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# CHILDHOOD EXPOSURE TO ENVIRONMENTAL LEAD

**Technical Report**

Prepared by:
**MONITORING AND ASSESSMENT RESEARCH CENTRE**
**King's College London, University of London**

With the support of:
**UNITED NATIONS ENVIRONMENT PROGRAMME**

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## 1. Introduction

### 1.1. Aim of this report

Considerable attention has been given to evaluating the significance of environmental pollution by lead. It has long been known that lead in sufficient quantities is a neurotoxin, but whether general environmental sources can result in the build-up and transfer of lead to an extent which might cause serious damage to human health is a question yet to be answered. Recent studies suggest that adverse health effects can occur at blood lead levels which are lower than the levels previously considered safe. Other studies emphasize the importance of the ingestion of soil and dust particles in contributing to the lead intake by young children, who are most at risk from exposure to lead.

For these reasons, re-evaluations of environmental quality standards for lead are called for. The key elements of such standards are the blood lead threshold and the impact of environmental lead exposure on blood lead concentrations in children. It may be necessary to adopt a lower blood lead threshold, whereas at the same time, the impact of environmental lead exposure on children's blood lead is probably greater than was previously assumed.

In this report, the exposure of children to environmental lead is discussed, along with the impact of environmental lead exposure on the concentration of lead in children's blood. The environmental pathways of lead to children are discussed in Chapter 2, the relationship between environmental exposure and actual lead intake in Chapter 3 and the concentration of lead in blood as a measure of internal exposure in Chapter 4. Factors other than lead intake which affect the concentration of lead in blood are considered in Chapter 5 and the action of confounding factors which may distort the relationship between environmental lead and blood lead in Chapter 6.

Epidemiological studies of environmental lead in relation to children are reviewed in Chapter 7 and a summary is given of quantitative estimates of the impact of environmental lead exposure on blood lead levels of children. A set of tentative conclusions concerning the scientific basis of standards for environmental lead is given in Chapter 8 and the usefulness of environmental and biological monitoring of lead is discussed in Chapter 9.

## 1.2. Children as a population at risk

There is general agreement that, within the non-occupationally exposed population, the foetus and children up to about six years of age constitute the population most at risk from lead exposure (WHO 1977a; EPA 1978; National Research Council 1980; Rostron 1982a, 1982b.)

The main reasons for this are that in comparison with adults (1) children are more susceptible to lead (2) they take in more lead with food per kg body weight (3) they exhibit mouthing which exposes them to lead in dust and dirt and (4) they absorb more lead from the gut.

(1) Susceptibility

It is well established that at a given level of lead in the blood (PbB), children suffer more severely from ill effects than do adults. The level of free erythrocyte protoporphyrin in blood begins to rise at lower PbB levels in children than in adults (Roels et al. 1976, 1978b; Cavalleri, Baruffini, Minoia and Bianco 1981; Piomelli et al. 1982). Adverse effects on the central nervous system (CNS), as measured by various tests of mental ability, have been suggested as occurring at PbB levels well below those at which CNS-effects in adults can be detected (Needleman et al. 1979; Yule, Landsdown, Millar and Urbanowicz 1981; Winneke, Hrdina and Brockhaus 1982; Needleman 1983; Winneke et al. 1983; for reviews cf. Rutter 1980; Bornschein, Pearson and Reiter 1980a, 1980b; Rostron 1982a, 1982b), although it is still a hotly debated issue at what level of blood lead concentrations these effects start to manifest themselves (Anonymous 1982a, 1982b, 1982c; Jones et al. 1983). Previously, it was thought that adverse CNS-effects did not occur in children who had PbB levels below 30 ug 100 $m\ell^{-1}$, but now some authors have begun to doubt the existence of a threshold below which adverse effects do not occur.

It has been suggested that acceptable levels of lead in blood should be lower for children than for adults (Roels et al. 1978b;

Grandjean 1981; Zielhuis 1981; Piomelli et al. 1982).

(2) Intake by food
Children take in more lead per kg body weight with their food than do adults, for the simple reason that they consume more food per kg of body weight. The difference may well be two- to threefold (Barltrop 1972; ICRP 1975) depending on the age of the child. Expressed per unit volume of blood, the intake in children has been asserted to be 1.5 times greater than in adult women (Duggan 1983a). The inhalation rate per kg of body weight is also greater (Knelson 1974) due to the higher metabolism in children.

(3) Mouthing behaviour
During some period in early life, the normal child will investigate its surroundings by hands and mouth (Lepow et al. 1974; Sayre, Charney, Nostal and Pless 1974; Charney, Sayre and Coulter 1980). The amount of dust and dirt ingested as a consequence of mouthing has never been directly measured. It has been suggested that the amount of ingested dust could be in the order of about 20-50 mg $d^{-1}$ (Duggan and Williams 1977) but this figure should not be taken as more than an 'educated guess'. Regardless of how large the ingested quantity actually is, it will be larger than the relative amounts of dust and dirt ingested by adults, although one recent study has suggested that lead in dust and dirt represents a pathway of lead intake for adults also (Gallacher et al. 1984b, 1984c).

(4) Absorption
Limited evidence suggests that the absorption of lead from the gut is more efficient in children than in adults (Alexander, Delves and Clayton 1972; Alexander, Clayton and Delves 1974; Ziegler et al. 1978). In animal studies, it has been clearly documented that very young animals absorb more lead from the gut than do adult animals (Jugo 1977; Quarterman and Morrison 1978; Mahaffey 1983).

However, a higher absorption rate does not necessarily mean that more lead is being retained as well; a number of children in the study by Ziegler et al. (1978) actually excreted more lead than they absorbed, indicating that lead excretion may also be higher in children than in adults. It has been pointed out, however, that this may be so only at low levels of exposure, and that at somewhat higher levels, more lead is actually being retained by children than by adults (Ryu, Ziegler, Nelson and Fomon 1983).

Points 2-4 would lead one to expect that, in general, children

should have higher blood lead levels than adults. But this is not the case (Chamberlain 1983a; Duggan 1983b, 1983c). Children living in environments not heavily polluted have repeatedly been shown to have blood lead levels only slightly higher than those of their mothers, and more or less equal to those of their fathers (Billick, Curran and Shier 1979; Mahaffey, Annest, Barbano and Murphy 1979).

