrol.

7.51. Encouraging greater use of diesel and other alternatives to petrol is an option which can be pursued in tandem with either of the other two main options, bearing in mind that other environmental effects might need to be balanced against the reduction in lead emissions. As we have noted (paragraph 7.9), there are signs that market forces are narrowing the price gap between petrol-engined and diesel-engined cars. These might be sufficient over time to bring about diesel penetration of up to 25 per cent of the car market, compared with a current share in the UK of about 0.5 per cent. If leaded petrol were to continue in use, lead emissions would be gradually reduced as diesel use increased. Fiscal inducements (as we understand have been applied in France) could of course be considered if it were thought desirable to accelerate the process. Beyond 25 per cent we understand the oil industry would have difficulties in meeting the demand for diesel fuel of the right quality at an economic price, because of practical refinery constraints. Liquid petroleum gas (LPG) is in many respects an attractive, high octane, fuel for cars, but its storage and distribution arrangements have certain obvious drawbacks. Like diesel oil, the supply is limited (capable of replacing perhaps up to 5 per cent of current petrol sales), and some fiscal weighting in its favour would almost certainly be necessary to persuade more than a small minority of car owners that it was worth incurring the initial expense and subsequent inconvenience. The current cost (excluding VAT) of converting a car to run on LPG is at least £300, according to the Society of Motor Manufacturers and Traders; it would therefore make much greater sense to use LPG in buses, taxis and short-haul commercial vehicles operating from depots, and to discourage its use in private cars. Of other possible fuels, methanol is perhaps the most promising. Widespread use of neat methanol as a fuel (as opposed to use as a blending agent with petrol) does not appear to be in immediate prospect (see paragraphs 7.65 and 7.68), and should perhaps be discounted for this purpose until research is much further advanced.

7.52. The final option would be the introduction of unleaded petrol and the progressive phasing out of leaded grades. By definition this would be the most effective way of bringing airborne lead emissions to a minimum. It does, however, have major technical and economic implications, and we devote most of the rest of this chapter to an examination of these.

Emission forecasts for alternative options

7.53. We asked the Department of Transport to estimate for us the comparative effects on lead emissions of six different scenarios:

- A continuation of the present position at 0.4 g/l lead (base case)
- B 0.4 g/l lead plus filters for new cars (WOPLIP's first option)

- C unleaded petrol for new cars with existing grades at 0.4 g/l lead progressively phased out*
- D 0.15 g/l (as planned from 1 January 1986)
- E 0.15 g/l plus filters for new cars
- F unleaded petrol for new cars with the (by then) existing grades at 0.15 g/l lead progressively phased out.

7.54. The results are shown in Figure 7.3. In the notes accompanying the graph, the Department have explained the various assumptions they have had to make about manufacturers' lead-times and the time required for negotiations in the European Community. The only comment we would make here is that, from our reading of the evidence and the various discussions we have had, the assumptions appear to be somewhat pessimistic. In particular, an overall timescale for unleaded petrol of 8 years from decision to implementation (with the suggestion that negotiations and industry preparations should proceed sequentially rather than in parallel) seems unnecessarily long, although clearly much would depend on the climate in which negotiations in the Community were conducted. We return to that issue later (paragraphs 7.113–7.127).

7.55. Comparison of the curves in Figure 7.3 demonstrates the valuable and early benefit which will result from the reduction of lead to 0.15 g/l by 1986, and serves to reinforce the Government's argument that the chosen course of action (curve D), as a means of bringing about a quick and substantial fall in emissions, was more attractive than the other main options considered by WOPLIP (curves B and C)**. We do not dissent from that judgement, in the context that it was made. However we seek to take a longer view of environmental problems. In view of our general conclusion at the end of Chapter V, we consider it undesirable that lead, with all its known characteristics, should continue to accumulate in the environment from this source, even at a reduced rate. We therefore **recommend** that reduction of the maximum permitted lead content of petrol to 0.15 g/l should now be regarded as an intermediate stage in the phasing out of lead additives altogether. We consider the practical implications of this recommendation in the remainder of the chapter.

Octane quality without lead

7.56. Once it is decided that leaded petrol should be phased out, a number of options for the introduction of unleaded petrol are in principle possible, with varying implications for the oil and motor industries and for the motorist. As we have noted (paragraph 7.19), the only otherwise acceptable alternative to lead as an anti-knock additive, the manganese compound MMT, has itself come under suspicion on health grounds. The basic choice is between maintaining present octane quality and following the low-octane route adopted in North America, Japan and Australia, which would mean car engines having to be

*This was in fact the UKPIA's preferred option at the time of the discussions which preceded the Government's decision of May 1981—see paragraph 7.83.

**The Department has in fact made appreciably more pessimistic assumptions than WOPLIP in relation to the unleaded option. Similar graphs in the WOPLIP Report and in the paper accompanying the Government's May 1981 statement (paragraph 7.43) show curves C and D crossing after 8 years, compared with nearly 12 years in Figure 7.3.

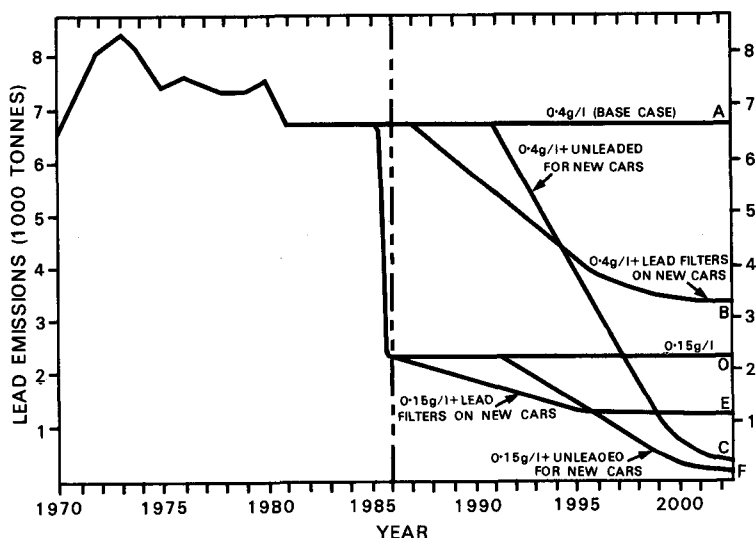


Figure 7.3
Lead emission forecasts for alternative options

Source: Department of Transport

Notes by the Department of Transport to Figure 7.3

1. The forecast emissions for each lead reducing option (A to F) are based on actual petrol consumption in 1981 (18.72 million tonnes). From current UK and European experience average lead in petrol is assumed to be 0.02 g/l below the maximum legal level. Emissions are assumed to be 70 per cent of lead in petrol. Additional considerations and assumptions have been made in arriving at the forecast for the following options:

2. Option B: 0.4 g/l plus filters on new cars

As these filters would need to be significantly larger than existing silencers, floor-pan modifications involving substantial design changes would be required for the majority of vehicles. For this reason a total lead-time of 5 years is allowed, with new vehicles being fitted by the beginning of 1987. An assumption of a 50 per cent filter efficiency has been made for vehicles throughout their life.

3. Option C: 0.4 g/l for existing cars plus unleaded for new cars

The graph assumes that this option is only practicable if implemented simultaneously with our European partners. A period of 3 years is allowed for discussion in Europe to persuade other Governments and a further 5 years for the motor industry to make the necessary changes.

4. Option D: 0.15 g/l for all cars

This is current UK policy, which will be fully implemented by 1 January 1986.

5. Option E: 0.15 g/l plus filters on new cars

Development work by filter manufacturers has shown that using petrol with 0.15 g/l lead content, lead filters can be designed to fit within existing silencer casings, thus obviating the need for redesign of car floor-pans or re-routing of exhaust systems. For this reason the graph assumes that under this option the manufacturers would need a shorter

lead-time than in option B to fit all new vehicles with filters. The 3 year period proposed should be sufficient to plan and set up arrangements for the manufacture and disposal of filters. An assumption of a 50 per cent filter efficiency has been made in this case also.

6. Option F: 0.15 g/l for existing cars plus unleaded for new cars

The same assumptions apply as in Option C.

re-designed to run at lower compression ratios. Finding a substitute for the lubricating properties of lead (paragraphs 7.21–7.24) is a separate issue, which we deal with later (paragraphs 7.74–7.76).

7.57. High octane petrol without lead can be produced by more intensive refining or by blending it with oxygenates—synthetic, oxygen-containing compounds, mainly derived from petroleum—or by a combination of both. ‘Straight-run’ petrol, i.e. the fraction obtained by straight distillation of crude oil, has a very low octane number, because most of the hydrocarbons in it have a simple molecular structure which readily breaks up under high compression and temperature in an engine cylinder. The object of refining is to increase the proportion of hydrocarbons with stronger and more compact molecular structures and hence higher octane numbers. This is achieved by heating the straight-run petrol and by subjecting it to more severe processes, most of which involve the use of catalysts (hence the terms ‘catalytic cracking’ and ‘catalytic reforming’). The various products obtained by these processes are then blended in varying proportions (depending on the characteristics of the original distillate) to form petrol of the required quality and octane number.*

7.58. Since the energy for refining comes for the most part from the burning of crude oil, it follows that the more severe the process the greater the overall crude oil requirement. Nevertheless it is technically possible to produce fairly high octane petrol by refining alone and it has been argued, by Bryce-Smith and others (¹⁷, ¹⁹⁴), that not only is this the most efficient route in terms of overall energy usage but that there may even be a net saving compared with present refinery practice using lead. The argument, it appears, rests very substantially on studies carried out in the early 1970s by the Universal Oil Products Company of Illinois, who design and license refinery equipment. Using mainly theoretical modelling techniques, UOP calculated that the energy needed for refining and using unleaded petrol was optimal at about 96 RON, taking car petrol consumption into account. By contrast studies by the European oil and motor industries (¹⁹¹) (see paragraph 7.82 *et seq.*), conducted with similar objectives in mind but based on actual refinery and car performance data, concluded that the optimum RON for unleaded petrol was 92. In neither case is it disputed that raising octane numbers above the optimum value causes refining costs to escalate steeply.

7.59. In practice we understand 95 RON is about the highest octane number which normal refineries are capable of producing by refining alone, and then only in limited quantities, since the most useful high octane components are

*For a simple account of hydrocarbon chemistry see paragraph 2.3 *et seq.* of our Eighth Report(*).

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those which demand the greatest expenditure of refinery energy and which depend on expensive facilities with limited capacity. The UK Petroleum Industry Association (UKPIA), in its evidence to us, rejects the argument that current surplus capacity in the industry would enable high octane petrol to be refined at little or no extra cost, pointing out that this surplus exists only in basic crude oil distillation facilities. No meaningful estimates, according to UKPIA, can be made of the investment that would be required to maintain present octane numbers without lead*, since it would involve a massive restructuring of UK refineries with large-scale replacement of current units by others based on novel technology. UKPIA has also criticised the UOP thesis on various points of detail.

7.60. On the evidence before us we find it difficult to come to any firm conclusion on these technical questions of refinery economics. Whatever energy savings may in theory be possible with unleaded petrol at 96 RON, the existing structure and characteristics of the oil industry must in practice place constraints on the amount and type of capital investment that can realistically be contemplated at any particular time. Such a judgement, however, can only be based on surmise. The evidence presented to us by UKPIA is (as it would itself acknowledge) a consensus view based on the fairly limited information which member companies are prepared to divulge to each other. Nevertheless we see no compelling reasons for challenging it, and we are reinforced in this view by the fact that all those countries who have so far introduced, or who plan to introduce, unleaded petrol on any scale have opted for an overall reduction in octane number. Whether or not their decision was a sensible one, the fact remains that it has been taken; and notwithstanding the autonomy enjoyed by subsidiaries of multinational companies in the oil industry there is a strong presumption that the pattern would repeat itself elsewhere if other countries decided to phase out lead from petrol.

7.61. Attempting to maintain high octane by refining alone introduces the question of higher aromatic content and increased emission of polynuclear aromatic hydrocarbons (PAH), which may themselves present air pollution problems⁽¹⁹⁵⁾. This matter will be considered in our next Report in the wider context of vehicle emissions.

7.62. As an alternative to more intensive petrol refining, high octane oxygenates can be used as octane improvers or 'petrol extenders'. Several of them can be made from sources other than petroleum and therefore may be cheaper to produce than petrol. Where derived from petroleum, however, their cost and availability will depend on the balance of demand for the full range of refinery products and at the margin they tend to be relatively expensive. Their use is also limited by the extent to which they modify the essential qualities of petrol.

7.63. The best known oxygenates are the alcohols (e.g. methanol, ethanol, and tertiary butanol (TBA)) and the ethers (e.g. methyl tertiary butyl ether (MTBE)). They need to be used in concentrations greater than 5 per cent to

*According to the Marketing Director of BP Oil, quoted in *The Times*, 13 October 1982, an investment of between £1,000 million and £2,000 million would be required, spread over 10 years.

have any worthwhile effects. There is already experience with these components in a number of countries. Ethanol is blended with petrol in concentrations of up to 20 per cent ('gasohol') in the USA, Brazil* and other countries with large agricultural surpluses. In Europe, some countries (notably France, FR Germany and Sweden) have been conducting major test programmes on possible use of methanol and ethanol. In general these programmes are motivated not only by the need to compensate for lead reductions but also by desires to provide a better cushion against fluctuations in crude oil price and supply, to correct a growing imbalance in demand for light and heavy fuels, and to reduce dependency on crude oil in the longer term.

7.64. A study recently completed for the Commission of the European Communities ⁽¹⁹⁶⁾ has concluded that in Western Europe only methanol, TBA and MTBE can be produced at a cost comparable to their value in the gasoline pool—i.e. do not involve greater overall refinery operating costs compared with the cost incurred in producing the same quantity and quality of gasoline without oxygenate addition. Because of supply limitations and technical constraints, however, it is estimated that oxygenates are unlikely to contribute more than 5 per cent of the pool by 1990. This would be sufficient to compensate for the loss of octane numbers if lead levels were reduced to 0.15 g/l throughout Western Europe, but would not permit widespread production of unleaded petrol without either octane reduction or substantial capital investment.

7.65. **Methanol** can be produced in large quantities from a wide range of materials and has a high RON value. But it has a low MON value (see paragraph 7.14 and box), has an energy content of only half that of petrol, increases petrol volatility, is corrosive to some engine components, and is prone to phase separation in the almost inevitable presence of water in the petrol distribution system. **TBA** has fewer drawbacks, but its price and availability is dependent on those of propylene oxide, of which it is a co-product, and it has no crude oil substitution value. **MTBE** is frequently cited as the most promising of the oxygenates, particularly by advocates of high octane unleaded petrol, since there is practical experience of blending it with petrol in concentrations of up to 10 per cent with few apparent technical problems. According to UKPIA, a concentration of 12 per cent MTBE would be needed to produce 97 RON petrol from a base value of 94 RON (the level to which refineries typically need to refine petrol before the addition of lead at 0.15 g/l). For a UK petrol market of 19 million tonnes per annum in 1985 this would amount to a demand of 2.3 million tonnes of MTBE per annum. Existing annual European MTBE production is currently running at about 0.5 million tonnes and a further 0.2 million tonnes of production capacity is under construction. None of this is in the UK. The UKPIA has estimated that provision of sufficient volumes of MTBE to replace lead in the UK without octane reduction would require the construction of 5 plants the same size as the recently reported proposal by Highland Hydrocarbons.

7.66. Besides the substantial capital costs of such undertakings, both the availability of suitable feedstocks and technical feasibility raise potential difficulties. The synthesis of MTBE depends at present on limited supplies of

*A 95% ethanol fuel is also widely sold in Brazil.

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refinery gas (isobutylene), which is reacted with methanol derived from natural gas (methane). The more complex process which Highland Hydrocarbons propose to use involves relatively untried technology, and we understand its economic success depends very much on the continuing availability of low-price butane from the North Sea installations⁽¹⁹⁶⁾.

7.67. General concern about the technical drawbacks of using higher levels of oxygenates in petrol, especially methanol, has led to a draft EC Directive proposing an overall limit of 10 per cent total oxygenates, of which not more than 3 per cent may be methanol. There are also health and safety considerations. Methanol is a highly toxic substance and in its pure form poses greater fire risks than petrol because it burns with an invisible flame. The combustion products of both methanol and MTBE contain aldehydes and are thus potentially toxic. Although these considerations have not prevented the trial use in the USA and FR Germany of car engines designed to run on pure methanol, the long-term health implications of greater use of these oxygenates have yet to be fully assessed. There is at present no evidence that MTBE itself is any more hazardous to health than petrol. We would, however, like to see more attention paid to the reactivity of MTBE and its breakdown products in the environment⁽¹⁹⁷⁾, and consider that they need to be better understood before production on a large scale is contemplated.