Various explanations can be proposed for this phenomenon. The additional intake through mouthing activity could be negligible compared with lead intake via food (Chamberlain 1981); however, the intake of lead from food alone is already so much larger in children than in adults, on a per kg body weight basis, that a difference in the metabolism of children and adults has in any case to be assumed; and in the absence of precise knowledge of the size of the difference, it does not seem possible to draw any conclusion on the amount of lead ingested through mouthing from the absence of considerable differences between blood levels in children and adults in non-polluted areas alone.

Another explanation would be that the distribution of lead in the various body tissues is different in children and in adults (Duggan 1983a). It is true that in children relatively more lead is to be found in the soft tissues compared with adults, where 90-95 per cent of the total body burden of lead is in the skeleton (Schroeder and Tipton 1968; WHO 1977a). This probably reflects mainly the fact that the lead concentration in children's bones is much lower than in adult bones; limited evidence from a study by Barry (1981) does not support the hypothesis that the lead concentration in soft tissues in children - including the brain - is higher than it is in adult soft tissues.

A more likely explanation would be that although uptake from the gut is higher in children than in adults, both through higher food intake and greater absorption efficiency, retention is not necessarily higher because the uptake may be offset, to a certain extent, by a higher excretion rate (Duggan 1983a). As mentioned, the Ziegler et al. (1978) study supports this; a recent study by Ryu et al. (1983) in addition has demonstrated that at levels of lead intake which are low - but still higher than in adults on a per kg body weight basis - children's blood lead levels in the first half year after birth remained below those of their mothers, and even decreased somewhat during the first months of life. A subsequent higher intake in some of the children resulted in a doubling of the children's blood lead levels within a few months, suggesting that only at low levels of intake is excretion able to balance uptake. The Ryu et al. (1983) study shows a similarity with a study from the Federal Republic of Germany (Haas et al. 1972) in which it was shown that blood lead levels in

hospitalized children aged 0-6 years were lower than at birth. For other examples cf. Duggan (1983b, 1983c).

It is well established that a child is born with a blood lead level which is somewhat lower (10-20 per cent) than that of its mother (Haas et al. 1972; Schaller et al. 1976; Kuhnert, Erhard and Kuhnert 1977; Buchet, Roels, Hubermont and Lauwerys 1978; Roels, Hubermont, Buchet and Lauwerys 1978a; Alexander and Delves 1981; Kaul, Davidow, Eng and Gerwirtz 1983; Zarembski, Griffiths, Walker and Goodall 1983; Tsuchiya, Mitani, Kodama and Nakata 1984). Over 90 per cent of the lead in blood is in the erythrocytes (Zielhuis 1974). At birth, children have a haematocrit value which is about twice that of their mothers (Zielhuis 1974; ICRP 1975) and it has been argued that this protects new-born children from the adverse effects of lead, as at a certain blood lead level, the concentration in the erythrocytes as well as in the plasma is lower in new-born children than in their mothers. It has to be pointed out, however, that the haematocrit decreases rapidly after birth and that between 0.5 to 2 years it is actually lower in children than in their mothers (ICRP 1975). Up to a certain level of exposure, the blood lead level in children apparently does not rise above its initial level. Still, this does not necessarily mean that the child excretes as much lead as it absorbs. A child grows and builds up a body burden of lead which may very well be about 50 mg when the child has reached adulthood (Schroeder and Tipton 1968; Barry 1978). If in the course of 20 years 35 mg of lead have been added to the body burden, this constitutes an average retention of 35 mg/(20 x 365) = 5 $\mu g\ d^{-1}$ (approximately). In recent years, it has become clear that lead intake via food by young children in many countries is probably only about 10-30 micrograms per day of which 50 per cent at most is being absorbed from the gut (cf. Section 2.7 for further details).

It could be argued that quite a large part of the absorbed lead simply goes into the formation of the total body burden over the years. The body burden figures used to arrive at this tentative conclusion may be too high for present-day situations, as levels of lead in blood and in food seem to have been declining (cf. Diehl 1982; Oxley 1982; Annest et al. 1983; Brunekreef, Noij, Biersteker and Boleij 1983; Elwood 1983a; Sherlock 1983). At least part of the reduction of lead in food has been ascribed to analytical artefacts (Sherlock 1983; Bloom and Smythe 1984); as the body burden of lead is mainly determined by the lead content of bones which is relatively high and therefore somewhat easier to measure without bias, it is possible that total body burden data as measured 10-20 years ago still have relevance for present-day situations.

Lack of specific data makes it difficult to arrive at reliable estimates of how much of the absorbed lead actually goes into the formation of the body burden; it is certainly not a negligible part. It is clearly a point that deserves additional attention.

## 2. Environmental pathways of lead

### 2.1. The exposure system

Once released into the environment, lead can reach children through a number of different pathways. The major sources and pathways are shown in Figure 1.1.

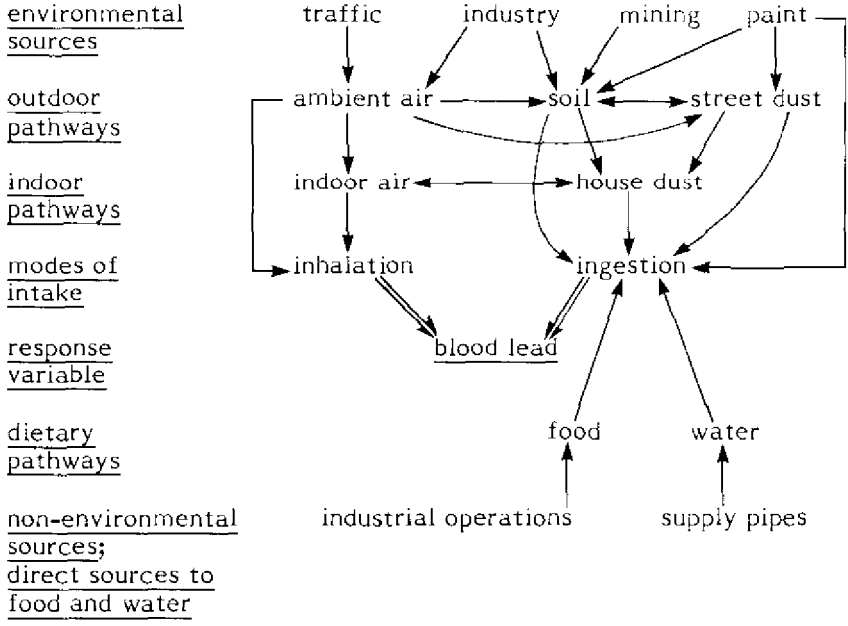



Figure 1.1 Sources of environmental lead and pathways to children

Although the figure looks complex it is, in fact, a simplification. A comparable flow chart in the NAS report (National Research Council 1980) 'Lead in the human environment' has over a hundred

arrows and interactions; Billick (1983) has aptly remarked that that flow chart certainly illustrates the complexity of the system, 'but whether it clarifies or confuses the understanding of what is happening is questionable.' It is hoped that Figure 1.1 will clarify rather than confuse; it mostly contains variables which can conceivably be measured in a single study. Four main categories of environmental sources have been discerned. Of these, vehicular traffic is the single largest source of environmental lead pollution in the industrialized nations, which accounts for over 90 per cent of all emissions into the atmosphere (WHO 1977a; National Research Council 1980; Harrison and Laxen 1984).

The organolead compounds tetra-ethyllead and tetra-methyllead have been added to petrol as an anti-knock agent in concentrations up to 1 g $\ell^{-1}$ in the past. At present, the maxiumum concentration is limited to 0.15 to 0.40 g $\ell^{-1}$ in many countries, and lead-free petrol is used in Japan and is increasing its market share in the U.S.A. In the future, lead will probably be removed from petrol in the countries of the European Communities as well (Anonymous 1984). In The Netherlands, the lead content of petrol will be reduced to a maximum of 0.15 g $\ell^{-1}$ in 1986 (Zielhuis 1984), and by the end of 1984 one manufacturer had actually started to offer lead-free petrol for sale.

It is estimated that some 75 per cent of lead in petrol is released into the atmosphere, mostly in the form of inorganic lead compounds (Habibi 1970; Chamberlain et al. 1978).

Industrial lead emissions are quantitatively less important, but they have led none the less to very high pollution levels near industrial sources in a number of countries (Roberts, Gizyn and Hutchinson 1974a; Roberts et al. 1974b; Einbrodt, Rosmanith, Dreyhaupt and Schröder 1975; Landrigan et al. 1975; Rosmanith, Einbrodt and Gordon 1975a; Rosmanith, Schröder, Einbrodt and Ehm 1975b; Rosmanith, Einbrodt and Ehm 1976; Roels et al. 1976, 1978b, 1980; Yankel, Lindern and Walter 1977; Schmitt et al. 1979; Zielhuis et al. 1979; Walter, Yankel and Lindern 1980; Cavalleri et al. 1981; Popovac et al. 1982; Prpic-Majic, Meczner, Telisman and Kensanc 1983). In mining districts, large quantities of lead can be found in the soil (Barltrop, Strehlow, Thornton and Webb 1974; Davies and Roberts 1978; Davies and White 1981a,b; Davies, Ginnever and Lear 1981c; Davies 1983; Culbard et al. 1983a, 1983b).

In the past, lead was a major constituent of paint in many countries (Chisholm 1973). In the U.S.A. especially, the combination of flaking high-lead paints and adverse social conditions in inner city areas has led to a large number of fatal poisonings among children (Ingalls, Tiboni and Werrin 1961; Anderson and Clark 1974; Chisholm

1982). Similar experiences have not been reported from other countries although this does not mean that crumbling paint locally does not contribute heavily to lead pollution of dust and dirt inside and outside dwellings (Millar and Cooney 1982; Reeves, Kjellström, Dallow and Mullins 1982).

The three major outdoor pathways are air, soil and dust. When airborne lead is inhaled, the smaller particles (less than about 1-2 μm in diameter) penetrate deep into the lungs, and experiments with radioactive lead have shown that lead is quantitatively absorbed (Knelson et al. 1972; Chamberlain et al. 1975, 1978; Chamberlain 1983a; Gross 1981). It has been argued that in these experiments more soluble forms of lead were used than are commonly encountered in the atmosphere (Lawther, Commins, Ellison and Biles 1972). At autopsy, the lead concentration in the lungs of adults was, however, not found to be elevated (Barry 1978) which reinforces the conclusion that no retention of lead occurs in the lung. Larger particles are trapped in the upper region of the respiratory tract, whence they can be ingested, thereby contributing to total exposure through another mode of intake. Soil and street dust may contribute to total exposure mainly when lead-bearing particles are ingested by children.

The main indoor pathways are indoor air and house dust; the respective modes of intake are the same as for the outdoor pathways, i.e. inhalation and ingestion. Food and drinking water constitute the main dietary pathways. Lead in drinking water mainly originates from lead dissolved in water supply systems, but in the case of food the picture is less clear (for further details cf. Chapter 6).

It must be stressed that it is generally not possible to derive fixed transfer coefficients indicating how large the transport of lead through some pathway is, irrespective of the situation which is being studied. Quite a number of 'transfer modifying variables' exist, and some knowledge of their value is necessary when studying lead intake from the environment by children in a specific environment. Some examples are the frequency of hand-to-mouth movements, which is an obvious determinant of the amount of dust which is being ingested; and a child's nutritional status which is a determinant of the blood lead concentration, given a certain intake of lead.

## 2.2. Selected environmental pathways

The main environmental pathways of lead to children are air and soil, dust, dirt and paint.

**2.2.1. Air lead.** The main sources of lead in outdoor air are

vehicular traffic and industrial emissions (WHO 1977a; National Research Council 1980; Chamberlain 1983a; Harrison and Laxen 1984). Consequently the concentration of lead in air varies with distance from roads and industrial sources (Daines, Motto and Chilko 1970; Little and Wiffen 1977). Near roads, a variation with elevation has also been reported, with higher levels at street level than at rooftop level (Darrow and Schroeder 1974; Lioy, Mallon and Kneip 1980). The traffic-generated lead aerosol is mostly in the submicron range (Chamberlain et al. 1978) so that upon inhalation it can penetrate deeply into the lung. Near industrial sources, more of the lead is in particles larger than 1 μm (Roberts et al. 1974a; Landrigan et al. 1975; Paciga, Roberts and Jervis 1975), and less of it will penetrate to the deeper regions of the lung.