7.68. In the long run there are various possibilities for supplementing or replacing petrol. Current opinion in the US motor industry is that all the known technical problems of using pure methanol as a fuel will be solved before the turn of the century. There is also the prospect of methanol being transformed chemically into MTBE and other ethers or into a mixed hydrocarbon substitute for petrol of almost 100 RON by the Mobil process, which is due to be tried commercially in New Zealand and South Africa. There is a well-established technology for producing high octane petrol from coal (for example, the Sasol process in South Africa), but in normal circumstances it appears to be uneconomic (even in the USA, which has relatively cheap coal). The feasibility of using hydrogen as a transport fuel cannot be ruled out, although it is likely to be decades before its safety and other practical problems are resolved.

7.69. Our conclusion therefore is that there is no immediate prospect of a breakthrough in petroleum refining and associated technology, or in the development of alternative fuels, which would permit average petrol octane values in Europe to remain at their present level in the event of substantial moves towards unleaded petrol during the remainder of the 1980s. We believe that moves within the next decade or so will be dominated by the present configuration and supply constraints of the European oil industry, and that removal of lead must inevitably lead to a reduction in octane number. As we discuss later, the oil industry's preferred grade for unleaded petrol would be 92 RON, although depending on market factors it is possible that limited quantities of 95/96 RON might be available, as has happened in the USA. For the motor industry, however, the general requirement would be to design engines that could run at lower compression ratios. We discuss the implications of that in more detail in paragraphs 7.75–7.81.

Transitional arrangements for existing cars

7.70. Once it is decided to go down the unleaded, low octane route, it would be necessary to have an extended transitional period during which the present generation of cars could see out their useful lives on petrol of the appropriate quality. We have been informed by oil industry representatives that continued use of lead (at 0.15 g/l) is the simplest and most economic way of meeting that need, and would avoid the problem of valve seat recession (paragraphs 7.21–7.24). The question then arises whether leaded petrol should continue virtually indefinitely for the relatively small number of cars which would remain on the road once the leaded grade ceases to be commercially viable for the major oil companies, which we understand might be after about 10 years.

7.71. Veteran and vintage cars were developed on unleaded petrol, at low compression ratios, and will therefore present no problem. Other cars over 30 years old will perform adequately on 92 RON, since RON values for premium petrol began to exceed that level only in the early 1950s. Since the majority of these cars will be doing very low mileages the valve recession problem can be overcome (as in the past) by periodic regrounding and tappet adjustment.

7.72. A more serious practical problem—which has been stressed by the Department of Transport and the motoring organisations—is that of more recent models with high compression engines and unhardened valve seatings, which in other words are dependent on the continued availability of high octane petrol with the necessary lubricating properties (whether or not these are achieved by the presence of lead). It is not unusual for certain present-day cars, even in normal conditions of use, to be giving good service well into their second decade, particularly if they have been manufactured to above-average standards and have been well looked after by their owners. One of the advantages claimed for the present policy of maintaining octane ratings with lead at the reduced level of 0.15 g/l is, of course, that this problem would not arise.

7.73. In our view, the addition of lead to petrol should for all practical purposes be discontinued after a reasonable transitional period. We feel it would be sensible for this period to coincide with the oil companies' suggested 10-year phasedown (although we note a comment by Ford that 15 years would be the 'minimum hardship' timescale, on the grounds that at least 10 per cent of the final cohort of 'leaded' cars would still be in use after that period). Whatever period is decided on for the phasing out of lead, we see no reason why the availability of high octane petrol should not continue indefinitely, for as long as there is a market for it. In the limited quantities that would be required, no problems should arise over the supply of suitable high octane blending components (e.g. MTBE). Some changes in the distribution and pricing structure would, however, have to be accepted, and owners of elderly cars might eventually have to pay premium prices for their petrol. The business of supplying high octane petrol would probably pass from the major oil companies to specialist companies, as has happened with tractor vaporising oil (used by certain veteran tractors) and 'Avgas' used by older piston-engined aircraft.

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7.74. There then remains the valve recession problem. One solution that has been suggested is that the problem could be overcome by the addition of phosphorus compounds such as tricresyl phosphate (TCP). These have been used in the past (as 'ignition control additive' (ICA) or 'upper cylinder lubricant') but their use has disappeared, largely because lead has made them unnecessary. There are also a number of technical drawbacks. TCP causes a build-up of deposits on spark plugs and can raise octane requirement, when present in petrol, by about 0.2 points. Phosphorus additives also 'poison' exhaust catalysts and hence have been banned in the USA. Finally, on environmental grounds, the renewed use of phosphorus compounds on any scale would be open to some objection. An alternative solution (and appreciably cheaper than TCP) would be to add lead in trace quantities at the BS 4040 minimum of 0.05 g/l. We would not rule this out altogether, particularly since the total gallonage of petrol involved would be small. But as we have said elsewhere our preference is for avoiding all unnecessary processing and usage of lead. The fitting of valve seat inserts in old engines (see Figure 7.2) is a relatively simple job and is often done as a standard routine when engines are reconditioned. Owners of cars over 10 years old who wish to continue covering high annual mileages would probably find the cost relatively modest when compared with the cost of maintaining their cars in adequate mechanical condition generally, not to mention the cost of poorer fuel consumption compared with that of more modern cars.

Implications for the motor industry

7.75. The Department of Industry has told us (and this is borne out by evidence from industry itself) that 'the industry is neutral as regards the merits of a further substantial reduction in the lead content of petrol or a move to lead-free petrol' but that it requires adequate time to adjust its production. The general consensus is that it would take 3–5 years. The industry has also stressed that, to avoid prejudicing the competitive position of UK manufacturers, any move towards more stringent lead emission controls must necessarily be made on a pan-European, not merely a European Community, basis. Otherwise (in the Department's words) 'they would have to compete in Europe from a home base working to different standards'.

7.76. There is also the question of costs. As we have mentioned in paragraph 7.43, the decision to reduce lead in petrol to a maximum of 0.15 g/l represents the greatest reduction which the Government believes can be achieved consistent with the continued use of car engines of the type currently in production for the European market. Any decision further to reduce lead in petrol would therefore have implications for the design and manufacture of cars in the UK, and in Europe generally. Although the changes required are not major, and do not involve novel technology, manufacturers would need to invest additional resources in redesigning high compression engines for operation at a lower compression ratio, in re-engineering of valve seats and other components to compensate for the loss of lubrication currently provided by the lead compounds, and in consequent re-engineering of vehicles in relation to engine tuning and emission standards.

7.77. The WOPLIP Report⁽¹⁸⁹⁾ estimated that the investment and engineering cost for the whole UK market (manufacturers and importers) of phasing out lead was of the order of £141 million at 1978 prices (perhaps £250 million at today's prices) (see Table 7.5). We asked the Society of Motor Manufacturers and Traders and the major UK manufacturers how much of this estimate was considered to be genuinely incremental to expenditure which the industry would be incurring anyway in updating and replacing current models over the relevant period. The SMMT evidently felt unable to answer the question, although one company commented 'virtually all'. Two other companies provided tentative estimates of the capital cost to them of introducing new engines to run on unleaded petrol—in one case £2–2.5 million, in the other £25–50 million. Although we decided it would be unproductive to pursue this question in detail, our impression is that much uncertainty exists in the industry as to the true incremental costs of moving to unleaded petrol and that the WOPLIP estimate should be treated with caution.

7.78. The American and Japanese markets already require cars which will run on unleaded petrol, and these will be joined by Australia in 1986. Those European manufacturers who export to the USA (Japan is in practice an insignificant market) already produce engines which can run on low octane unleaded petrol without damage. There are, of course, other factors besides technical requirements which determine the extent to which particular export markets are exploited. For example the US 'Corporate Average Fuel Economy' (CAFE) requirements (see paragraph 7.112) penalise imports of high performance and luxury cars where the manufacturer cannot balance them with more economical models (or qualify for exemption as a 'low volume manufacturer'). We note that BL are now finding it difficult to meet CAFE targets, because their current contribution to the US market is largely confined to the Jaguar range of high performance models. In this respect they are differently placed from several other major manufacturers in continental Europe, whose exports to the USA include volume cars, some of which have diesel engines⁽¹⁹⁸⁾.

7.79. In principle, a move towards unleaded petrol in Europe could give a greater stimulus to the export of domestic European models which at present cannot be exported to countries with unleaded petrol. Thus even a unilateral move by one country might not necessarily place its indigenous industry at a disadvantage. Some support for this view within the British motor industry has been quoted. According to a spokesman of the British Automotive Parts Promotional Council: 'This industry has the technology; all the car manufacturers have engines which will run on lead-free petrol. We don't stand in its way. In fact, it could mean more business for us'.*

7.80. In practice, of course, the European industry and market are large enough to be autonomous, particularly for volume cars, and there is a natural tendency towards common standards. At present most of these are built around high compression engines, requiring high octane petrol, with the

**The Guardian*, 14 September 1982.

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associated benefits in terms of performance and fuel economy. They are also designed for emission standards which are considerably less stringent than those demanded by the USA and Japan, and it is these (rather than the questions of compression ratio and lead content) which are the significant competitive factor. But, whilst these standards may well inhibit the ability of some (though not all) European manufacturers to export to the USA (and in theory to Japan), the converse is not true. Although some imported Japanese models are fitted with high compression engines, to satisfy the needs of certain sectors of the market, the majority of models are now sold with low compression engines similar to, if not identical with, the equivalent models sold in Japan. These already achieve standards of fuel economy which compare favourably with European models with higher compression engines. Although the evidence we have received does not stress the point, it is clear to us that the prospect of further Japanese penetration lies behind much of the concern about the competitive implications of a move to unleaded petrol, at least in the UK.

7.81. We agree that the motor industry needs to be given adequate notice of any change. We also consider it essential to remove as soon as possible the present uncertainty about future requirements (including the possibility that unleaded petrol might become necessary in Europe to meet gaseous emission standards—see paragraphs 7.36 and 7.123–7.125). But provided the industry is given protection from immediate outside competition by a long enough period of notice, on the evidence before us we doubt whether the question of costs is particularly significant. As we see it, car manufacturers could justify a claim that there were real costs involved only if they could show that there were substantial R & D and capital expenditure in re-designing engines additional to what they would otherwise be undertaking, or that the average costs of production with parallel production lines for engines destined for different markets were significantly higher than at present.

Implications for the oil industry

7.82. As we have already indicated, we agree with the general consensus in the oil industry that, within the normal range of octane requirements for petrol engines, the addition of lead saves refinery costs and some crude oil. This consensus largely derives from a study, 'the rational utilisation of fuels in private transport' (commonly known as the RUFIT study), conducted between 1977 and 1980 by the Oil Companies' Study Group for Conservation of Clean Air and Water in Europe (CONCAWE) as part of a wider joint study under EC auspices with the Common Market Committee of Motor Manufacturers (CCMC) on the inter-relationship between energy economy, fuel quality and emission standards in vehicles. The main purpose of the RUFIT study was to determine the optimum fuel quality, from the overall energy conservation standpoint, in relation to different levels of lead content. The original RUFIT Report⁽¹⁹⁰⁾ dealt with the impact on crude oil requirements and refining costs of reducing lead from 0.6 g/l to 0.4 g/l and 0.15 g/l, but in a second Report⁽¹⁹¹⁾ the results were extrapolated to the unleaded petrol case. A study carried out between 1979 and 1980 by the Australian Committee on Motor Vehicle Emissions (COMVE) for the Australian Transport Advisory Council (ATAC)

came to broadly similar conclusions⁽¹⁸⁵⁾ (see paragraph 7.34). Figure 7.4, taken from the second RUFIT Report, illustrates the relationship between lead content and refinery fuel consumption at different octane values.

7.83. The RUFIT study has had a major influence on subsequent discussion of the economic implications of further lead reductions, e.g. in the WOPLIP Report (paragraph 7.41) and in a recent study by the Fellowship of Engineering⁽²³⁾, and is also reflected in evidence to us from the UK Petroleum Industry Association and the Department of Transport. The UKPIA have told us that of the various options considered by WOPLIP the one chosen by the Government was the one least favoured by the oil industry, whose first preference (in the event of further reductions from the then level of 0.4 g/l) was for an unleaded regular grade of 92 RON for new cars, with continued availability of 97 RON at 0.4 g/l for existing cars. (The present 2 star grade (90 RON) would have disappeared, because of the practical difficulty of distributing more than one leaded grade in parallel to the unleaded grade.) This option would have involved the industry collectively in considerably lower levels of additional capital investment and operating costs and in the case of some refineries would have involved no significant extra cost.

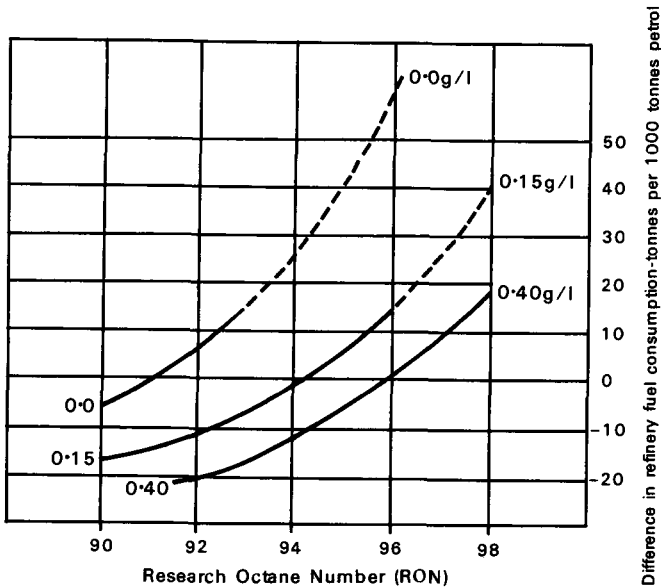


Figure 7.4

Effect of lead content on refinery fuel consumption

Incremental crude v RON: constant petrol consumption

Base case: 1,000 tonnes petrol, 96 RON, lead content 0.4 g/l

Source: Reference⁽¹⁸¹⁾

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7.84. The position now is that most companies have committed (or are about to commit) resources to instal new plant capable of satisfying the Government's requirements (i.e. 0.15 g/l of lead at existing grades by the end of 1985). These plans assume that there is to be no further reduction in lead content for the foreseeable future. A decision that the reduction to 0.15 g/l should be a merely transitional stage in the complete elimination of lead from petrol would carry different investment implications for many companies, and UKPIA has stressed the need for an early decision one way or the other. (We were informed in December 1982 that final investment decisions—where they were still open—could not be postponed by more than a few months.)

7.85. 'Clear pool octane' (i.e. average octane of petrol produced by refineries before the addition of lead compounds) is already around 92 RON in this country. The marketing of unleaded petrol would therefore present no major problem for the industry and could begin virtually immediately. A transitional requirement to produce 97 RON petrol at 0.15 g/l could be met in various ways, depending on the circumstances of individual refineries and their owners. In some cases, major investment could be reduced or even avoided altogether and the demand would be met by additional refining, blending and imports. In other cases, companies are likely to take the view that the transitional stage is likely to be too long (or the prospect of European agreement on unleaded petrol too uncertain) to justify postponement or modification of the investment already planned.

7.86. Continued production of 97 RON with reduced lead content in parallel to the introduction of the unleaded grade would obviously be less attractive to the industry than the original proposal it put to the Government, because of the extra cost of having to refine to 97 RON with only 0.15 g/l lead compared with 0.4 g/l; but as usage of premium grade declines (with pre-1986 cars reaching the end of their lives), clear pool octane number—and hence costs of refining—would also decline. Figure 7.5 shows the predicted change in clear pool octane number over time, taking as a starting point the octane value (93.6) corresponding to existing petrol grades with 0.15 g/l of lead. Initially the disappearance of 90 RON 2-star leaded petrol would cause a slight rise, but by year 4 the level would be back to 93.6, and thereafter would continue to decline. After 10 years most existing cars would be reaching the end of their useful lives and the clear pool value would be only marginally above its present value (i.e. with 0.4 g/l of lead) of about 92 RON.

7.87. As we have already indicated in paragraph 7.55, we favour the combined route of 97 RON at 0.15 g/l for existing cars and 92 RON unleaded for new cars as providing the fastest and most effective means of reducing lead emissions from petrol, and since this would have significantly different investment implications for many companies compared with the present plan for a finite reduction to 0.15 g/l for all cars, we would stress the need for the oil industry to be given as early warning as possible of the change of plan.

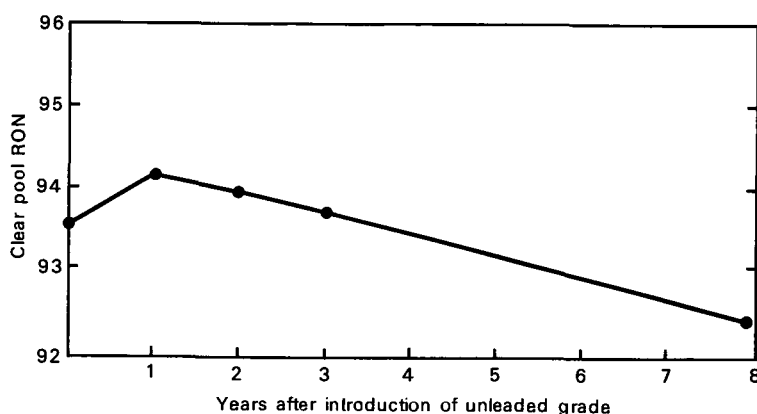


Figure 7.5

Effect on clear pool octane of phasing out leaded petrol

Assumes introduction of 92 RON unleaded, with 97 RON leaded at 0.15 g/l being phased out over 10 years.

Source: UK Petroleum Industry Association

Effects on national energy costs

7.88. Apart from questions of competition, there has been much discussion about the economic effects of reducing or phasing out lead in petrol. In considering this question, we have found that the RUFIT study⁽¹⁹¹⁾ provides the most satisfactory model.

7.89. We have already seen (Figure 7.4) how refining costs increase, as octane quality is raised, at any given level of lead. On the other hand raising the compression ratio of a car engine to take advantage of higher octane will give improved fuel economy. Since these two elements—vehicle consumption and refinery consumption—move in opposite directions, it is possible to demonstrate that for a given vehicle population, covering a constant mileage, and a refinery system of given characteristics, there is an optimum RON value for each lead level at which the energy used in the total vehicle-refinery system is at a minimum. It can also be shown that total energy consumption increases as lead is progressively reduced. The effects of these relationships are shown in Figure 7.6, also taken from the RUFIT study. It will be seen that the optimum RON value for unleaded petrol is 92, and this provides the basis for the oil industry's proposals for phasing out lead (see paragraph 7.83).

7.90. According to the RUFIT analysis, the planned reduction in the lead content of petrol from 0.4 g/l to 0.15 g/l will not materially affect vehicle fuel efficiency, but it will increase the amount of crude oil otherwise required for petrol (currently about 22 million tonnes per annum in the UK) by about 1.9 per cent, as may be seen from Figure 7.6. This increase is attributable solely to

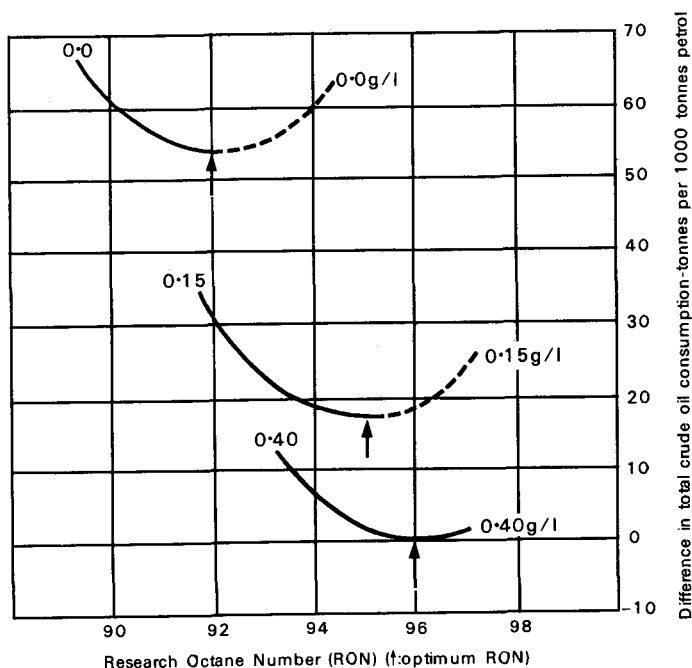


Figure 7.6

Effect of lead content on crude oil consumption and optimum octane number

Base case: 1,000 tonnes petrol, 96 RON, lead content 0.4 g/l

Source: Reference (191)

additional energy used in the refining process. Improvements in refinery efficiency are unlikely to yield more than marginal savings. Some small additional savings would be made as a result of the winding down of lead additive manufacture and of improved spark plug and exhaust system durability (see paragraph 7.96).

7.91. Reduction of lead content to zero, assuming this is accompanied by reduction of average octane to 92 RON, would mean a negligible refinery penalty, which UKPIA estimates at about 0.2 per cent, but there would be a more substantial penalty (5 per cent) resulting from poorer fuel economy at lower compression ratios. The combined penalty of 5.2 per cent may be seen from Figure 7.6. The savings attributable to additive manufacture and car maintenance factors would here be somewhat greater.

7.92. It is important, however, to appreciate that these penalties have been calculated on a deliberately artificial basis. As the WOPLIP Report pointed out, the deterioration in fuel economy which can be predicted on basic thermodynamic principles to occur when compression ratio is reduced by a given amount is liable to be masked by extraneous factors. This is particularly true if

the reduction in compression ratio is phased in over a period of years, as new models of car gradually replace older models. During that period it could be expected that motor manufacturers would maintain, if not step up, their efforts to achieve improved fuel economy through weight reductions, better aerodynamics and improved engine, tyre and transmission system design. Accordingly WOPLIP suggested that 'the only reliable basis for assessing the fuel economy implications of use of lower octane fuel in vehicles is to assume that *other factors relevant to their fuel consumption are constant*' (our italics). This is precisely the basis on which the RUFIT calculation was made—i.e. the relative amount of crude oil required to enable a given design of engine to cover a constant mileage at different octane values, assuming a fixed relationship between fuel economy and compression ratio.

7.93. This type of calculation—of a potential or theoretical cost—has a legitimate place in economic analysis. But we question whether the textbook approach should be applied to the exclusion of the equally valid, and arguably more realistic, calculation of the actual cost (if any) which, in resource use terms, might be predicted to occur by the time the vast majority of cars in this country are running on 92 RON petrol, after taking into account technological and other factors affecting fuel consumption.

7.94. Table 7.6 provides the basis for such a calculation. For this purpose we assume that unleaded petrol would be introduced, for new cars, from the same date (1 January 1986) on which the lead content of existing petrol is reduced from 0.4 to 0.15 g/l* and that because of distribution constraints only 4 star leaded petrol (97 RON) would continue to be sold. In order to compare the long-term cost of a switch to unleaded petrol with the cost of the present plan to reduce lead to 0.15 g/l, it is necessary to forecast demand for petrol at the end of the period of phasing out the leaded grade. According to UKPIA it is reasonable to assume that after 10 years demand for leaded petrol would be reduced to insignificant levels, and we have therefore based the calculations on 1996.

7.95. Forecasting future petrol demand is notoriously difficult because of the large number of variables. UKPIA believe that demand will be 'flat' over the next decade or so and that by 1996 it will be around 18 million tonnes per annum, or slightly below the present level. This forecast, however, has built into it the assumption that during the 10 year period, 1986–1996, overall fuel economy will improve by 20 per cent although this will be largely cancelled out by factors which would otherwise cause a rise in demand. (See Note 1 to Table 7.6 for further details.) The 20 per cent figure is regarded as highly conservative and we understand that predictions of up to 40 per cent are made within the motor industry. UKPIA regards 30 per cent as a 'middle of the road' estimate, but for present purposes we have treated it as the upper end of the range.

7.96. Because of the multi-product nature of the oil refining process it is not possible to make a precise estimate of the amount of crude oil (or equivalent

*For the reasons given in the Department of Transport's notes to Figure 7.3 and discussed in paragraph 7.54, introduction of unleaded petrol might in practice be delayed by a few years.

TABLE 7.6

Estimates of crude oil required for petrol in 1996 at different lead levels and on various assumptions about improved fuel economy
(Millions of tonnes of crude oil, including equivalent energy from other sources; RON values are for average pool octane after addition of lead)

	<i>Overall improvement in fuel economy 1986—1996</i>		
	0%	20%	30%
Forecast demand for petrol in 1996 on the basis of 96.4 RON ¹	22.5	18.0	15.75
96.4 RON: 0.15 g/l Pb Additional crude oil for refinery fuel ² (compared with 96.4 RON: 0.4 g/l Pb)	0.43	0.34	0.30
92.4 RON: unleaded (i) Additional crude oil for refinery fuel ³	0.04	0.04	0.03
(ii) Additional car crude oil consumption due to reduced compression ratios ³ (compared with 96.4 RON: 0.4 g/l Pb)	1.13	0.90	0.79
	1.17	0.94	0.82
Total crude oil required for petrol ⁴			
96.4 RON: 0.4 g/l Pb	27.00	21.60	18.90
96.4 RON: 0.15 g/l Pb	27.43	21.94	19.20
92.4 RON: unleaded	28.17	22.54	19.72
Overall increase (decrease) in total crude oil requirement (taking 0.15 g/l as base)			
96.4 RON: 0.4 g/l Pb	(0.43)	(5.83)	(8.53)
96.4 RON: 0.15 g/l Pb	BASE	(5.49)	(8.23)
92.4 RON: unleaded	0.74	(4.89)	(7.71)
Increase (decrease) in total crude oil requirement exclusive of fuel economy element (unleaded compared with 0.15 g/l)			
(i) Additional crude oil for refinery fuel	(0.39)	(0.30)	(0.27)
(ii) Car consumption	1.13	0.90	0.79
(iii) Lead additive manufacture and car maintenance ⁵	(0.07)	(0.07)	(0.07)
Net energy benefit forgone	0.67	0.53	0.45

Notes to Table 7.6

¹UKPIA forecasts that annual demand for petrol will grow from 18.72 m tonnes in 1981 to 19.1 m tonnes in 1986 (the year in which it is assumed the new unleaded grade would be introduced, in parallel to the planned reduction in lead content from 0.4 to 0.15 g/l for leaded petrol). By 1996 (when the majority of existing vehicles will have been phased out) it is forecast that demand on the basis of existing pool octane (96.4 RON) would fall to 18m tonnes. This forecast assumes an overall improvement in fuel economy during the period of 20 per cent largely offset by growth in demand of nearly 18 per cent due to increased vehicle mileage, 'trading up' by car owners and other factors ($19.1 \times 0.8 \times 1.178 = 18$). The different figures for forecast demand in the Table have been obtained by varying the 20 per cent factor. The 0 per cent column has been calculated to serve purely as a base-line and does not represent UKPIA's actual minimum forecast, which is for 18 m tonnes. The 30 per cent column makes no allowance for any stimulus which greater fuel economy might give to car ownership and use.

²Petrol demand multiplied by 0.019 (RUFIT factor from Figures 7.5 and 7.7).

³UKPIA's apportionment of RUFIT factor, 0.052, from Figure 7.7 (0.002 refinery/0.05 car; the refinery element differs slightly from that implied by Figure 7.5).

⁴Petrol demand multiplied by an average petrol/crude oil conversion factor 1.2, taken from the RUFIT study⁽¹⁹⁾, plus additional costs at reduced lead levels as above. (As noted in paragraph 7.96 the use of the 1.2 factor is to be treated with caution. However in a similar calculation the WOPLIP Report (Annex 12) multiplied a postulated petrol demand by a factor of 1.197 to arrive at an equivalent crude oil demand, which was then further increased by various factors representing refinery and/or fuel consumption penalties.)

⁵UKPIA's broad estimates of annual energy savings attributable to reduced lead additive manufacture and transport and to improved durability of spark plugs and exhaust systems (expressed as million tonnes of crude oil):

at 0.15 g/l compared with 0.4 g/l	—	0.04m
at zero lead compared with 0.4 g/l	—	0.11m

energy) required to meet any given forecast of overall petrol demand. Varying one element (petrol) has an impact on the way the barrel is 'cut' and may introduce distortions if demand for other petroleum products remains constant. There is therefore no single factor which can be used to convert any given quantity of petrol into the equivalent quantity of crude oil. Nevertheless, as explained in Note 4 to Table 7.6, it is possible (by applying a calculation similar to one made by WOPLIP) to arrive at a very broad estimate, which helps to illustrate the relative magnitude of the crude oil requirements on different assumptions about lead content and fuel economy and their various permutations, as shown in the Table. Thus, on the assumption that fuel economy improves by 20 per cent over the 10 year period, the overall energy requirement, expressed in terms of crude oil, would be about 21.9 million tonnes at 0.15 g/l and 22.5 million tonnes without lead. If ancillary savings in lead additive manufacture and longer spark plug and exhaust system life are taken into account (Note 5 to Table 7.6), moving from 0.15 g/l to the unleaded position would add the equivalent of 0.5 million tonnes, or about 2½ per cent, to the overall energy required for motoring.

7.97. Our conclusion from this analysis is that whilst there is indeed an economic cost in both the 0.15 g/l and the unleaded options compared with the present position at 0.4 g/l or with each other, the potential penalties for the unleaded option are better seen as benefits forgone than as perceived costs. They are also small in absolute terms*, and altogether trivial when compared with the most conservative estimate of the benefits likely to accrue from

*0.5 million tonnes of crude oil would have cost about £70 million at January 1983 prices—equivalent to roughly three days of UK North Sea tax revenue in 1982/83.

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substantial and continuing improvements in fuel economy. We consider it improbable in the extreme that any such penalties would be experienced in the form of higher absolute expenditure compared with today.

Fuel economy and improved technology

7.98. We have seen much practical evidence of the kinds of improvements in fuel economy which are currently being made and can be expected for the future. By these we mean improvements which are due to technological factors, rather than factors such as consumer taste (e.g. for 'performance'), driving style, safety measures (e.g. speed limits) etc., which we discuss later. Even on the basis of well-tried engine technology, it can be demonstrated that there is potential scope for achieving improved fuel economy to a degree which could easily outweigh the effect of a drop of 5 or 6 octane numbers.

7.99. For a start, existing engines could be manufactured to the much finer tolerances and higher standards of quality control achieved by some manufacturers. This would help to reduce the problem of 'octane spread'—the need for unnecessarily high octane fuel in order to compensate for 'production scatter' between individual cylinder compression ratios (as a result of poor manufacturing) or uneven fuel distribution. We understand from UKPIA that there have been some notorious examples of this phenomenon among certain European models (including British ones). There has been some improvement in recent years, but octane spread in Europe is still, on average, about 5 points, which means that a typical car might waste about $2\frac{1}{2}$ points when running on its recommended fuel. We have been informed that this waste is equivalent to $1\frac{1}{2}$ per cent of total petrol consumption, or about 0.3 million tonnes per annum for the UK petrol-driven vehicle population. Another engine phenomenon which causes a waste of octane points is called octane requirement increase (ORI). The octane requirement of a new or decarbonised engine progressively increases by 2–7 numbers (depending on the engine design and operation), and eventually stabilises somewhere between 10,000 and 20,000 miles. The increase is due to the effect of lead, carbonaceous and oil additive deposits in the combustion chamber. Manufacturers therefore have to specify a better fuel than the new engine requires to cope with this phenomenon. Although the use of unleaded fuel in current engines will not necessarily reduce ORI, there may be scope for improvement in engines designed specifically for unleaded fuel.

7.100. Other measures could include greater use of diesel engines, better design of fuel and combustion systems, and electronically controlled ignition which enables, through a feedback system, knock to be detected and avoided. A note describing these and other potential solutions is in Appendix 5.

7.101. Recent developments in engine technology suggest that the boundaries within which thermodynamic relationships between compression ratio, octane requirement and fuel economy operate may be shifting—to the extent of calling in question some of the assumptions which lie behind the RUFIT study. The May 'Fireball' system, in its Jaguar application, has demonstrated the feasibility of running an engine efficiently on 91 RON petrol at a compression

ratio of 11.5:1. This compares with typical compression ratios of 9:1 or 10:1 in conventional engines currently requiring 97 RON petrol. If the trend towards higher compression ratios at lower octane requirements continues, the potential energy saving in higher octane petrol may in practice be unattainable or simply not needed. As we have mentioned earlier, frictional and other energy losses set an upper limit to the compression ratio of any given engine design; emission control standards may also act as a constraint. Raised compression ratios and leaner mixtures with wider spark plug gaps increase the ignition voltage required for good initiation of combustion. This imposes stringent demands on the insulation and water exclusion properties of the whole system. Finally, as engine weight increases with compression ratio, there may be further constraints in terms of suspension and braking system design and handling characteristics. We understand that these last considerations make it unlikely that petrol engine compression ratios in popular family cars will rise above 12:1 in the foreseeable future. The demand for high octane petrol could therefore substantially diminish.

7.102. It should also be remembered that engine design is only one factor contributing to improved fuel economy and may even be outweighed by other factors such as weight reductions, better aerodynamics, and reduced frictional losses in transmission systems, wheels and tyres. As far as European cars are concerned, we understand that the contribution would be shared about equally between engine design, on the one hand, and the other factors combined. On any reasonable view, the thermodynamic element has to be seen as a relatively small factor in the range of potential fuel savings.

Costs to the motorist

7.103. In very broad terms the energy penalty of 2½ per cent involved in moving to unleaded petrol from 0.15 g/l leaded (paragraph 7.96 and Table 7.6) would represent an extra 0.1p or so for each mile driven, or about £10 per annum to the average private motorist driving 10,000 miles at 30 mpg and with petrol costing £1.70 per gallon at the pump. This is within the same order of magnitude as the calculations made by WOPLIP (Table 7.5). We would however argue, on the basis of our conclusion in paragraph 7.97, that it is not instructive to express the penalty in these terms.