Lead in outdoor air is usually sampled with high volume samplers; these devices are known to sample particles up to about 10 μm quite efficiently (Wedding, McFarland and Cermak 1977; van der Meulen, Hofschreuder, van de Vate and Oeseburg 1984). Consequently, the amount of lead which can actually reach the alveoli in the lung is being overestimated by high volume measurements, and the bias will most probably be larger near industrial lead sources than near roads.

Other devices, sampling lower volumes of air, are sometimes used, and the resulting air lead concentrations are usually lower than those measured by high volume samplers at the same spot and time (Lieback and Ruden 1983). Indoors, the concentration of lead in air is typically lower than outdoors (Daines, Smith, Feliciano and Trout 1972; Johnson et al. 1978; Alzona et al. 1979; Cohen and Cohen 1980). It has been shown that large particles in outdoor air penetrate less well into buildings than do small particles (Cohen and Cohen 1980). Presumably the indoor/outdoor ratio therefore differs in areas where air lead is predominantly of industrial origin from that in areas where vehicular traffic is the main source.

Inside driven cars, the concentration of air lead has been shown to be equal to or lower than the concentration of outdoor air lead measured on the street where the car was being driven (Bevan, Colwill and Hogbin 1974; Chamberlain et al. 1978), but higher than the concentrations measured at nearby fixed monitoring sites (Rohbock 1981; Den Tonkelaar 1983). This is due to the rapid decrease of the lead concentration in the air next to the road.

Due to the many sources of variability mentioned above, the concentration of lead in the air which is actually being inhaled cannot be well estimated from measurements at fixed sites in outdoor air; a correlation of only 0.20 (Spearman's rank correlation coefficient) has

been reported between the concentration of lead in air as measured with personal samplers and the concentration of lead in air measured at fixed outdoor sites (Tosteson, Spengler and Weker 1982). The range of outdoor air lead concentration in this particular study was small, 0.1 to 0.5 μg $m^{-3}$; when larger ranges of air lead are being studied, the correlation between the concentrations of lead in inhaled and outdoor air will be higher, especially when there are systematic, large differences in outdoor air lead between areas where people spend most of their time.

**2.2.2. Wet and dry deposition.** From the air, lead is transferred to the earth's surface by dry and wet deposition (Galloway et al. 1982). The dry deposition flux is related to the concentration of lead in air; the relationship has been expressed in the following equation

$$F = V_g C \qquad \text{(Chamberlain et al. 1978)}$$

$F$ = flux (mass per surface unit per time unit)
$V_g$ = deposition velocity (distance units per time unit)
$C$ = concentration of lead in air (mass per volume unit)

The deposition velocity is a unit which depends on the structure of the surface to which deposition takes place; if the surface is rough, more mass is being transferred to it per surface unit from the air at a given air lead concentration than when the surface is smooth. For different types of grass fields, the deposition velocity was shown to range from 0.05 to 1 cm $s^{-1}$ for example (Davidson, Miller and Pleskow 1982). As a result there may be large differences of dry deposition fluxes in areas with comparable outdoor air lead concentrations.

Wet deposition of lead occurs when lead particles are trapped by rain and snow, and thereby transferred to the earth's surface. It depends on precipitation volume, intensity and duration (Lindberg 1982). The ratio between wet and dry deposition is not fixed, but depends on climatic factors. For a deciduous forest in the eastern U.S.A. which has a yearly precipitation of 1,400 mm, it was shown that wet deposition accounted for 45 per cent of the total atmospheric deposition of lead (Lindberg and Harris 1981). For New York City, a value of 56 per cent has been reported (Nriagu 1978a). The input of lead from the air into other environmental pathways is thus not a fixed function of the air lead concentration.

**2.2.3. Lead in soil.** The concentration of lead in soil has been shown

to be high in or near mining areas (Barltrop et al. 1974; Nriagu 1978b; Davies 1983; Culbard et al. 1983a), near industrial lead sources (Roberts et al. 1974a; Landrigan et al. 1975; Yankel et al. 1977), and near (mostly wooden) houses painted with high-lead paints (Ter Haar and Chadzynski 1979; Reeves et al. 1982). Vehicular traffic causes elevated lead concentrations in soil within about 100 m of busy roads (Page and Ganje 1970; Page, Ganje and Joshi 1971; Fergusson, Hayes, Yong and Thiew 1980; Healy and Aslam 1980; Agrawal, Patel and Merh 1981; Garcia-Miragaya, Castro and Paolini 1981; Byrd, Gilmore and Lea 1983) and adds only slightly to lead concentrations away from roads (>150 m).

In most soils, lead is highly immobile (Khan 1980; Scokart, Meeus Verdinne and de Borger 1983); as the pollutants are usually deposited on the top layer, the concentration of lead in soil in polluted areas may vary sharply with depth (Roberts et al. 1974a; Farmer and Lyon 1977; Steinnes 1983). The amount of lead recovered from a soil sample varies with the extraction method used (Khan 1980; Köster and Merkel 1982). It is possible to recover virtually all lead from samples by using hot concentrated acids, but the use of less strong extractants enables different proportions of total lead to be recovered from different soil samples (Köster and Merkel 1982; Harrison and Laxen 1977). Consequently, extraction methods and sampling depths should be reported when studying soil lead concentrations.

The accessibility of soils determines their potential as a pathway of lead to children; it is obvious that if soils are inaccessible because they have been paved, they cannot contribute much to exposure. In gardens and playgrounds, type and density of vegetation may influence the possibility of direct contact with the soil (Barltrop et al. 1974; Seifert, Drews and Aurand 1984). No attempt has yet been made to develop 'measures of accessibility'.

**2.2.4. Lead in street dust.** Lead concentration in street dust was shown to be elevated in inner city areas with high traffic densities (Cool, Marcoux, Paulin and Mehra 1980; Fergusson et al. 1980; Fergusson and Ryan 1984; Graf, Baars, Grote and Ubelmesser 1980; Anagnostopoulos 1983) and near industrial lead sources (Roberts et al. 1974a; Yankel et al. 1977) as a consequence of wet and dry deposition. In addition, crumbling paint may contribute to lead in street dust (Ter Haar and Aronow 1974; Reeves et al. 1982). Paint on street curbs and bridges has also been implicated as a source of lead in street dust (Franz and Hadley 1981; Landrigan et al. 1982). As with lead in soil, the extraction method used to recover lead from

street dust determines which proportion of lead will actually be recovered (Day, Fergusson and Chee 1979; Ellis and Revitt 1982; Jones and McDonald 1983; Gibson and Farmer 1984). The variety of sampling methods used are great; they may include sweeping a certain area with brooms (Elwood et al. 1977; Harrison 1979) or using a specially designed vacuum cleaner (Brunekreef et al. 1983). The concentration of lead in the dust has been shown to depend on the particle size (Rameau 1972; Linton, Natusch, Solomon and Evans 1980; Ellis and Revitt 1982).