7.104. In practice, the motorist would perceive no fuel consumption penalty in a gradual movement towards lower compression engines. This is already apparent if a 'snapshot' is taken of cars available on the market today. Figure 7.7, compiled from motoring magazine road test data, plots the relationship between engine size and average fuel consumption of a representative group of cars in the 'family' range of 950–1650 cc, distinguishing cars which require 2 star petrol from those requiring higher grades. We recognise that data from the motoring press may be susceptible to minor errors and inconsistencies which the standard government test figures avoid, and that fuel consumption is related to many other factors besides engine size. Nevertheless we feel that compared with the government tests (which use a standard reference fuel and

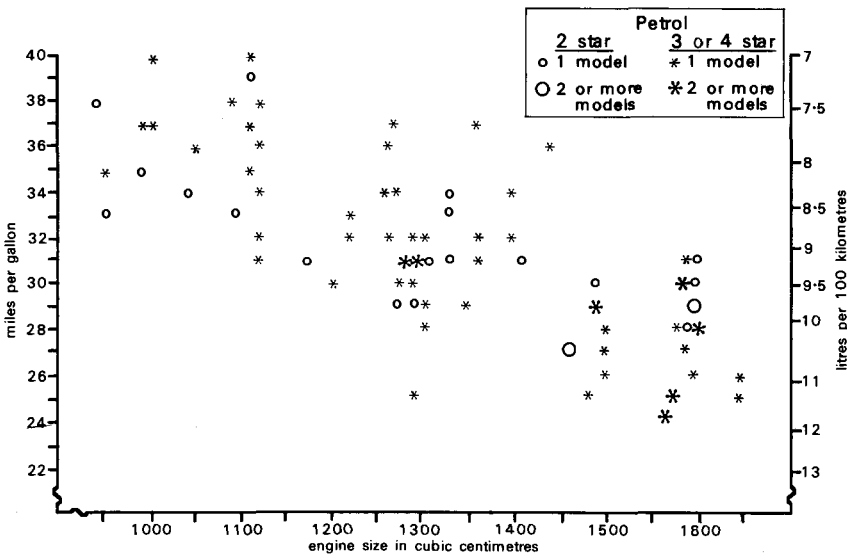


Figure 7.7
Relationship between engine size, recommended grade of petrol and average petrol consumption

Mpg figures are averages of overall petrol consumption recorded in road tests; only models tested by at least two magazines have been included (23 2-star models and 61 3- and 4-star models).
Sources: Autocar, Motor and What Car? February/March 1983

are carried out, usually by the manufacturers themselves, in laboratory and test-track conditions) they give a more useful guide to the comparative overall fuel economy of different models. They are carried out using the grade of fuel recommended by the manufacturers and in real-life driving conditions (which the Government tests have been criticised* for not simulating sufficiently accurately). They are also widely relied on by the car buying public.

7.105. The picture that emerges from Figure 7.7 is one of apparent randomness, with high compression engines not enjoying any consistent superiority over low compression ones. The underlying explanation, which is perhaps not of great concern to many motorists, is that the pool of cars available at any one time contains a great variety of designs—engines, transmissions, bodywork and other features—at different stages of their evolution. When a new design is introduced, it is likely to be significantly more efficient than the one it replaces. But the majority of designs in the pool, given the long commercial life of the main mechanical elements of a car, will be several years old. If we assume an engine has a production life of 10 years or more, it is likely to serve a succession of models. It follows that at any particular time it will be the age of the car

*For example, by the Automobile Association, *Drive*, April 1983.

design rather than the compression ratio of the engine that will be the major determinant of fuel efficiency.

7.106. Consumers, therefore, will not experience any worsening of fuel economy as they switch to new, low compression cars but on the contrary will continue in general to benefit from the steady improvements we have discussed earlier. It is possible that some people will forgo this benefit, or even tolerate a slight loss, by 'trading up' to regain lost performance. We understand that this has not occurred to any marked degree in America and Japan, and it is possible to counteract it by setting official fuel consumption ceilings for manufacturers (see paragraph 7.112).

7.107. The effect of the introduction of unleaded petrol on petrol prices is impossible to predict with any confidence, because of the complex pricing and marketing strategies of the oil industry and the difficulty (for those outside the industry) of getting hold of reliable data. If we assume it is left to market forces to determine prices, the best guide we have is the difference in price between leaded and unleaded gasoline in the United States, typically about 6 or 7 cents per US gallon, within a range of about 2–12 cents. This can to some extent be checked against informal expressions of view by oil industry spokesmen, for example a recent statement by the Marketing Director of BP Oil* that unleaded 92 RON petrol would cost only about 1p more than the present 2 star price. Initially, according to UKPIA, the major oil companies would set the differential between leaded and unleaded petrol at a level which maximised their commercial return. But after a few years, as usage of leaded petrol declined, they would wish to accelerate the process and pull out of the leaded business as quickly as possible (leaving the residual demand to be handled by specialists, as we have suggested in paragraph 7.73). Whatever happens, the price difference would be very small—a matter of a few pence at the most—and any increase in pump price directly attributable to the removal of lead would be vastly less than the increases regularly experienced as a result of fiscal changes, the vagaries of the world market or the external value of the pound sterling.

7.108. There is, however, a case for some regulation of the price of unleaded petrol. In situations where leaded and unleaded petrol of the same grade co-exist, as in the USA and Canada, a price differential in favour of leaded petrol can result in misfuelling. Leaving aside the question of damage to exhaust catalysts (paragraph 7.29 and box), continued use of leaded fuel in cars designed to run satisfactorily on unleaded petrol would frustrate lead emission control policy and could also serve to retard the rate at which owners traded in their present cars for new, 'unleaded' models. We understand that the solution adopted in North America, of having different sized fuel tank inlets and fuel pump nozzles so as to make it physically difficult to put leaded petrol into an 'unleaded' car, has been the subject of abuse, with owners modifying their cars illicitly or using adaptor funnels intended for emergency use only. To avoid these problems, it is intended that leaded and unleaded petrol in Australia should cost the same^(185, 199). This will involve some fiscal adjustment, and we

**The Times*, 13 October 1982.

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recommend that the same policy should be applied in this country, to ensure that the price of unleaded petrol does not exceed that of the highest grade of leaded petrol during the period in which leaded petrol is phased out. Whether a fixed differential in favour of unleaded petrol should be maintained, as advocated by the Campaign for Lead-free Air (CLEAR) and others, we are less certain, although we believe the matter should be kept under review.

7.109. As far as capital costs of new cars are concerned, we have to rely on statements by industry rather than attempt calculations ourselves. Although the WOPLIP Report attempted an overall estimate of the incremental investment and engineering cost for the whole UK market (paragraph 7.77 and Table 7.5), for perhaps obvious reasons it did not attempt the highly speculative task of forecasting the effect on average car prices of phasing out lead. One industry source has suggested a price increase (at today's prices) of £6–14 per car; another has suggested an increase of £60–100, and that this would be higher if geared to UK requirements only. Clearly much will depend on individual manufacturers' marketing strategy at the time. For the reasons we have already indicated (paragraph 7.81), we suspect that the first estimate may be a more reliable guide to the level of price increase which ought in practice to be sufficient to amortize actual costs.

7.110. As we mentioned earlier (paragraph 7.25–7.26), the use of unleaded petrol results in some savings in maintenance costs. It is generally accepted that sparking plugs and exhaust systems last longer than with leaded petrol (although we understand the Department of Energy disputes this), and UKPIA have estimated the overall saving at the equivalent of 50,000 tonnes of crude oil per annum (less than £1 per motorist). This has been taken into account in Table 7.6. There is some evidence that engine oil changes can be made less frequent, although UKPIA has told us that this is unsubstantiated. Overall, we believe maintenance savings are unlikely to make more than a marginal difference to total energy demand, although in individual cases they may be quite significant. For instance motorists who neglect to have their engines tuned and plugs changed at the recommended intervals are likely to waste less fuel on unleaded than on leaded petrol.

Other factors affecting energy usage

7.111. As we have seen, any increase in the real cost of motoring due to the so-called energy penalty would be very small and would be completely swamped by savings resulting from the various factors discussed in paragraphs 7.98–7.102 and Appendix 5. That is not to say that those savings might not be even greater if present octane quality were maintained. If therefore the view is taken that the theoretical $2\frac{1}{2}$ per cent penalty resulting from the reduction in compression ratios must be counteracted explicitly, an equivalent saving could be achieved by a change in driving habits, such as a reduction in average speed. Studies by the Department of Transport of the effects of the temporary speed restrictions at the time of the world oil crisis have indicated that it is possible to achieve savings of the same order of magnitude as the 'penalty' which we have been discussing. They do not of course, take into account wider implications for

the economy, both favourable and adverse (for example, fewer accidents but longer journey times), which would need careful study.

7.112. Acceleration is as important a factor as speed in relation to fuel economy. Besides low maximum speed limits, American motorists have become accustomed to quite modest standards of acceleration compared with what are regarded as normal in Europe. These are partly due to tight emission controls (which affect performance), but they are also the result of government measures to discourage high fuel consumption. The US Department of Transportation has set 'corporate average fuel economy' (CAFE) standards for large car manufacturers (including importers), which will bring the average fuel consumption of each manufacturer's range of cars (including diesel cars, which currently take 7 per cent of the US car market), calculated on a sales-weighted basis for each model year, down to at most 33 mpg (Imperial) by 1985. Failure to reach the standards results in fines. The great majority of manufacturers confidently expect to achieve and in many cases surpass the 1985 standard, despite the handicaps of stringent emission limits and low octane petrol⁽¹⁸⁸⁾. In this country motor manufacturers have agreed a voluntary programme of improving fuel economy of their petrol-driven model ranges by 10 per cent during the 10 years up to 1985. The programme is going well, and is reinforced by strong consumer pressures; but since it does not set sales-weighted overall targets it has arguably not been such a powerful driving force as the CAFE standards, even when allowance is made for the obvious differences between Europe and the United States.

European Community implications

7.113. We have already referred to Directive 78/611/EEC⁽¹⁸⁹⁾, which has the effect of limiting the lead content of petrol sold in Member States to a maximum of 0.4 g/l. A Member State may prescribe any limit below 0.4 g/l but not lower than 0.15 g/l. The Directive also requires Member States to take all appropriate steps to ensure that reducing lead content does not significantly increase other pollutants in petrol or cause quality (which we understand includes octane number) to deteriorate. The text is reproduced at Appendix 6.

7.114. As the preamble makes clear, the purpose of the Directive (made under Article 100 of the Treaty of Rome, which requires a unanimous decision by Member States) was two-fold: firstly, the protection and improvement of public health and the environment; secondly, the approximation of laws. It should be noted that there is nothing in the Directive that prevents unleaded petrol being sold within the Community, should an oil company wish to do so for commercial reasons.

7.115. The values chosen for the upper and lower limits for lead content were effectively determined by the progressive reductions introduced by the Federal German Government, for precautionary health reasons, in 1972 and 1976 respectively. The concept of a minimum limit was promoted by the UK, among others, primarily because it was considered that if any Member State prescribed a maximum level below 0.15 g/l, it would create technical barriers to

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trade with members whose motor industries were geared to higher limits. In this respect the lead in petrol Directive—viewed as an environmental measure—can be said to be less stringent than other Directives on lead.

7.116. As we explained in paragraph 7.20, 0.15 g/l has tended to be regarded as the lowest practical level of lead that satisfies current European engine technology, car performance requirements, refinery practice and fuel economy objectives. Unilateral reduction of the maximum permitted lead content of petrol would thus have some effect on competition between motor manufacturers and oil refiners in different countries of the Community, although a long period of notice would diminish that effect.

7.117. If, notwithstanding its provisions, legislation were to be enacted in the UK contrary to the Directive on lead in petrol, the Commission of the European Communities or another Member State would doubtless consider challenging this unilateral act by bringing the matter before the European Court of Justice under Article 169 or Article 170 on the ground that the UK had failed to fulfil an obligation under the Treaty. There is also the possibility that an individual company or person claiming to be sufficiently affected might seek a remedy before an appropriate national court.

7.118. An alternative possibility which has been put to us is that the UK could invoke the terms of Article 36 of the Treaty of Rome. This provides that Article 30 and other Articles relating to quantitative restrictions shall not preclude prohibitions or restrictions on imports, exports or goods in transit justified on grounds of (among other things) the protection of health and life of humans, animals or plants. The Article goes on to say that 'such prohibitions or restrictions shall not, however, constitute a means of arbitrary discrimination or a disguised restriction on trade between Member States'. It has been strongly argued, by CLEAR and others, that the wording of the Article would enable the Government to require that only unleaded petrol be sold if it considered that this was a measure essential in the interests of public health; and even the Department of Transport has not ruled out the possibility that this might be so.

7.119. We believe that this proposition may be unsound. Paragraph 36 of the European Court's judgement in Case 148/78, generally known as the *Ratti* case⁽²⁰⁰⁾, contains the following statement:

'When, pursuant to Article 100 of the Treaty, Community Directives provide for the harmonisation of measures necessary to ensure the protection of the health of persons and animals and establish Community procedures to supervise compliance therewith, recourse to Article 36 ceases to be justified and the appropriate controls must henceforth be carried out and the protective measures taken in accordance with the scheme laid down by the harmonising Directive.'

7.120. The Directive on lead in petrol appears to us to be just such a Directive. Accordingly we believe that it falls within the terms of the *Ratti* judgement and that it would not be open to the UK to invoke Article 36. However if further research were to disclose that the health hazard of lead in petrol was far greater than the present state of knowledge indicates, it might be that this would undermine the agreement on which the Directive was based. This in turn might enable the UK Government to invoke Article 36 in the very unlikely event that in these circumstances the Commission and all other Member States did not feel it desirable to amend the Directive so as to permit the elimination of lead from petrol.

7.121. We come, therefore, to the conclusion that in the event of a decision to move to unleaded petrol in this country, the UK Government has no option but to open negotiations with its partners and the Commission with a view to an amending Directive. We note that the Department of Transport has suggested (notes to Figure 7.3) that negotiations could take up to 3 years, although clearly there would be scope for some preparatory work proceeding in parallel to minimise delay in implementation.

7.122. The course of events could, however, be influenced by other developments in the Community. We note that strong pressures have been building up in the European Parliament, supported by a joint campaign by the European Environmental Bureau and the Bureau Européen des Unions de Consommateurs (representing environmental and consumer organisations in Member States), in favour of the elimination of lead from petrol. The Parliament will shortly be debating a draft resolution, prepared by its Environment, Public Health and Consumer Protection Committee, calling upon the Commission to submit proposals to the Council for the abolition of the minimum limit, for reduction of the maximum limit to 0.15 g/l, for unleaded petrol to be on sale from 1985, and for a programme 'to resolve finally and in full the problem of atmospheric lead pollution'⁽²⁰¹⁾. There has also been growing Parliamentary interest in such a move at home—notably in a recent House of Lords debate initiated by Baroness Ewart-Biggs⁽²⁰²⁾ and, in the House of Commons, in a private member's bill which after a brief debate failed to receive a second reading⁽²⁰³⁾.

7.123. Other factors have been under active consideration at Community level for the past few years which could also affect future use of lead in petrol. The WOPLIP Report⁽¹⁸⁹⁾, after explaining that no Community clearance was needed for the option (subsequently adopted by the Government) of reducing lead to 0.15 g/l, pointed out that 'the risk would be that the action taken might not harmonise with other long term initiatives contemplated in the Community, e.g. going for lead-free petrol'. (It should be noted that Article 6 of the Directive empowers the Commission to collect relevant data from Member States and to make 'suitable proposals for such data to be taken into account in order to develop further Community policy on the lead content of petrol'. The Commission has not yet had occasion to invoke this procedure.)

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7.124. Although no Member State (or any other Western European country) has so far officially favoured the introduction of unleaded petrol, the Commission set up an ad hoc working group in December 1981 ('Evolution of Regulations, Global Approach—Air Pollution', or 'ERGA') to consider the need and scope for further reductions in the gaseous exhaust emission limits* currently set by Directive 70/220/EEC⁽²⁰⁴⁾. This Directive is not, of course, directly concerned with lead, but in evidence to us the Commission has commented that elimination of lead from petrol could become an issue if ERGA (which has been asked to report by 30 June 1983) 'considers limit values at levels which will necessitate the use of catalytic post-combustion devices and . . . that such devices cannot be made lead-resistant for the period envisaged for the enforcement of such stringent limits**'. In this case the ad hoc group might recommend to the Commission to provide for lead-free petrol in the Community'.

7.125. We note that this initiative has recently been given a more positive thrust. Section 21 of the third Community Environment Action Programme, as approved by the Council of Environment Ministers in December 1982⁽²⁰⁵⁾, contains the following passage:

'The Commission will study how to strengthen the measures to control pollution from motor vehicles. It will in particular study, together with interested parties, the possibility that all new cars on the market after a certain date be required to use anti-pollution devices or fuels which considerably reduce the present level of exhaust pollution, and make appropriate proposals. It will draw up long-term guidelines for the motor vehicle sector in general and in so doing take account, inter alia, of the need for the European motor industry to meet the strict environment protection norms laid down by its major competitors such as the USA and Japan.'

7.126. As we have commented elsewhere, it is important for the continuing success of the UK oil and motor industries that the present uncertainty surrounding the future of lead in petrol should be resolved as quickly as possible. The findings of the ERGA group will have a significant bearing on this, and on any renegotiation of Directive 78/611/EEC. An early new initiative by the Commission seems probable, and we would like to impress upon the Government the need to be ready to respond to it urgently.

7.127. Important though the ERGA study is to the development of a long-term Community strategy on vehicle emissions, we consider that a minimum limit for lead in petrol is no longer justified, on the evidence already available. Accordingly we **recommend** that the Government should initiate negotiations immediately with the Commission and our European partners with a view to securing the removal of the minimum limit contained in Article 2 of Directive 78/611/EEC and any consequential amendments to the Directive necessary to enable Member States to require unleaded petrol of appropriate

*As we have already mentioned (paragraphs 7.29 and 7.61), we propose to deal with the wider issue of air pollution by motor vehicles in our next Report.

**See paragraph 7.37 on the current technical assessment of lead-tolerant catalysts.

quality to be sold in their territories. The objective of these negotiations would be that from the earliest practicable date all new petrol-engined vehicles sold in the UK should be required to run on unleaded petrol.

Conclusions

7.128. Examination of the technical and economic implications of unleaded petrol illustrates the pitfalls of basing policy on estimates which in turn depend on so many imponderables. Many of the predictions we have seen about the consequences of change seem at best to rest on 'worst case' assumptions which can be neither proved or disproved. Having looked at the issues from many angles, we can find no compelling arguments for the retention of leaded petrol.

7.129. We recognise that retention of lead in petrol at 0.15 g/l might marginally save energy. But the extra annual cost of moving to unleaded petrol would be disproportionately small compared with the fuel economies which are possible on the most conservative assumptions. At most, it can be said that some additional benefit would be forgone; and even then it is not certain how much of that benefit could be realised in practice if (as has been suggested) technological advance is effectively bringing down the octane requirement of the average car.

7.130. When major economic or technological boundaries are changed, a process of re-optimisation begins. The oil crisis and tightening emissions control have provided an enormous stimulus to improvements in car design and fuel economy throughout the world. We strongly suspect that if Europe had also (like the United States and Japan) to accommodate the phasing out of lead—for whatever reason—the stimulus would be all the greater.

7.131. Economic and ecological systems are very similar in their capacity to absorb shocks more effectively than 'worst case' assumptions predict. In this instance it seems unlikely that further changing of the boundaries would result in a worse outcome than the planned position with lead retained at 0.15 g/l. Indeed there are even grounds for hoping that the fresh stimulus to the system could produce a net benefit. Industry however needs a firm and early signal before the re-optimisation process can start. The present uncertainty about future European policy on lead in petrol must be resolved quickly, once and for all.

7.132. Our conclusion is that it would be right for the UK to give a lead to the rest of Europe in phasing out the use of lead in petrol altogether. We therefore **recommend** that, concurrently with the EC negotiations, the Government should begin urgent discussions with the UK oil and motor industries with a view to reaching early agreement on a timetable for the introduction of unleaded petrol, having regard to the time required for essential production changes and the desirability of matching refinery investment as far as possible to long-term rather than interim requirements. We believe it should be possible for all new petrol-engined vehicles to be running on unleaded petrol by 1990 at the latest.

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7.133. In recommending this move, we are concerned not merely to reinforce the welcome steps which have already been taken to reduce airborne concentrations of lead in this country and consequent dispersal and accumulation of lead in the environment. We also (as the terms of our Royal Warrant require) attach importance to the international dimension. Besides the legal aspects of our obligations as a member of the European Community, other factors give the UK a direct interest in the use of lead in petrol elsewhere in Europe. A general reduction in the use of lead in petrol in Europe would bring about a reduction in the amount of lead imported in foodstuffs from Europe and borne on the wind.

7.134. Finally, as we noted in paragraph 6.41, a reduction in the use of lead products of any kind has both a direct and an indirect effect on the introduction of lead into the environment. For not only does it reduce the contribution which those products make, when dispersed in the environment, to the body burden of lead, but it also reduces the contribution made by manufacturing and recycling processes.

CHAPTER VIII

CONCLUSIONS

Introduction

8.1. In this chapter we seek to draw together the essential arguments and findings of the Report, linking them to our major recommendations. A complete list of recommendations is in the final chapter.

8.2. Our conclusions are based on the total picture that emerges from the evidence we have received and from the published reports and papers we have studied. As we have stressed, in Chapter I and elsewhere, there are often uncertainties in the literature, particularly in relation to the sampling procedures and the accuracy of the measurements. More often than not it is difficult to be confident that the situations measured were typical and therefore theoretical estimates cannot always be usefully compared with actual data. Although we have approached all the information critically, we decided that constantly to stress the difficulties would be an excessively negative approach and of little value as a guide to future policy. Instead we have seen our task as making the best assessment from the existing information and drawing robust conclusions, the validity of which is not dependent on the precise accuracy of any particular investigation or calculation.

The significance of lead as an environmental pollutant

8.3. Lead released to the environment can remain in an accessible form for hundreds of years; its environmental residence time is long compared with other common pollutants (Paragraph 1.6).

8.4. Lead does not progressively accumulate through food chains to any marked extent (3.12).

8.5. Lead has effects on micro-organisms and on biological processes in the soil (3.3).

8.6. The effect of lead on plants is limited but sufficient for the selection of lead-tolerant strains on lead-bearing soils and at some roadsides (3.10).

8.7. Lead has a number of effects on the biochemical processes of animal cells, on the enzyme systems concerned with haem and neurotransmitter synthesis and on RNA. Lead is thus potentially toxic to all vertebrates (5.16–5.19).

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8.8. Lead cannot be made innocuous by chemical change, although the low solubility of many of its compounds limits their availability to living organisms (1.6 and 2.23).

8.9. Organic compounds of lead are generally more toxic than inorganic ones, but there is little evidence that bio-methylation of inorganic lead occurs in nature (3.2 and 3.4).

8.10. We conclude that lead's long persistence and potential toxicity to a very wide range of organisms identify it as a pollutant of particular significance in the environment.

8.11. High levels occur naturally in regions where lead-bearing rocks are close to the earth's surface (2.16).

8.12. Man uses far more lead than he does other toxic metals. At least a quarter of it is widely and irretrievably dispersed in the environment (1.7 and 2.3).

8.13. Throughout the world, levels of lead in the environment are now several times higher than they were 200 years ago. This phenomenon is not confined to sites close to sources of lead (2.2).

8.14. Because lead has been dispersed so widely as a result of man's activities, there are strictly speaking no uncontaminated sites from which 'natural' concentrations in the environment may be determined; but the concentrations found at rural sites away from immediate contamination by industrial processes or petrol engines may reasonably be used for purposes of comparison (2.2).

8.15. In man and other vertebrates, body burdens of lead in inner city areas or alongside major roads may be elevated compared with those in rural areas (3.13 and 4.35).

8.16. In man there is much individual variation in the blood lead concentration at which the features of frank poisoning occur, but they have occasionally been described with blood lead concentrations in the region of 50 $\mu\text{g}/\text{dl}$. Various biochemical changes may occur at lower blood lead concentrations. Whether these changes are deleterious is unknown: the body is often able to withstand minor biochemical perturbations. Many animals appear to respond to lead in a similar way. There is at present no basis for postulating a threshold concentration of lead below which there are no effects (5.6; 5.16–5.19; 5.22).

8.17. Animal studies have provided little guidance on the effects of lead at low concentrations on behaviour. Most of the experiments have been inadequately designed for reliable conclusions to be drawn (5.14–5.15).

8.18. The results of behavioural studies with children are difficult to interpret, because of confounding factors, but have shown that if there are any effects at low concentrations of lead they are small (5.10–5.12).

8.19. At present the average blood lead concentration of the UK population is about one quarter of that at which features of frank lead poisoning may occasionally occur. We are not aware of any other toxin which is so widely distributed in human and animal populations and which is also universally present at levels that exceed even one tenth of that at which clinical signs and symptoms may occur (5.23).

8.20. We note the Government's view that the safety margin may at present be too small in some circumstances and that it should be increased wherever practicable. In our view it would be prudent to take steps to increase the safety margin for the population as a whole. We reach this conclusion without coming to any judgement on the possible effects of low concentrations of lead on children's behaviour (5.25).

8.21. We conclude that measures should be taken to reduce the anthropogenic dispersal of lead wherever possible and that they should be accompanied by a well designed programme to monitor the human body burden of lead (4.55 and 5.25).

Anthropogenic sources and pathways of lead in the environment

8.22. Man obtains his body burden of lead from many sources and the contributions of different components vary, depending greatly on environmental factors and on personal habits (4.12 and 4.20).

8.23. For most people in the UK food and drink form the major pathway for lead uptake, but there is considerable uncertainty as to the relative contributions of the several sources of lead to this pathway (4.23–4.30).

8.24. Exceptional factors may increase the significance of particular pathways. For instance, persons living in areas with plumbosolvent water and having lead plumbing or lead-lined water tanks may receive more than half of their uptake from the water. Social factors, for example smoking and alcohol consumption, also influence the relative importance of pathways (4.50).

8.25. The importance of lead from petrol is difficult to evaluate since it reaches the body through several pathways. On present evidence, for large numbers of adults in the UK it contributes at least 20 per cent of their uptake; for the majority it contributes less (4.51).

8.26. For young children lead in dust carried to the mouth by the hands or on objects sucked or placed in the mouth may constitute around half the uptake. Because of the congruence of environmental and behavioural factors, socially disadvantaged children may be particularly exposed to lead uptake via dust. Lead in dust may arise from soil, paint, emissions from petrol engines and industrial processes, and a variety of other sources. We recommend that research is undertaken to assess the relative contributions of these sources (2.25; 4.52–4.53; 6.38).

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Opportunities for reducing environmental contamination by lead

8.27. For several years industrial countries have sought to lower the exposure of the population to lead and hence the lead concentration in the body. The combination of their actions, and probably other unknown factors, seem to have been successful and there is evidence (including data from the UK) of falling average blood lead concentration (4.40 and 4.44).

8.28. As overall usage of lead products declines, so there will be a corresponding decline in contamination from manufacturing and handling processes (6.41 and 7.134).

8.29. Lead levels in tap water exceeded 50 $\mu\text{g/l}$ in over 10 per cent of British homes in 1975. We note the Government's efforts since then to encourage local authorities and water authorities to reduce these levels by water treatment or by pipe and tank replacement. We recommend however that financial constraints should not be allowed to hamper the rate of progress and that the Government should set an early and firm target date for substantial completion of all surveys, investigations and remedial work relating to plumbosolvency (2.13 and 6.7–6.9).

8.30. Although food is the major pathway of lead uptake for most people, many details of this pathway are obscure. It is therefore not possible to indicate measures that would result in a comprehensive reduction in lead levels in food. However, we believe that most, if not all, measures to reduce dispersion of lead in the environment are likely to result in a decrease in the lead content of man's diet. We welcome the moves by a major can manufacturer to phase out the use of lead solder. We recommend that the detailed work being undertaken in this field by the Ministry of Agriculture, Fisheries and Food is fully supported and, if necessary, extended (4.23–4.25 and 6.30–6.34).

8.31. While the principal danger from lead in paint arises from old formulations applied many years ago, lead at any level in paint represents a long-term addition to other potential sources of environmental contamination. We therefore recommend that the maximum permitted concentration of lead in paint for household use should be progressively reduced to a level comparable to that applied in the USA, and that the lead content of all paint should be labelled where it exceeds that level. We also recommend that there should be continuing research into narrowing the range of uses for which there are grounds for preferring leaded paint (6.21).

8.32. We welcome the recently published leaflets, including that issued by the Department of the Environment, designed to publicise the dangers of lead in paintwork and to advise on the proper techniques for surface preparation, particularly stripping. However these will be effective only if they reach their target audience, including groups for whom English is not the first language. We recommend more active steps to publicise the potential hazards (6.27–6.28).

8.33. We support the Government's action in encouraging local authorities to identify in their own properties paintwork surfaces containing high levels of lead, particularly in areas frequented by children. Steps should be taken to ensure that local authorities have access to modern equipment for the detection of lead in paintwork *in situ* (6.23–6.24).

8.34. In view of the potential significance of dust as a pathway for lead, particularly to children, and of the shortage of data in this area, we recommend priority should be given to research on the origins of lead in dust (6.38).

8.35. Lead shot from spent cartridges and lead fishing weights poison wildlife. We recommend that as soon as substitutes are available the Government should legislate to ensure their adoption and use (6.42–6.45).

8.36. We welcome the renewed campaign by the Department of Trade to draw attention to the dangers of cosmetics containing lead (6.46).

8.37. Bearing in mind that the contribution of airborne lead from petrol is such an all-pervasive addition to people's uptake from other sources, and that it is amenable to central control, we conclude that this source should be reduced to the lowest practicable level. Whilst we welcome the major reduction in airborne lead that will be achieved by the Government's present policy of reducing the lead content of petrol to 0.15 g/l by the end of 1985, we can find no compelling arguments for the retention of leaded petrol except as an interim measure to enable the majority of existing cars to be phased out (7.55 and 7.128).

8.38. The development of engines to run on unleaded petrol would remove an impediment to the control of other gaseous emissions by the fitting of exhaust catalysts, a requirement currently being considered by the Commission of the European Communities, already demanded by the USA and Japan, and shortly to be demanded by Australia (7.36 and 7.123–7.125).

8.39. We recommend that the Government should initiate negotiations immediately within the European Community in order to secure the removal of the minimum level for lead in petrol currently contained in Article 2 of Directive 78/611/EEC. The objective of these negotiations would be that from the earliest practicable date all new petrol-engined vehicles sold in the UK should be required to run on unleaded petrol (7.127).

8.40. We recommend that, concurrently with these negotiations, urgent discussions should be held with the UK oil and motor industries with a view to reaching early agreement on a timetable for the introduction of unleaded petrol, having regard to the time required for essential production changes and the desirability of matching major refinery investment as far as possible to long-term rather than interim requirements. We believe it should be possible for the changes to be implemented by 1990 at the latest (7.132).

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8.41. Substantial continuing improvements in engine efficiency make it unlikely that any overall energy penalty will be actually experienced as a result of the switch from 97 RON petrol with 0.15 g/l lead to 92 RON unleaded and the consequential change to engines with lower compression ratios. A potential net energy saving (equivalent to about $2\frac{1}{2}$ per cent of crude oil requirement) will, however, have to be forgone (7.91-7.102).

8.42. Wider moves in Europe to reduce or discontinue the use of lead in petrol will bring benefits in the form of reduced concentrations of lead in transfrontier aerial movements and in lower levels of food contamination (7.133).

8.43. Our overriding concern, in formulating our recommendations, has been to reduce the amount of lead dispersed in the environment by man. We consider that the cumulative effect of these actions will be a substantial reduction in the rate of accumulation of lead in the environment, to the benefit of present and future generations.

CHAPTER IX

RECOMMENDATIONS

1. A well designed programme to monitor the body burden of lead in man, to accompany measures designed to reduce further the release of lead to the environment, should be undertaken in consultation with the Medical Research Council and started as soon as possible (Paragraph 4.55).

2. Further long-term studies of persons exposed to lead and lead salts in industry should be undertaken (5.21).

3. Research should continue into the effects of lead at low concentrations, particularly on children (5.24).

4. The Medical Research Council should encourage experimental studies on the effects of low concentrations of lead on the behaviour of animals; particular attention should be paid to experimental design (5.24).

5. The anthropogenic dispersal of lead and man's exposure to it should be reduced further (5.25).

6. The Government should set an early and firm target date for completion of surveys to identify plumbosolvency in water supplied for human consumption and of remedial programmes of water treatment or pipe replacement; a comprehensive report of progress since 1975 should be published (6.9).

7. The criteria for the award of home improvement or repair grants for the replacement of lead plumbing should be reviewed, with the aim of making such grants more widely available. Publicity campaigns should be conducted in areas where pipe replacement is considered necessary, and special attention should be given to property where the incentive for initiating action may be unclear. Financial constraints should not be allowed to hamper the pipe replacement programme (6.6).

8. The adequacy of measures to encourage any necessary replacement of lead plumbing in publicly owned buildings, and in privately owned buildings not eligible for home improvement grants, should be reviewed (6.6).

9. A definitive view should be reached as soon as possible, for public information and discussion, on whether lead solder in modern plumbing systems can contribute significantly to the lead content of drinking water (6.11).

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10. The Government, in collaboration with the paint industry, should establish the quantities of lead-based paints currently sold in the UK (6.16).