As a consequence, the results of measurements pertaining to different size fractions of the dust cannot be directly compared. The concentration of lead in the dust also depends on whether the samples were taken from the pavement, the gutter or from the road surface itself (Cool et al. 1980). The variability of dust lead concentrations in time and space has only been assessed on a limited basis (Duggan 1984; Gallacher et al. 1984a; Hamilton, Revitt and Warren 1984); it is probably rather large, suggesting that collection of large area samples and some repetition of sampling are needed to reduce the variability in estimates of exposure to dust lead. Lead in street dust is usually expressed as weight ratio, mg $kg^{-1}$ of dust; sometimes lead loadings are used (µg of lead per $m^2$ of pavement) which are thought to reflect the total available lead better than the lead concentration in the dust itself (Brunekreef et al. 1983), but which are probably even more variable than the lead concentration in the dust (Hamilton et al. 1984). There is a definite need for standardization of street dust sampling procedures and methods; at present, the results of different studies can only be compared with care, and not without reference to the sampling methods and procedures.

**2.2.5. Lead in house dust.** For lead in house dust, the same major sources have been identified as for lead in street dust. In addition it has been shown that the house dust in lead workers' homes may contain very high levels of lead (Baker et al. 1977; Elwood et al. 1977; Rice et al. 1978; Fergusson 1981; Kawai, Toriumi, Katagiri and Maruyama 1983). This was found in spite of changing their work clothes and showering by the lead workers in the factory (Rice et al. 1978) and it has been suggested that lead is being transported home on shoes, socks, etc. (Elwood et al. 1977).

The same problems in sampling and analysis exist as with street dust. Sometimes samples are taken from the house vacuum cleaner (Yankel et al. 1977; Culbard et al. 1983a, 1983b). As vacuum cleaners and vacuum cleaning practices vary across houses, the dust inside the cleaners is ill defined.

Specially designed vacuum cleaners have been used to standardize sampling across homes (Solomon and Hartford 1976; Brunekreef, Veenstra, Biersteker and Boleij 1981; Brunekreef et al. 1983). In house dust as well as street dust the lead concentration varies with particle size (Johnson, Fortmann and Thornton 1982) so sampling has sometimes been restricted to the smaller particles, as these tend to have the higher lead concentration and are presumed to stick to children's hands more readily than do large particles (Duggan and Williams 1977; Brunekreef et al. 1983). For house dust there is consequently the same need for standardization of sampling procedures and methods. One method which has been used to evade the variability associated with sampling floor dust is to measure lead deposition in homes (Brunekreef et al. 1981, 1983; Aurand, Drews and Seifert 1983; Seifert et al. 1984). Sampling periods of one week to a few months have been used when this method was applied, thereby giving a somewhat more integrated picture than is obtainable when spot samples of floor dust are taken.

For soil and dusts in general, it has not been clearly established which are the most relevant characteristics which should be measured to estimate the exposure of children. All that can be said at present is that lead should be measured on surfaces which are accessible to children - but accessibility as such is not a clearly defined item either, as mentioned earlier. At best, the various measures of lead in soil and dust are crude approximations of actual lead intake, and this should be borne in mind when analysing the data from studies on the relationship between environmental lead and blood lead, as will be discussed further in Chapter 7, Section 4.

The transfer of environmental lead into the food chain will be discussed in Chapter 6.

An important aspect of studying environmental pathways for lead is the absence or presence of a steady state. The concentration of lead in air will quickly respond to changes of lead emissions into the air in the area under study, but this is not true for the concentration of lead in most other pathways. The concentration of lead in surface soil will slowly increase for years after emission has started - and may take years to decrease after emission has stopped, as lead is persistent in most soils. Street dust is subject to removal in periods of rainfall or street cleaning; house dust is moved by cleaning practices as well. Therefore, the concentration of lead in street and house dust probably responds more quickly to emission changes but, here again, time lags of uncertain lengths are likely. It is thus of importance to obtain historical information on emission changes when studying a particular environment.

## 3. Exposure/dose relationships

The main modes of lead intake from the environment by children are inhalation and ingestion.

Children inhale more air per kg body weight than do adults (Knelson 1974). For persons at rest, the difference is about twofold for very young children (< 3 years); when children grow older, the difference gradually decreases. There is not much difference between boys and girls until they have reached puberty. From about 12-13 years of age, ventilation in boys is somewhat higher than in girls.

In addition to the higher inhalation rate per kg body weight at rest, children tend to be more active than adults. To an unknown extent, the real volume of inhaled air per kg body weight will thus be higher again. If the same proportion of inhaled lead is deposited in the lungs, and if the same proportion of the deposited lead is absorbed from the lungs in children as in adults, the uptake from air in the first 3-5 years of life is probably larger by a factor of at least two. Depending on air lead concentrations, this may be important as part of total uptake.

The ingestion of soil and dust by children is extremely hard to quantify. It depends on the frequency with which hands and objects are mouthed, on the amount of dust removed from hands and objects by mouthing, and on the concentration of lead in the dust.

Mouthing frequencies of children have been observed, and may range from 2.4 to 6.4 times per hour (Lepow et al. 1974; Brunekreef, Smit, Dieckman and Heemskerk 1978). There are no observations of the amount of lead or dust on children's hands just before and after mouthing. Mouthing is considered to be an aspect of normal child development (Charney 1982) and it is reported to occur at least until children are 5 or 6 years of age (Barltrop 1966; Vostal, Taves, Sayre and Charney 1974; Charney 1982).

Mouthing frequency appears to depend on a number of social factors like inadequate child care, quality of play environment, presence of siblings who 'teach' each other the habit, etc. (Green, Wise and Callenbach 1976; Stark, Meigs, Quah and De Louise 1978, 1982a, 1982b; Madden, Russo and Cataldo 1980; Hunt, Hepner and Seaton 1982; O'Hara 1982).