11. The Government should supplement precautionary labelling of leaded paints by promoting publicity to ensure that users and potential users are aware of the dangers and the alternatives (6.16).

12. The maximum permitted concentration of lead in paint for household use should be progressively reduced to a level comparable to that applied in the USA, and in the meantime all paint containing more lead than this should carry a warning label (6.21).

13. Research on the formulation of paints should be directed towards further reducing the range of applications for which there are grounds, whether technical or financial, for preferring leaded paints (6.21).

14. Research should continue into lowering the amount of lead necessary for satisfactory yellow road paint, and the use of yellow road paint containing the least practicable amount of lead should be mandatory (6.20).

15. Local authorities should review the techniques and equipment available for the detection and measurement of lead in paintwork (6.24).

16. More active steps should be taken to publicise the potential hazards of lead in old paintwork and to ensure that the publicity reaches its target audience, including those for whom English is not the first language (6.27).

17. To reinforce the role of public authorities, manufacturers and retailers in advising the public about the potential hazards of lead paintwork, the Government should conduct an early campaign in the media to underline the message of its information note 'Lead in Paintwork', and there should be periodic reminders to the public to ensure that the lessons are not forgotten (6.28).

18. There should be a continuing effort to gain a better understanding of the various pathways and mechanisms by which food is contaminated with lead (6.34).

19. More data should be obtained on the lead content of alcoholic drinks at the point of consumption (6.35).

20. Priority should also be given to research to assess the relative contributions that different sources and pathways can make to lead in dust (6.38).

21. The Industrial Pollution Inspectorates should consider the scope for reducing the BPM emission limits currently applicable to scheduled lead processes (6.41).

Recommendations

22. Urgent efforts should be made to develop alternatives to lead shot and lead fishing weights (6.45).

23. As soon as these alternatives are available, the Government should legislate to ban any further use of lead shot and fishing weights in circumstances where they are irretrievably dispersed in the environment (6.45).

24. Local authorities should accord a high priority to the monitoring and other work necessary to establish the extent of human exposure to lead in their areas and to reassure the public that any necessary remedial action is being taken without delay (6.47).

25. There should be adequate publicity, drawing attention to the risks associated with exposure to lead and advising how to avoid or minimise these, to enable people significantly to reduce their own exposure to lead from localised sources (6.48).

26. The reduction of the maximum permitted lead content of petrol to 0.15 g/l should be regarded as an intermediate stage in the phasing out of lead additives altogether (7.55).

27. The Government should initiate negotiations immediately within the European Community to secure the removal of the minimum level for lead in petrol currently set by Directive 78/611/EEC (7.127).

28. The Government should begin urgent discussions with the UK oil and motor industries in order to agree a timetable for the introduction of unleaded petrol, having regard to the time required for essential production changes and the desirability of matching major refinery investment to long-term rather than interim requirements (7.132).

29. The price of unleaded petrol should not exceed that of the highest grade of leaded petrol during the period in which leaded petrol is phased out (7.108).

Acknowledgement

As already mentioned, our original plan was to deal with the lead problem as one of a number of issues in a more wide-ranging report. Our decision to make it the subject of a separate report and to complete this within a relatively short period presented a considerable challenge—above all to our small Secretariat, who responded magnificently. It is a great pleasure to record our gratitude to all of them for their efficient teamwork and untiring support. We are happy to include among them Mr John Dore, who retired last September after some 5 years as Assistant Secretary (Administration). We are grateful to him for his help in the earlier stages of this study and for his wise counsels, which those of us who were relatively new to the Commission and Secretariat have particularly valued. We also wish to reiterate our thanks to those who provided evidence and to our two consultants.

ALL OF WHICH WE HUMBLY SUBMIT FOR YOUR MAJESTY'S
GRACIOUS CONSIDERATION

RICHARD SOUTHWOOD (Chairman)
GATHORNE CRANBROOK
ROGER NATHAN
DONALD ACHESON
CHRISTOPHER BLAKE
ROBERT CLARK
BARBARA CLAYTON
GORDON FOGG
ROBERT CUMMINGS
CHARLES SUCKLING
ALBERT ARCHER
JOHN EDMONDS
GEOFFREY LARMINIE
RICHARD THORNTON
MARY WARNOCK
DAVID WILLIAMS

T. E. Radice (Secretary)

M. G. Schultz (Assistant Secretaries)

J. M. Wilkinson

March 1983

APPENDIX 1

MEMBERS OF THE COMMISSION

Chairman:

PROFESSOR T. R. E. SOUTHWOOD, MA, PhD, DSc, ARCS, FIBiol, FRS

Linacre Professor of Zoology, University of Oxford.

Fellow of Merton College, Oxford.

Vice-President, Royal Society.

Honorary Foreign Member, American Academy of Arts and Sciences.

Chairman of the Trustees, British Museum (Natural History).

Member, National Radiological Protection Board.

Members:

PROFESSOR E. D. ACHESON, MA, DM, FRCP, FFCM, MFOM

Professor of Clinical Epidemiology and Director, MRC Environmental Epidemiology Unit, University of Southampton.

Honorary Consultant Physician to the Royal South Hants Hospital.

Member, University Grants Committee.

Chairman, Southampton and South West Hampshire Health Authority.

Chairman, MRC Advisory Group on Lead and Neuropsychological Effects in Children.

A. ARCHER, ESQ, MBE, FIEHO

President, Institution of Environmental Health Officers.

Chairman, Standing Conference of Co-operating Bodies: Investigation of Air Pollution, Warren Spring Laboratory.

Honorary Research Fellow, Department of Chemistry, University of Aston in Birmingham.

Formerly City Environmental Officer, Birmingham.

PROFESSOR C. BLAKE, MA, PhD, FRSE

Bonar Professor of Applied Economics and Dean of the Faculty of Arts and Social Sciences, University of Dundee.

Member, Committee on Industrial and Social Conditions, Scottish Council Development and Industry.

Member, Council for Applied Science in Scotland.

PROFESSOR R. B. CLARK, DSc, PhD, FIBiol, FLS, FRSE

Professor of Zoology, University of Newcastle upon Tyne.

Editor, *Marine Pollution Bulletin*.

Appendix 1

PROFESSOR B. E. CLAYTON, MD, PhD, FRCP, FRCPath

Professor of Chemical Pathology and Human Metabolism, University of Southampton.

Honorary Consultant to the Southampton and South West Hampshire Health Authority.

Chairman, Joint Committee on Medical Aspects of Water Quality.

Deputy Chairman, DHSS Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment.

Member, DHSS Standing Medical Advisory Committee.

Member, DHSS Committee on Medical Aspects of Contamination of Air and Soil.

Member, MRC Advisory Group on Lead and Neuropsychological Effects in Children.

Member, British Paediatric Association.

THE RT HON THE EARL OF CRANBROOK, MA, PhD, FLS, FRSA

Chairman, Sub-Committee 'G' (Environment), House of Lords Select Committee on the European Communities.

Member, House of Lords Select Committee on Science and Technology.

Member, Natural Environment Research Council.

Trustee, British Museum (Natural History).

R. H. CUMMINGS, ESQ, OBE, BSc, PhD, FInstPet, FGS, FIMM, MIGeol, FMinE

Chairman and Chief Executive, Robertson Research Group.

J. W. EDMONDS, ESQ, MA

Industrial Officer, General, Municipal, Boilermakers and Allied Trades Union.

Member, TUC Nationalised Industries and Fuel and Power Industries Committees.

PROFESSOR G. E. FOGG, BSc, PhD, ScD, Hon LLD, FIBiol, FRS

Professor of Marine Biology, University College of North Wales.

Chairman, Council of the Freshwater Biological Association.

Chairman, Scientific Advisory Committee, British Antarctic Survey.

Chairman, Scientific Advisory Committee, Royal Botanic Gardens, Kew.

Trustee, British Museum (Natural History).

F. G. LARMINIE, ESQ, OBE, MA

General Manager, British Petroleum Environmental Control Centre.

Trustee, Bermuda Biological Station.

Member, Council of the Marine Biological Association of the United Kingdom.

THE RT HON LORD NATHAN, MA, FSA, FRSA, FRGS

Senior Partner, Herbert Oppenheimer Nathan & Vandyk, Solicitors.

Member, Sub-Committee 'G' (Environment), House of Lords Select Committee on the European Communities.

Vice-President, and member of the Environment Committee, Royal Society of Arts.

Member, Watt Committee on Energy.

C. W. SUCKLING, ESQ. PhD, DSc, CChem, FRSC, FRS

Consultant in science, technology and innovation.

Non-executive Director, Albright and Wilson Ltd.

Visiting Professor, University of Stirling.

Member, Science Consultative Group, British Broadcasting Corporation.

Member, Biosciences Sub-Committee, University Grants Committee.

Member, Electricity Supply Research Council.

R. E. THORNTON, ESQ, OBE, DL, JP, MA

Farmer.

Member, Council of the Country Landowners' Association.

MRS M. WARNOCK, MA, BPhil, FCP

Writer and broadcaster.

Senior Research Fellow, St Hugh's College, Oxford.

Chairman, Advisory Committee on Animal Experiments.

Chairman, Committee of Inquiry into the Implications of *in vitro* Fertilisation.

D. G. T. WILLIAMS, ESQ, MA, LLB, LLM

President of Wolfson College, Cambridge.

Reader in Public Law, University of Cambridge.

Formerly member of the Clean Air Council and the Commission on Energy and the Environment.

APPENDIX 2

ORGANISATIONS AND INDIVIDUALS CONTRIBUTING TO THE STUDY

Those organisations and individuals marked * gave oral evidence at formal Commission meetings; those marked † gave oral evidence during visits by the Commission.

Government Departments

Department of Agriculture and Fisheries for Scotland.

Department of Energy.

Department of the Environment.

Department of the Environment for Northern Ireland.

Department of Health and Social Security.

Department of Industry (including Laboratory of the Government Chemist and Warren Spring Laboratory).

Department of Trade.

Department of Transport* (including Transport and Road Research Laboratory).

Foreign and Commonwealth Office—Embassies in Tokyo and Washington.

Ministry of Agriculture, Fisheries and Food.

Scottish Development Department.

Scottish Home and Health Department.

Welsh Office.

Other organisations

Agricultural Research Council (including research establishments).

Associated Octel Company Ltd.

Association of Public Analysts.

Atomic Energy Research Establishment, Harwell.

Australian High Commission, London.

Automobile Association.

British Association for Shooting and Conservation.

British Ceramic Research Association.

British Ecological Society.
BL Technology Ltd.
British Medical Association.
British Petroleum plc.
Campaign for Lead-free Air (CLEAR).^{*}
Chemical Industries Association.
Commission of the European Communities.[†]
Confederation of British Industry.
Conservation Society.
Council of Science and Technology Institutes Ltd.
Esso Petroleum Company Ltd.
Fellowship of Engineering.
Food and Drink Industries Council.
Ford Motor Company Ltd.
Friends of the Earth.
Greater London Council.
Health Education Council.
Health and Safety Executive.
Imperial Chemical Industries plc.
Imperial Metal Industries plc.
Institute of Biology.
Institute of Petroleum.
Institution of Environmental Health Officers.
Johnson Matthey Chemicals Ltd.
Joint Unit for Research on the Urban Environment, University of Aston
in Birmingham.
Lead Development Association.
London Borough of Greenwich.
Medical Research Council.
Metal Box plc.
Motor Industry Research Association.
National Anglers' Council.
National Water Council.
Natural Environment Research Council (including research establishments and grant-holders in universities).

Appendix 2

Nature Conservancy Council.
Northumbrian Water Authority.†
North West Water Authority.†
Oil Companies' International Study Group for Conservation of Clean Air
and Water in Europe (CONCAWE).
Paintmakers' Association of Great Britain Ltd.
Royal Automobile Club.
Royal College of Physicians (Faculty of Occupational Medicine).
Royal Colleges of Physicians of the UK (Faculty of Community
Medicine).
Royal Society of Chemistry.
Science and Engineering Research Council.
Scottish Health Education Council.
Shell Oil UK Ltd.
Society of Motor Manufacturers and Traders Ltd.
South Yorkshire County Council.
Talbot Motor Company Ltd.
Texaco Ltd.
Trades Union Congress.
United Kingdom Petroleum Industry Association Ltd.*
United States Embassy, London.
Vauxhall Motors Ltd.
Water Research Centre.
Wildfowl Trust.

Individuals

Dr B. J. Alloway (Westfield College, University of London).
Dr D. Barltrop (Westminster Children's Hospital, London).
Dr M. Birkhead (University of Oxford).
Professor J. A. Blair (University of Aston in Birmingham).
Professor D. Bryce-Smith* (University of Reading).
Professor C. Caro (Imperial College of Science and Technology, Univer-
sity of London).
Dr A. C. Chamberlain (Harwell Laboratory).
Miss S. Connell (University of Sussex).

Dr B. E. Davies (University College of Wales, Aberystwyth).
Professor Sir Richard Doll (University of Oxford).
Professor J. H. Edwards (University of Oxford).
Dr P. C. Elwood* (MRC Epidemiology Unit (South Wales)).
Professor A. Goldberg (University of Glasgow).
Professor D. G. Grahame-Smith (University of Oxford).
Mr N. Haigh (Institute for European Environmental Policy).
Dr R. M. Harrison (University of Lancaster).
Mr P. G. Harvey (University of Birmingham).
Dr J. F. Iles (University of Oxford).
Dr G. Kazantzis (London School of Hygiene and Tropical Medicine).
Dr A. Klug (MRC Laboratory of Molecular Biology, Cambridge).
Professor Sir Hans Kornberg (University of Cambridge).
Professor P. G. Lawther* (University of London).
Dr D. P. H. Laxen (University of Edinburgh).
Dr J. N. Lester (Imperial College of Science and Technology, University of London).
Dr and Mrs T. D. McArdle.
Mr R. Macrory (Imperial College of Science and Technology, University of London).
Dr M. H. Martin (University of Bristol).
Dr C. Mason (University of Essex).
Dr M. R. Moore (University of Glasgow).
Dr R. Murray.
Dr C. M. Perrins (University of Oxford).
Professor R. Perry (Imperial College of Science and Technology, University of London).
Dr R. Russell Jones (St. John's Hospital, London, and CLEAR*).
Professor M. Rutter (Institute of Psychiatry, London).
Dr R. C. Shroter (Imperial College of Science and Technology, University of London).
Mr E. Silvester.
Dr M. V. Stack (University of Bristol).
Dr R. Stephens (University of Birmingham and CLEAR*).
Mr D. Streeter (University of Sussex).

Appendix 2

Professor W. Taylor.*

Dr I. Thornton (Imperial College of Science and Technology, University of London).

Mr D. Wyatt (University of Oxford).

Mr and Mrs A. Wynn.

APPENDIX 3

NOTE ON UNITS AND CONVERSION FACTORS

A variety of units are used in the literature both for the concentration of lead and for other measurements. For the convenience of readers who wish to compare figures from the literature with those in this Report we list below the most important conversion factors.

Units of lead concentration

$1 \mu\text{g/g} = 1 \text{ mg/kg} = 1 \text{ ppm}$ (by weight)

$20.7 \mu\text{g/dl} = 1 \mu\text{mol(Pb)}/1 \simeq 0.2 \mu\text{g(Pb)}/\text{g}$ (blood)

Other units

$100 \text{ mg/m}^2 = 1 \text{ kg/ha}$

$1 \text{ tonne} = 10^3 \text{ kg} = 0.98 \text{ tons}$

$1 \text{ (imperial) gallon} = 4.55 \text{ litres} = 1.201 \text{ US gallons}$

$1 \text{ litre} = 0.22 \text{ (imperial) gallons} = 0.264 \text{ US gallons}$

$1 \text{ ha} = 10^4 \text{ m}^2 = 0.0039 \text{ square miles} = 2.47 \text{ acres}$

$\text{miles per gallon} \times \text{litres per 100 km} = 282.45$

Key

g	gram
μg	microgram (10^{-6} grams)
mg	milligram (10^{-3} grams)
kg	kilogram (10^3 grams)
ppm	parts per million
Pb	lead
l	litre
dl	decilitre (10^{-1} litres)
m	metre
km	kilometre (10^3 metres)
μmol	micromole (10^{-6} moles)
ha	hectare

APPENDIX 4

ESTIMATION OF INTAKE AND UPTAKE OF LEAD BY MAN

1. Chapter IV describes the intake of lead by inhalation and ingestion and its uptake from the lungs and gut. Here we give details of the data, assumptions and calculations used for the model balance schemes of the intake and uptake of lead by man in the UK. **It should be emphasised that many of these data have considerable variances, and that these calculations have many limitations and provide no more than our best estimates of the range and relative orders of magnitude of the intake and uptake of lead from different sources and different pathways. They do not enable individuals to assess their own likely body burden of lead.**

2. The eleven columns (A–L) in Table 1 each represent a different case. These cases do not purport to be typical or average, but to span a range of possible situations, some of them deliberately extreme.