Pica, which is Latin for 'magpie', is the tendency actually to chew and eat non-food items on a regular basis, usually in excessive amounts, and is considered an abnormality (Barltrop 1966; Palmer and Ekvall 1978; Charney 1982). The etiology of pica is not well

understood; exaggerated mouthing behaviour, addiction, personality disturbances, emotional factors and nutritional status have all been mentioned as possible causes (Mooty, Ferrand and Harris 1975; Palmer and Ekvall 1978). Due to the fact that pica itself is inconsistently defined in the literature, it is also difficult to estimate its prevalence reliably. Barltrop (1966), for example, has estimated its prevalence as high as 48 per cent for one-year-old children living in Boston. This figure was based on the results of a questionnaire sent to parents of a random sample of all children living in Boston, and 'pica' was defined as placing non-food objects into the mouth rather than actually swallowing them, as the objects which were allegedly ingested included blankets, shoes and tooth brushes. It would seem that the prevalence of mouthing rather than pica has been estimated in this particular study.

The amount of lead on children's hands has been measured by several investigators. In Table 3.1. the findings are listed and details about the circumstances of measurement are given. From the results it appears that in urban environments up to 20-30 μg of lead can be found on a child's hand during normal play. Near industrial sources,

**Table 3.1.** Lead on children's hands in a number of investigations

| Reference | Lead on hands (μg per hand) | Remarks |
|---|---|---|
| Vostal et al. 1974 | 20 | Median in urban children (2-6 years of age) |
| | 5 | Median in suburban children (2-6 years of age) |
| Roels et al. 1980 | 244-436 | School-age children near smelter (10-14 years of age) |
| | 13-20 | Urban children (10-14 years of age) |
| Brunekreef et al. 1983 | 12 | Inner city children (4-6 years of age) |
| | 5 | Suburban children (4-6 years of age) |
| Charney et al. 1980 | 49 | Children with PbB 40-70 μg 100 $m\ell^{-1}$ (1-6 years of age) |
| | 21 | Children with PbB ≤29 μg 100 $m\ell^{-1}$ (1-6 years of age) |

or in homes where the lead content of dust is high through paint or other causes, levels of lead on the hand can be much higher and may exceed 100 µg.

The amount of dust which may stick to a child's hand has been determined experimentally by Duggan and Williams (1977). It appears that 2 mg of dust may easily stick to each finger of the moist hand of a child. No information is available about the average amount of lead and/or dust present on a child's hand during the day, as the data mentioned in Table 3.1 are essentially based on spot samples of unknown representativity.

At present, only rough estimates are possible regarding the amount of lead which can be ingested by mouthing children. If 10 mg of dust with a lead content of 300 mg $kg^{-1}$ is ingested daily, this would contribute 3 µg to daily intake. If, however, 100 mg of dust with a lead content of 1,000 mg $kg^{-1}$ is ingested daily, the contribution would be 100 µg. In other words, the contribution may be small or large in relation to the food contribution which will be discussed later in Chapter 6.

The available data on mouthing frequency, hand lead levels and hand dust levels suggest that the ingestion of soil and dust particles may be an important pathway of environmental lead to children. In the assessment of importance, only indirect evidence is available; this evidence consists of associations between blood lead, and soil, dust or hand lead, which will be discussed in Chapter 7.

Most probably, the between-person variability of the factors which influence the ingestion of soil and dust particles is large; at a certain level of environmental pollution, some children may ingest much larger amounts of lead than will others. Although several of these factors are hard to quantify, an attempt should be made to incorporate them into the design of studies on lead intake from the environment by children.

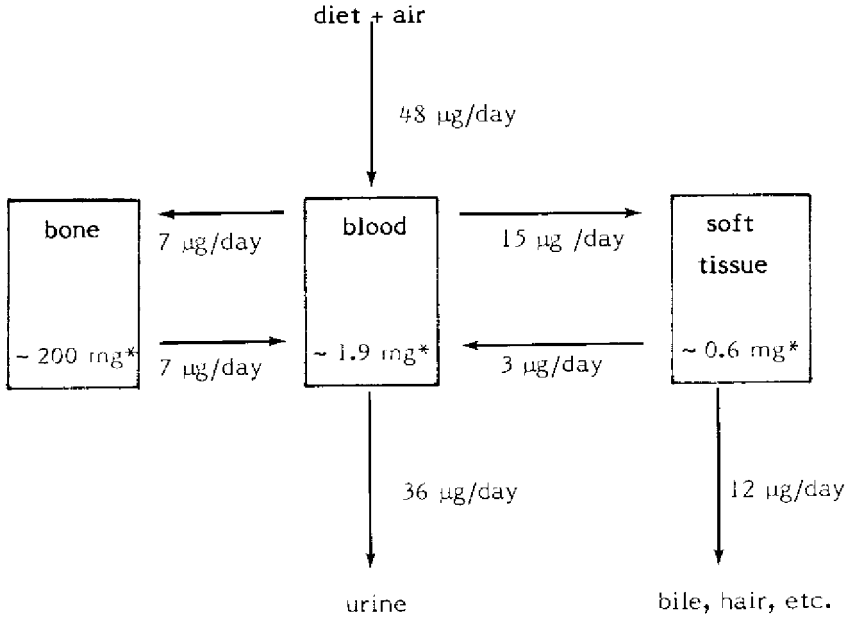
## 4. The concentration of lead in blood as a measure of internal exposure

The concentration of lead in blood (PbB) is widely regarded to be the most relevant indicator of biologically active lead in the human body (Zielhuis 1974, 1975; WHO 1977a; Zielhuis and Wibowo 1978; National Research Council 1980; Ratcliffe 1981).

In adults, the half-time of lead in blood has been estimated to be

about 20 days in studies of an experimental nature (Rabinowitz, Wetherill and Kopple 1973, 1974, 1976, 1977; Chamberlain et al. 1975, 1978; Gross 1981). After continuous, heavy exposure, however, the half-time seems to be prolonged due to the slow release of lead from bone into blood (Hammond 1982; O'Flaherty, Hammond and Lerner 1982; Kang, Infante and Carra 1983).

A three-compartment model for the metabolic behaviour of lead in the adult human body has been proposed by Rabinowitz et al. (1976). The model was derived from an experiment in which subjects ingested 300-360 µg of lead daily and is shown in Figure 4.1.




* total amount of lead in compartment

**Figure 4.1** Three-compartment model for metabolic behaviour of lead in the adult human body according to Rabinowitz et al. (1976)

In adults, who are in a steady state, more than 90 per cent of the total body burden of lead is in the skeleton where it has an extremely long half-time of approximately 20 years. In children, the concentration of lead in the skeleton is much lower than in adults (Barry 1981). There are no direct data on the blood lead half-time in children. David, Weintrob and Arcoleo (1982) measured blood lead in 29 children aged 4.3-11.6 years on four occasions spaced one month apart to evaluate the stability of the blood lead concentration. The differences in the average blood lead concentrations were generally insignificant, and the correlations between measurements were from 0.72 to 0.81, indicating a reasonable stability of blood lead over time in these children. The average blood lead concentration in these children was 25 μg 100 $m\ell^{-1}$, which indicates that the daily intake of lead was rather high.

A recent study by Rabinowitz, Leviton and Needleman (1984) on blood lead concentrations of children aged less than two years showed that at this age the correlation between serial blood lead determinations was low (less than 0.5). Only the correlation between blood lead levels determined at 1.5 years and 2.0 years of age was higher at 0.61, although this is still lower than the David et al. (1982) findings. The blood lead levels of the children in this study were generally below 10 μg 100 $m\ell^{-1}$ and this may mean that the relative error in the blood lead determinations was larger than in the David et al.(1982) study. Comparison of the results of these two studies suggests that at very young ages and/or at low levels of exposure, the measured concentration of lead in children's blood is more variable than at higher ages and/or higher levels of exposure. More specific data are necessary before conclusions can be reached concerning the use of single blood lead determinations as an index of internal exposure in studies on very young child populations

It is important to express the short-term, within-subjects variability of blood lead as a percentage of total variability, as Lucas (1981) has pointed out. If within-subjects variability is large compared with total variability, there is not much between-subjects variability left which could be explained by differences in lead exposure. Using data from four studies performed between 1965 and 1975, Lucas (1981) has asserted that within-subjects variability is usually more than 50 per cent of total variability of blood lead, and that this more or less invalidates the use of blood lead as a health effect indicator of internal exposure in environmental exposure or health effect studies. Angle and McIntire (1979) reported that in their study more than 60 per cent of observed blood lead variability was true between-subjects variability. This study was performed in

the years 1971-1977.

The correlation coefficients reported by David et al. (1982) can be used to estimate the proportion of total variability which is taken up by between-subjects variability (cf. Chapter 7.4). This is consequently 72 to 81 per cent. A recent study by Delves, Sherlock and Quinn (1984) has shown that PbB values in adults who were only exposed to environmental lead were very stable over a period of 7-11 months. In men who had an average PbB value of 12.2 µg 100 $m\ell^{-1}$, the within-subjects variance of about 0.3 was small relative to a total variance of 5.0, and even in women who had an average PbB value of 8.5 µg 100 $m\ell^{-1}$ and a total variance of only 1.5, the within-subjects variance of about 0.3 was small. The most recent study used by Lucas (1981) was the Southern California Study performed in 1974 by Johnson, Tillery and Prevost (1975). In this study, a second blood sample was taken from the same subjects one week after the first sample. In 1976, the same investigators studied a population living in Dallas using the same protocol, and in this study the within-subjects variance of the blood lead concentrations was much smaller than in the first, leading the investigators themselves to doubt the quality of their own blood lead analysis in the first study (Johnson et al. 1978). It would seem that the recent studies just cited prove the blood lead concentration to be a much more usable variable than Lucas (1981) suggested.

Part of the within-subjects variability of blood lead is associated with the error of sampling and analysis. As the concentration of lead in blood is low, care should be taken to obtain uncontaminated samples; venous blood samples generally offer better opportunities for avoiding contamination than do capillary samples (Johnson et al. 1978; Angle and McIntire 1979; Mahaffey et al. 1979). The chemical analysis of the samples requires skill and experience; participation in some blind interlaboratory control programme is necessary to maintain a high standard of performance (Maher, Roettgers and Coulon 1979; Hunter 1980; Berlin 1982; Vahter 1982; Colinet 1983; Zwennis 1984). In recent years, much effort has been devoted to improving the quality of sampling and the analysis of blood lead, and within the same laboratory the relative standard deviation (coefficient of variation) of sampling and analysis may be below 10 per cent (Saltzman, Meager and Meiners 1983).

Compared with the effort devoted to improving sampling and analysis practices (which, in itself, is completely justified), surprisingly little work has been done to define total, within-subjects variability of blood lead concentrations over a given period of time. As will be argued more fully in Chapter 7, Section 4, it is the ratio

between within-subjects variability over time and between-subjects variability, and not the analytical error alone, which determines the usefulness of PbB as an indicator of internal exposure in environmental exposure and health effect studies.

Few studies have attempted to establish a quantitative relationship between lead intake and blood lead in children. Ryu et al. (1983) studied the relationship between dietary lead intake and blood lead in 29 children of 0-6 months of age. Judging by the average blood lead level of the mothers of the study children, which was 9.6 μg 100 $m\ell^{-1}$, prenatal exposure had been low. Dietary lead intake was established by measuring lead in human milk for four breast-fed infants, and by supplying infant formula of a known and repeatedly checked lead content to the parents of the remaining 25 children for a period of four months after birth. On average, dietary lead intake was only 17 μg $d^{-1}$. After four months, the average blood lead level was 6.1 μg 100 $m\ell^{-1}$. For another period of two months, 17 children remained in the study, 10 of which were kept at a dietary lead intake of 16 μg $d^{-1}$. Their blood lead level was 7.2 μg 100 $m\ell^{-1}$ at the end of the study period. The remaining seven children received canned infant formula and/or milk in this period, and their average dietary lead intake was 61 μg $d^{-1}$. At the end of the study period, their blood lead level had increased to 14.4 μg 100 $m\ell^{-1}$. These data suggest a distinct curvilinearity of the PbB/lead intake relationship, as a fourfold increase in intake only doubled the resulting PbB level.