- A. Non-smoking and non-drinking adults living and working in a rural area or small town.
- B. As for A, but smoking cigarettes regularly.
- C. As for A, but taking alcoholic drinks regularly.
- D. As for A, but regularly smoking cigarettes and taking alcoholic drinks.
- E. Two-year old children living in a rural area or small town.
- F. Non-smoking and non-drinking adults living and working in an inner city area.
- G. As for F, but regularly smoking cigarettes and taking alcoholic drinks.
- H. As for F, but with lead pipes and a plumbosolvent water supply, and spending all day at home.
- J. As for F, but living beside a busy road, and spending all day at home.
- K. As for F, but with the entire fruit and vegetable component of the diet grown close to a main road (i.e. with large deposition of airborne lead). This is a worst case assumption.
- L. Two-year old children living in an inner city area.

These eleven cases do not purport to include all groups of people or all situations.

3. Row 1 of the Table shows the ambient outdoor air lead concentration assumed for each case. For Cases A–E in a rural area or small town a value of $0.15 \mu\text{g}/\text{m}^3$ (see paragraph 2.8) has been taken and for Cases F–H, K and L, in an inner city area, a value of $1.0 \mu\text{g}/\text{m}^3$ (see paragraph 2.8). In the extreme

TABLE 1
Model balance schemes for lead intake and uptake

	RURAL/SMALL TOWN					INNER CITY					
	Adults A	Adults (smoking) B	Adults (drinking) C	Adults (smoking/ drinking) D	Children (2-yrs old) E	Adults F	Adults (smoking/ drinking) G	EXTREME CASES			Children (2-yrs old) L
								Adults with high water lead H	Adults with high air lead J	Adults with high food lead K	
INHALATION											
1. Outdoor air lead concentration ($\mu\text{g}/\text{m}^3$)	0.15	0.15	0.15	0.15	0.15	1.0	1.0	1.0	2.5	1.0	1.0
2. Indoor air lead concentration ($\mu\text{g}/\text{m}^3$)	0.11	0.11	0.11	0.11	0.11	0.75	0.75	0.75	1.9	0.75	0.75
3. Time spent indoors (hours/day)	16	16	16	16	20	16	16	20	20	16	20
4. Volume of air respired (m^3/day)	15	15	15	15	6.0	15	15	15	15	15	6.0
5. Lead intake from air ($\mu\text{g}/\text{day}$)	1.9	1.9	1.9	1.9	0.7	13	13	12	30	13	4.8
6. Smoking rate (cigarettes/day)	—	40	—	40	—	—	40	—	—	—	—
7. Lead intake from smoking ($\mu\text{g}/\text{day}$)	—	6.0	—	6.0	—	—	6.0	—	—	—	—
8. Total lead intake by inhalation ($\mu\text{g}/\text{day}$)	1.9	7.9	1.9	7.9	0.7	13	19	12	30	13	4.8
9. Percentage lead absorption in lungs	50	50	50	50	70	50	50	50	50	50	70
10. Total lead uptake from lungs ($\mu\text{g}/\text{day}$)	1.0	4.0	1.0	4.0	0.5	6.3	9.3	6.0	15	6.3	3.4
INGESTION											
11. Dietary lead intake ($\mu\text{g}/\text{day}$)	100	100	100	100	47	100	100	100	100	210	47
12. Lead intake from solder ($\mu\text{g}/\text{day}$)	15	15	15	15	6.9	15	15	15	15	15	6.9
13. Lead intake from food ($\mu\text{g}/\text{day}$)	85	85	85	85	40	85	85	85	85	195	40
14. Tap water lead concentration ($\mu\text{g}/\text{l}$)	10	10	10	10	10	10	10	300	10	10	10
15. Consumption of tap water in beverages (l/day)	1.1	1.1	1.1	1.1	0.5	1.1	1.1	1.1	1.1	1.1	0.5
16. Lead intake from tap water beverages ($\mu\text{g}/\text{day}$)	8.5	8.5	8.5	8.5	4.4	8.5	8.5	255	8.5	8.5	4.4
17. Lead intake from cooking water ($\mu\text{g}/\text{day}$)	0.8	0.8	0.8	0.8	0.4	0.8	0.8	25	0.8	0.8	0.4
18. Lead intake from tableware glaze ($\mu\text{g}/\text{day}$)	3.0	3.0	3.0	3.0	—	3.0	3.0	3.0	3.0	3.0	—
19. Consumption of alcohol (pints beer/day)	—	—	4	4	—	—	4	—	—	—	—
20. Lead intake from alcohol ($\mu\text{g}/\text{day}$)	—	—	23	23	—	—	23	—	—	—	—
21. Dust lead concentration ($\mu\text{g}/\text{g}$)	—	—	—	—	800	—	—	—	—	—	1,400
22. Lead intake from dust ($\mu\text{g}/\text{day}$)	—	—	—	—	80	—	—	—	—	—	140
23. Total lead intake by ingestion ($\mu\text{g}/\text{day}$)	112	112	135	135	132	112	135	383	112	222	192
24. Percentage lead absorption in gut	10	10	10	10	53	10	10	10	10	10	53
25. Total lead uptake from gut ($\mu\text{g}/\text{day}$)	11	11	14	14	70	11	14	38	11	22	102
SUMMARY (see also Table 4.1)											
26. Total lead uptake from lungs and gut ($\mu\text{g}/\text{day}$)	12	15	15	18	70	18	23	44	26	29	105
27. Percentage of daily lead uptake from inhalation	8	26	7	23	1	36	41	14	57	22	3
28. Percentage of daily lead uptake from ingestion	92	74	93	77	99	64	59	86	43	78	97
29. Lead uptake from petrol ($\mu\text{g}/\text{day}$)	2.0	2.0	2.0	2.0	3.3–45	6.8	6.8	6.5	15	17	5.9–80
30. Percentage of daily lead uptake from petrol	16	13	14	11	5–64	39	30	15	56	59	6–76
31. Predicted blood lead concentration ($\mu\text{g}/\text{dl}$)	7	9	9	11	—	11	13	20	14	15	—

All values are approximate and those below 100 are rounded to two significant figures.
By inner city is meant the inner areas of the larger conurbations.

situation of Case J, with a house in close proximity to a busy road in an inner city area, a value of $2.5 \mu\text{g}/\text{m}^3$ has been used which is higher than usually encountered in the UK (see paragraph 2.8) but lower than found in many European cities⁽³⁷⁾. The concentration of lead inside buildings has been reported to be in the range 60–100 per cent of that outside^(13, 37). Row 2 is calculated as 75 per cent of Row 1. Row 3 gives the number of hours each day spent indoors for each case: this has been taken as 16 for all except Cases H and J (who could be housewives) and the children (Cases E and L) for whom a higher figure of 20 has been used.

4. To calculate the amount of lead inhaled it is necessary to know the volume of air breathed each day. This depends on the age, condition and activity of the person. Calculations usually assume a healthy adult male, but estimates of the volume of air breathed range between about 10 and $25 \text{ m}^3/\text{day}$ in the published literature. Figures of about $15 \text{ m}^3/\text{day}$ have been widely used⁽²⁸⁾ and this value is used here for the adults in Cases A–D and F–K. There are few data for children, but we have used a figure of $6 \text{ m}^3/\text{day}$ ⁽¹⁰⁵⁾ for the two-year old children in Cases E and L. The intake of lead from the air (Row 5) is simply calculated from the figures in Rows 1–4.

5. Smokers have an additional source of lead intake: tobacco contains lead, probably mainly from the use of lead arsenate pesticides. It has been estimated that smoking 20 cigarettes adds between 1 and $6 \mu\text{g}$ to the daily inhalation of lead^(107, 111). Cases B, D and G are assumed to smoke 40 cigarettes/day (Row 6) with a lead intake of $3 \mu\text{g}/20$ cigarettes. The daily inhalation of lead from smoking is shown in Row 7.

6. The total lead intake by inhalation is shown in Row 8. This is the sum of the intake from the air (Row 5) and the intake from smoking (Row 7).

7. Only a proportion of the lead inhaled is absorbed into the bloodstream from the lungs; most of the remainder is exhaled (see paragraph 4.22). The degree of absorption depends upon the chemical and physical form of the lead, particularly the particle size⁽²⁸⁾, and on the rate of breathing. For the purpose of calculation a single value for the percentage absorption of all inhaled lead is taken. There are published values for adults between about 5 per cent and 65 per cent, but a value of 50 per cent is often used⁽²⁸⁾ and has been adopted here for the adults in Cases A–D and F–K (Row 9). No direct measurements have been made for children, but the Lawther Working Party⁽¹³⁾ suggested that a value of 70 per cent was reasonable; that figure has also been used here for Cases E and L (Row 9). Row 10 shows the daily uptake of lead in the lungs; the values are calculated by multiplication of the figures in Rows 8 and 9.

8. Row 11 shows estimates of dietary lead intake based on the MAFF Total Diet Study⁽⁶⁹⁾. These figures cover lead in food and certain beverages, but not in tap water, alcoholic drinks or meals eaten away from home. For the adults in Cases A–D and F–J we have used the figure $100 \mu\text{g}/\text{day}$, which is the mean intake of the average person based on MAFF data from 1975–1981. In the extreme situation of the adults in Case K it is assumed that all the fruit and

vegetable components of the diet come from a garden or allotment beside a main road with consequent heavy contamination by aerial deposition of lead. The figure of 210 $\mu\text{g/day}$ is derived by using the maximum rather than mean lead contents for all fruit and vegetables in the MAFF Total Diet Study data⁽⁶⁹⁾. There are no direct data on the average dietary lead intake of young children, but the ratio of the average energy requirements of adults and two-year old children is approximately 0.47⁽¹³⁾. Assuming that the children's diet is composed of foods of similar lead content to those in the diet of adults, a *pro rata* dietary lead intake of 47 $\mu\text{g/day}$ has been used for the children in Cases E and L.

9. The dietary lead intake can be divided into intake from solder (in canned foods) and from the food itself. Row 12 gives estimates of the lead intake from solder which may contaminate food during canning and storage. A study by MAFF showed that about 20 per cent of dietary lead is associated with canned food and that canned food comprises about 6.2 per cent (by weight) of the average diet⁽⁶⁹⁾. Therefore it is estimated that 20 $\mu\text{g/day}$ (for adults in Cases A–D and F–K) of lead intake is from canned food and 80 $\mu\text{g/day}$ from uncanned food. Knowing that the total dietary food intake (corresponding to Row 11) is 1.46 kg/day⁽⁶⁹⁾, it is calculated that the overall lead concentration in uncanned food is 58.4 $\mu\text{g/kg}$. Hence, assuming the same lead concentration in food before canning, the intake of lead from the cans is about 14.7 $\mu\text{g/day}$. The *pro rata* figure for the children in Cases E and L is 6.9 $\mu\text{g/day}$.

10. Row 13 shows the estimated intake from the food itself, obtained simply by subtracting Row 12 from Row 11.

11. Row 14 shows the concentration of lead in tap water. For Cases A–G and J–L a figure of 10 $\mu\text{g/l}$ has been used, as about 65 per cent of households in Great Britain have a tap water lead concentration at or below this value⁽⁴⁴⁾. For Case H, with lead piping and plumbosolvent water, a high value of 300 $\mu\text{g/l}$ ⁽⁴⁴⁾ has been used (though even higher values may be encountered for individual households). Row 15 shows the consumption of tap water for beverages. The figures used, 1.1 l/day for the adults in Cases A–D and F–K and 0.5 l/day for the children in Cases E and L, are based on data from the Water Research Centre (WRC)⁽²⁰⁶⁾. The daily intake of lead in tap water beverages is shown in Row 16. This is calculated from Rows 14 and 15, but making allowance for a proportion of the tap water consumed as tea. A number of studies have shown that tea leaves absorb lead, reducing the concentration by about 35 per cent⁽²⁰⁷⁾. The WRC data show that on average tea accounts for about 65 per cent of the consumption of tap water by adults and about 35 per cent by children⁽²⁰⁶⁾. Foods, particularly acid fruits, take up lead from cooking water and from deposits on the cooking vessels from water previously used. An estimate of the lead intake via this pathway can be made using unpublished data from a MAFF study in Ayr which showed that the lead concentration in food ($\mu\text{g/kg}$ food) due to absorption from cooking water is approximately $0.46 \times$ concentration of lead in the water ($\mu\text{g/l}$). The study also found that about 0.18 kg/day of food was prepared in this way. Row 17 shows the daily intake of lead from cooking water calculated from these data. For Cases A–D, F, G, J

Appendix 4

and K the estimate is $0.8\text{ }\mu\text{g}$ and for Case H, with a high water lead concentration, $25\text{ }\mu\text{g}$. A figure of $0.4\text{ }\mu\text{g}$ (*pro rata* for dietary intake) has been taken for the children in Cases E and L.

12. Row 18 shows the estimated intake of lead from glazes on ordinary tableware. For the adults in Cases A–D and F–K a figure of $3\text{ }\mu\text{g/day}$ ⁽¹²⁰⁾ has been used. It is considered that the input from this source is negligible for the children in Cases E and L.

13. The values for the daily dietary intake of lead (Row 11) from the MAFF Total Diet Study⁽⁶⁹⁾ do not include lead intake from alcoholic drinks. There are few data on the lead content of alcoholic drinks in the UK and these show a considerable range of values⁽⁶⁹⁾. Cases C, D and G are assumed to have a daily consumption of 4 pints of beer (Row 19) in which the lead concentration is $0.01\text{ }\mu\text{g/g}$ ⁽⁶⁹⁾ corresponding to about $5.8\text{ }\mu\text{g/pint}$. The resulting intake of lead is shown in Row 20. This value for the lead content of beer is at the lower end of the range of values reported and is no greater than that for the lead concentration in tap water in most households.

14. Ordinary children, not suffering from pica, ingest lead from dust and soil picked up on their fingers. It is extremely difficult to quantify this intake. The concentration of lead in dust varies considerably and there is great uncertainty over the amount of soil or dust ingested. The rural children (Case E) are assumed to be exposed to a lead in dust concentration of $800\text{ }\mu\text{g/g}$, and the inner city children (Case L) to $1,400\text{ }\mu\text{g/g}$ (Row 21), and all are assumed to ingest 0.1 g/day of dust⁽¹⁸⁾. The consequent lead intakes are shown in Row 22. This ingestion pathway is assumed to be negligible for the adults in Cases A–D and F–K.

15. Row 23 shows the estimated total intake of lead by ingestion. This is obtained by addition of the figures in Rows 11, 16, 17, 18, 20 and 22. Only a proportion of the ingested lead is absorbed into the bloodstream; the remainder passes directly to the faeces. The percentage absorption of lead is known to vary greatly depending on the contents of the gut and on the form of the lead ingested and it is considered to be much higher in children than in adults. An overall absorption of 10 per cent is assumed for adults⁽¹³⁾ and 53 per cent for children⁽¹²⁵⁾ in Row 24. Row 25 shows the total lead uptake from the gut, obtained by multiplication of Rows 23 and 24.

16. The total body uptake of lead, from both lungs and gut, is shown in Row 26. This is obtained by addition of Rows 10 and 25.

17. The percentages of the total uptake from inhalation and ingestion are shown in Rows 27 and 28 respectively.

18. Row 29 provides an estimate of lead derived from petrol. For adults there are two components: lead inhaled from the air and lead ingested in food. The first is taken as 90 per cent of the lead uptake by inhalation (minus lead from tobacco). The second component is based on an estimate that $13\text{ }\mu\text{g}$ of the

daily dietary lead intake are contributed by aerial deposition⁽¹¹⁹⁾. (This estimate is based on measurements of the fallout rate and concentration in food of the naturally occurring isotope ²¹⁰Pb.) Thus for cases A–D and F–J the lead derived from petrol is calculated as:

$$0.9\left(\frac{\text{Row } 5 \times \text{Row } 9}{100}\right) + \left(13 \times \frac{\text{Row } 24}{100}\right) \mu\text{g/day}$$

For Case K the same calculation is performed but to the figure of 13 in the above equation is added the extra (relative to Case F) 110 μg of lead in the daily dietary intake (Row 11) which is assumed to be deposited from the air. For the children in Cases E and L the same principle is followed with the lead uptake from petrol calculated as:

$$0.9\left(\frac{\text{Row } 5 \times \text{Row } 9}{100}\right) + \left(\frac{\text{Row } 11 \times 13 \times \text{Row } 24}{100}\right) + \left(P \times \text{Row } 22 \times \frac{\text{Row } 24}{100}\right) \mu\text{g/day}$$

where P is the fraction of lead in dust derived from petrol. Table 2 shows values for Row 29 assuming different values for P, and in Table 1 the figure in Row 29 is expressed as a range for 0–100 per cent of lead in dust being derived from petrol. Row 30 expresses the lead uptake from petrol as a percentage of the total lead uptake; the figures for Cases E and L are again expressed as a range for 0–100 per cent of lead in dust being derived from petrol.

19. Row 31 gives a prediction of the blood lead concentration for the adults, obtained from Row 26 and Figure 4.2. No attempt is made to predict the blood lead concentration of the children in Cases E and L.

TABLE 2

Model of the potential contribution of petrol lead to the total lead uptake for children

	Case E in Table 1					Case L in Table 1				
Percentage of lead in dust from petrol	0	25	50	75	100	0	25	50	75	100
Total lead uptake ($\mu\text{g/day}$) (Row 26 of Table 1)	70	70	70	70	70	105	105	105	105	105
Uptake of petrol lead by inhalation ($\mu\text{g/day}$)	0.4	0.4	0.4	0.4	0.4	3.0	3.0	3.0	3.0	3.0
Uptake of petrol lead in diet ($\mu\text{g/day}$)	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Uptake of petrol lead in dust ($\mu\text{g/day}$)	0	11	21	32	42	0	19	37	56	74
Total lead uptake from petrol ($\mu\text{g/day}$) (Row 29 of Table 1)	3.3	14	24	35	45	5.9	25	43	62	80
Percentage of daily lead uptake from petrol (Row 30 of Table 1)	5	20	34	50	64	6	24	41	59	76

APPENDIX 5

THE DIESEL AND OTHER ENGINES NOT NEEDING HIGH OCTANE FUEL

Note by Atlantic Research Associates

1. Knocking (see paragraph 7.11 of the Report) occurs as a result of spontaneous ignition of the petrol and air mixture in the corner of the cylinder furthest away from the spark plug (the end-gas zone). If it can be arranged for the fuel admission to be delayed until late in the compression stroke then there will not be sufficient time for the abnormal end-gas state to be reached, and hence there will be no knock. Several such systems exist, with the diesel engine being the best example.

The diesel engine (c.f. Figure 7.1)

2. Diesel fuel, which is much less volatile than petrol, is injected into the highly compressed air in the cylinder almost at the end of the compression stroke and spontaneously ignites in the high air temperature. Ignition occurs mainly from the fuel sprays and no end-gas mixture results. Thus there is no knock. (What is called diesel knock is in fact mainly piston slap at light loads and when idling.)

3. Diesel engines will positively not run on high octane leaded fuels. Diesel fuel is in fact close to zero octane number. To obtain compression ignition a high compression ratio is used, ranging from 12:1 to 22:1 according to the design. Thus diesels have high thermal efficiencies.

4. The best high speed diesel engines for cars are based on a British design using the Ricardo Comet combustion system. It is now almost universally used, except by Mercedes-Benz. There is a worldwide move towards the diesel car on economy grounds, which Britain has been slow to follow.

5. Diesel cars currently in production in Europe have fuel economy advantages compared to equivalent petrol cars of about 15 per cent on motorway driving, about 30 per cent in urban traffic and up to 60 per cent on short winter trips (where the choke severely penalises the petrol car).

6. Because they do not yet benefit from economies of high volume production,* and because they incorporate an expensive injection pump, diesel cars are more expensive than petrol cars of equivalent power. The break-even time

*See, however, paragraph 7.9 of Report on use by Volkswagen of petrol engine parts in diesel cars.

between extra initial cost and fuel saved may be several years for the average motorist, or 20,000–50,000 miles, depending on the model and manufacturer's pricing policy.

7. The diesel engine does however need a special fuel designed to ignite by compression without a spark plug. This fuel comprises only a minor proportion of the barrel of petroleum, and to some extent is competed for by the jet engine and by home heating, so it can never fuel the whole car population: 25 per cent is usually regarded as the highest possible ultimate market share.

Stratified charge system

8. Another engine, similar to the diesel in some respects but having spark ignition, is the direct ignition stratified charge engine (DISC). This engine was pioneered (by Texaco, Ford, MAN and others) originally for use on battlefields, where it could use any fuel, ranging from aviation gasoline with lead to diesel fuel. It is called a multi-fuel engine in this guise, but it was later realised that its ideal fuel is an unrefined cut of the crude oil with a boiling point ranging from 40°C to 33°C, or in other words a mixture of petrol, kerosine, heating oil, 'Avtur' and diesel fuel. This is known as 'wide cut' fuel, and is the cheapest fuel of all. Texaco have stated that the overall economics of fuel consumption from the oil well to the car are worst with an unleaded petrol engine, better with a diesel engine, but by far the best with a DISC engine on 'wide cut' fuel.

9. DISC engines are not dominated by octane numbers but do have an expensive injection pump as well as an ignition system. Their adoption would effect a major upheaval in the world's oil refining industry, much of which would be rendered obsolete.

The May 'Fireball' system (Figure A)

10. A Swiss engineer, Michael May, has been working on the theory that octane number does not present such an unbreakable barrier to further efficiency as has been generally supposed. He has designed a combustion system which by the use of high turbulence and short flame path prevents the end-gas knocking zone from forming so readily. By this means he has been able to run ordinary petrol engines using 97 octane fuel with compression ratios as high as 15:1 and with close to diesel efficiencies.

11. Jaguar have applied this system to their V12 model with great success, with one version running on unleaded 91 octane petrol at a compression ratio of 11.5:1.

12. The May system and similar systems such as the Ricardo high ratio compact chamber (HRCC) deserve to be given more attention by manufacturers. They are promising because intrinsically they impose no extra costs.

Appendix 5

Figure A
The May 'Fireball' system

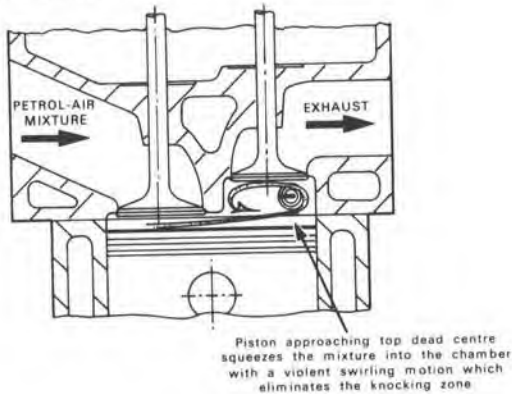
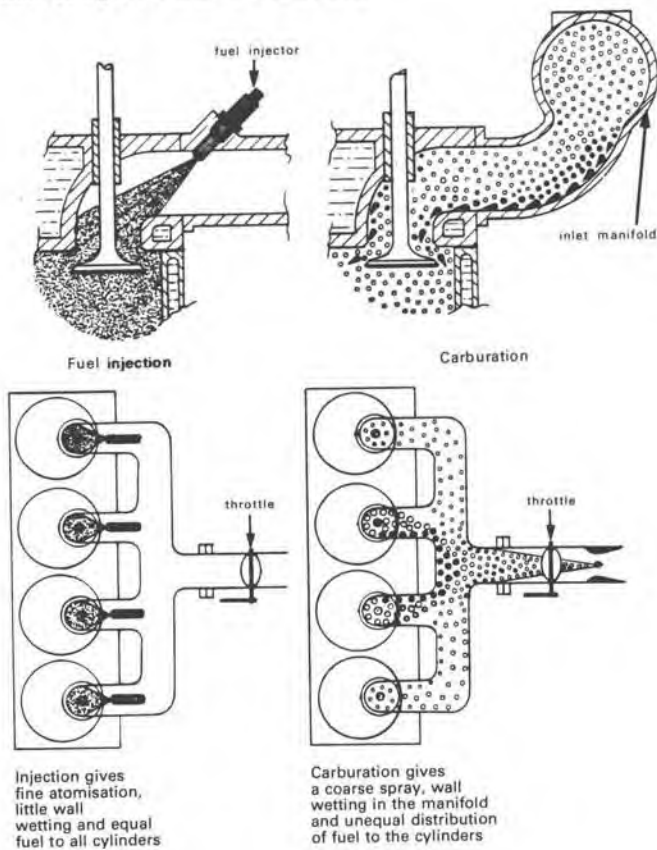


Figure B
Fuel injection compared with carburation



Petrol injection (Figure B)

13. The advantages of petrol injection over carburation lie mainly in the multi-point or port injection system. The petrol is injected behind the inlet valve in each cylinder so that all cylinders receive the same mixture, conforming exactly to the manufacturer's specification. Bad distribution of mixture in many carburetted engines is a frequent cause of knock.

14. Another advantage of port injection is that it mitigates the acceleration knock or front-end octane problem which results from the high octane fraction of petrol being left in the inlet manifold when the throttle is suddenly opened. Port injection ensures that all the fuel enters the cylinder.

15. Most injection systems have been used to provide extra power, but they are potentially much more useful for accurate mixture preparation, distribution and control.

Knock avoidance systems

16. In order to maximise efficiency in an ordinary petrol engine it is necessary to set it up as close to the knock limit as possible. This is difficult because of the unpredictable way in which engine performance drifts in use. A large allowance is therefore usually made, which contributes further to 'octane spread' and the unnecessary waste of several octane numbers (see paragraph 7.99 of Report).

17. Modern technology allows us to detect knock in the engine by using a sensor and to feed back a signal to the ignition system, commanding it to apply a little spark retard to control the knock. Thus the engine can run close to knocking without running 'over the edge', and thus is much less sensitive to fuel octanes.

18. This system was pioneered by General Motors and is used by them in production, as well as in other models such as the Saab Turbo. It is not an expensive system if the superiority of electronic ignition over contact breakers and points (which through wear and misfire can waste a great deal of petrol) is accepted.

Bi-fuel system

19. When a car is cruising gently its engine would be satisfied by fuel of as little as 60 or 70 octane; it only needs 97 octane for hard acceleration or hill climbing. This has led to suggestions that a bi-fuel system could be used: a low octane main fuel and an ultra high octane secondary fuel to be injected on command from the feedback sensor.

Research potential

20. The above examples illustrate how much scope there is for economies in transport fuel. Commercial pressures have forced truck manufacturers along the path towards turbo-charged direct injection diesel engines, but the sheer convenience of lead as an easy way of adding octane numbers at will has been a

Appendix 5

disincentive to research in the petrol engine field. Disproportionate attention has been given to the high performance area—hence the desire for higher compression ratios and higher octane fuel.

21. Given a moratorium in the performance race, there is great scope for research into improved low friction engines, with electronic spark and perfect mixture control, with knock avoidance systems, and even possibly using cheaper refinery cuts as fuel.

22. The potential fuel savings which could be achieved through a mixture of diesel, stratified charge and refined petrol engines is so large that the losses incurred by a reduction of 6 octane numbers in the fuel for present day engines would be utterly swamped.

23. Although the UK motor industry, as now constituted, has very limited resources to engage in this development work, the country possesses some unique 'centres of excellence' which deserve to be given more support.

APPENDIX 6

COUNCIL DIRECTIVE

of 29 June 1978

on the approximation of the laws of the Member States concerning the lead content of petrol

(78/611/EEC)

THE COUNCIL OF THE EUROPEAN COMMUNITIES,

Having regard to the Treaty establishing the European Economic Community, and in particular Article 100 thereof,

Having regard to the proposal from the Commission,

Having regard to the opinion of the European Parliament⁽¹⁾,

Having regard to the opinion of the Economic and Social Committee⁽²⁾,

Whereas the protection and improvement of public health and of the environment currently constitutes a major preoccupation common to all industrialized countries and pollution caused by products emitted in the exhaust gas of vehicles has reached a disquieting level owing to the continuous increase in the density of motor traffic; whereas, following the introduction of measures in Directive 70/220/EEC⁽³⁾, as last amended by Directive 77/102/EEC⁽⁴⁾, designed to curb air pollution caused by the emission of carbon monoxide, unburned hydrocarbons and nitrogen oxide from motor vehicles, action should be taken at this stage with a view to limiting lead particle emissions by such vehicles, the lead in question deriving from plumbiferous petrol additives acting as an anti-knock agent;

Whereas the national laws concerning the composition of petrol, and in particular the rules governing the limitations of the lead content in motor vehicle petrol, vary from one Member State to another; whereas such differences directly affect the proper functioning of the common market;

Whereas, owing to the important effect of lead upon public health and the environment, it is

necessary to reduce the lead content of petrol at Community level;

Whereas the financial, economic, industrial and qualitative consequences of a reduction of the level of lead in petrol to a maximum value of between 0.40 g/l and a value of 0.15 g/l have demonstrated that such a reduction is feasible within a relatively short period;

Whereas lead is only one of the constituent elements in the composition of petrol; whereas the reduction of this element must not have the effect of aggravating the air pollution by other pollutants which would be one of the main consequences of any modification in this composition;

Whereas detailed studies of the various aspects of the measures which might serve to reduce atmospheric lead should be continued at Community level; whereas Member States should for this purpose provide the Commission with relevant information;

Whereas the reduction of the lead content of petrol raises specific technical and economic problems in Ireland; whereas a temporary derogation for that country should not have severe repercussions on trade in petrol given that Irish refining installations at present only partially cover domestic requirements and that all petrol exported by that country to another Member State will have to comply with the provisions of the Directive which apply in that State; whereas there should therefore be a derogation from the provisions concerning the reduction of the lead content of petrol in Ireland;

Whereas a sudden change in the supply of crude oil or petroleum products in clearly defined circumstances could lead a Member State to authorize an increase in the lead content of petrol; whereas an appropriate procedure should therefore be laid down for such a situation,

⁽¹⁾ OJ No C 280, 8. 12. 1975, p. 9.

⁽²⁾ OJ No C 116, 30. 9. 1974, p. 18.

⁽³⁾ OJ No L 76, 6. 4. 1970, p. 1.

⁽⁴⁾ OJ No L 32, 3. 2. 1977, p. 32.

Appendix 6

HAS ADOPTED THIS DIRECTIVE:

Article 1

For the purpose of this Directive, 'petrol' means any fuel intended for the operation of internal combustion spark-ignited engines used for the propulsion of vehicles.

Article 2

1. From 1 January 1981, the maximum permitted lead compound content, calculated in terms of lead, of petrol placed upon the Community internal market shall be 0.40 g/l.
2. Without prejudice to paragraph 1, a Member State may require, in respect of petrol placed upon its market, that the maximum permitted lead content be less than 0.40 g/l. However, it shall not establish limits lower than 0.15 g/l.

Article 3

Member States shall take all appropriate steps to ensure that the reduction of the lead content does not cause a significant increase in the quantities of other pollutants or to a deterioration in the quality of petrol.

Article 4

The lead content of petrol shall be established in accordance with the procedures set out in the Annex.

Article 5

Where a Member State establishes, on the basis of a test performed in accordance with the procedures described in Article 4, that any petrol fails to comply with the requirements of Articles 2 and 3, it shall take the necessary measures to ensure that these requirements are fulfilled.

Article 6

Member States shall, at the Commission's request, supply it with information on:

- (a) the effects of the implementation of this Directive, and in particular Article 3 thereof;
- (b) developments as regards systems to reduce the emission of lead and of any polluting substitutes in exhaust gases;
- (c) development of the concentrations of lead and polluting substitutes in the urban atmosphere and their effect on public health;
- (d) the effects on energy policy of the various possible ways and means of reducing pollution caused by lead emission in exhaust gases.

The Commission shall report to the Council and the European Parliament on the information thus obtained and, in the light of the data compiled, shall make any suitable proposals for such data to be taken into account in order to develop further Community policy on the lead content of petrol.

Article 7

1. Notwithstanding Article 2(1), the Government of Ireland may provide that for a period of five years commencing on 1 January 1981 petrol may be placed on the market in Ireland even though its lead content is greater than 0.40 g/l, without, however, exceeding the current content of 0.64 g/l.
2. Before the end of the period referred to in paragraph 1 the Council shall, acting by a qualified majority on a proposal from the Commission, decide on the duration of a second derogation period of not more than five years.

Article 8

If, as the result of a sudden change in the supply of crude oil or petroleum products, it becomes difficult for a Member State to apply the limit to the concentration of lead in petrol referred to in Article 2(1), that Member State may, after having informed the Commission, authorize a higher limit within its territory for a period of four months. The Council, acting by a qualified majority on a proposal from the Commission, may extend this period.

Article 9

1. The Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive within 18 months of its notification and shall forthwith inform the Commission thereof.
2. The Member States shall ensure that they communicate to the Commission the texts of the provisions of national law which they adopt in the field governed by this Directive.

Article 10

This Directive is addressed to the Member States.

Done at Luxembourg, 29 June 1978.

For the Council
The President
S. AUKEN

Appendix 6

ANNEX

Reference methods

For the measurement of the lead content of petrol the reference method shall be that laid down in the international standard ISO 3830 (First edition of 15 February 1977) 'Petroleum products—petrol—measurement of the lead content—iodine monochloride method'.

The results of individual measurements shall be interpreted on the basis of the method described in BS 4306: 1968, published by the British Standards Institution.

For the methods indicated, the versions in the various languages published by the ISO and the BSI respectively shall be authentic, as shall other versions which the Commission certifies as conforming to them.

reproduced from: *Official Journal of the European Communities*. **L197**, 19–21, 22 July 1978.

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