In a study performed in Scotland, bottle-fed infants were shown to have an average blood lead level of 14 μg 100 $m\ell^{-1}$ at a dietary intake of only about 10 μg $d^{-1}$. The average blood lead level was 23 μg 100 $m\ell^{-1}$ at intakes of 50-70 μg $d^{-1}$, and 30 μg 100 $m\ell^{-1}$ at an intake of 160 μg $d^{-1}$ (DOE 1982). At comparable levels of lead intake, the PbB levels in the Scottish study were higher than in the study by Ryu et al. (1983). There is no ready explanation for this difference.

## 5. Factors other than lead intake which affect the concentration of lead in blood

It has already been discussed that lead absorption from the gut is higher in children than in adults, but that the concentration of lead in blood is not necessarily higher in children than in adults, indicating

that the excretion of lead and/or the transfer to bone are also higher in children than in adults.

There are a number of factors which potentially affect the concentration of lead in blood in children at a given lead intake. Absorption, excretion and distribution patterns vary with age, which makes age a prime selection variable in studies concerning environmental lead and blood lead in children.

Various nutritional factors have been implicated as determinants of PbB. The intake of calcium and phosphorus are inversely related to PbB and/or to lead uptake from the gut (Barton, Conrad, Harrison and Nuby 1978; Heard and Chamberlain 1982; Blake and Mann 1983; Blake, Barbezat and Mann 1983; Heard, Chamberlain and Sherlock 1983); a high intake of fat seems to cause a higher absorption of lead from the gut (Barltrop and Khoo 1976; Bell and Spickett 1983); milk consumption was shown to be inversely related to PbB in two observational studies (Johnson and Tenuta 1979; Brunekreef et al. 1983) and in one human experiment (Blake and Mann 1983). This probably indicates the importance of milk or milk products in the diet as a source of calcium. In animal experiments the milk component lactose has been shown actually to enhance lead uptake from the gut when lead and milk are consumed together (Bell and Spickett 1981; Bushnell and De Luca 1981). The experiments by Bushnell and De Luca (1981) were done, however, at unrealistic levels of lactose consumption, and recent data suggest that at normal levels of intake, lactose does not increase lead uptake from the gut (Bushnell and De Luca 1983).

A study by Kostial and Kello (1979) has suggested that the retention of lead administered in the stomach by tube is greater in rats fed with cow's milk than in rats fed with 'solid' human diets. This may be due to the greater absorption of lead administered in fluids than in solid food, as is discussed later. As mentioned earlier, milk consumption has been shown to decrease lead retention in a human experiment (Blake and Mann 1983). Iron and zinc deficiency have also been associated with increased lead absorption from the gut (Watson, Hume and Moore 1980).

In the U.S.A., 65 per cent of all two- to three-year-old children were reported to receive less than the recommended dietary allowance (RDA) of calcium, and 98 per cent were reported to receive less than the RDA for iron (McCabe 1979; Babich and Davis 1981). It is not clear, however, whether all these children were 'deficient' to an extent that the absorption and/or toxicity of ingested lead were being enhanced.

Recent evidence suggests that lead compounds in water ingested

by fasting individuals are absorbed much more efficiently than when taken in solid food (Rabinowitz, Kopple and Wetherill 1980; Heard et al. 1983). After fasting for 12 hours, about 50 per cent of lead ingested via drinking water was absorbed. When taken with a meal, absorption was only 3-7 per cent. Other studies (Blake 1976; Moore, Meredith, Campbell and Watson 1979c) suggest that even after two hours of fasting, absorption is still about four times greater than when lead is ingested in a meal. The important and tentative implication of this is that lead consumed in drinking water and dust is more important than equal amounts of lead consumed via solid food, in so far as drinking water and dust are ingested between meals. It may only be presumed that these results are valid for children as well.

The chemical form in which (inorganic) lead is administered does not seem to have a large influence on the uptake from the gut (Karhausen 1972; Barltrop and Meek 1975; Mahaffey 1983); the size of the lead particles seems to be more relevant (Barltrop and Meek 1979), with the small particles being more effectively absorbed than the large ones. This is particularly relevant to exposure to paint lead, as it implies that ingested paint flakes do not contribute as heavily to intestinal absorption as their lead content would suggest.

Seasonal variation of children's blood lead is sometimes observed, and it has been suggested that exposure to sunlight is its main cause (Hunter 1977). One proposed mechanism is that in summer vitamin D is synthesized in the body, and that vitamin D increases the absorption of lead from the gut. It has, however, been demonstrated that the active vitamin D metabolite in this respect is 1,25 dihydroxycholecalciferol, which has no seasonal variation, and that the metabolite 25 hydroxycholecalciferol, which does show seasonal variation, does not affect lead metabolism (Rosen et al. 1980; Chesney et al. 1981; Mahaffey et al. 1982). Other explanations for seasonal variation of blood lead have been proposed, such as increased exposure to pollution during outdoor play or through seasonal variations in petrol consumption (Einbrodt et al. 1975; Billick, Curran and Shier 1980). In some studies, seasonal variation of blood lead was absent (McCusker 1979).

It is not easy to decide which meaningful variables should be - and could be - incorporated in the design of studies on blood lead/environmental lead relationships. Age in itself is important, and age is also related to many of the factors mentioned in this section. Selection of a specific age category, or incorporation of the age variable in the analysis of the data seems a necessity in any study. Some consideration of nutritional factors would also be useful. In addition, it would be better to conduct studies within a short period

of time, to avoid seasonality effects on the outcome of the study.

## 6. Identification of confounding factors

In addition to the dependent variable under study, it is necessary to identify and control or eliminate the effect of confounding or interfering factors. What is a confounder or what is the variable of interest in a specific study depends largely on the hypotheses to be tested. If the influence of air lead on blood lead is to be investigated, then tap water lead and food lead are (potential) confounders, while air lead would be a (potential) confounder in a study on the relationship between dietary lead intake and blood lead. If the impact of traffic emissions on blood lead is to be evaluated, all lead in the environment which does not originate from traffic is a potential confounder of the traffic lead/blood lead relationship, and attempts should be made to design and/or analyse the study so that the effects of traffic lead and lead from other sources can be separated.

Theoretically, all sources and pathways mentioned in Figure 1.1 should be considered in the design phase of a study either as determinant, potential confounder or selection variable, that is to say studies can be restricted to areas where one or more sources are of negligible influence. The various environmental sources and pathways have already been described in Chapter 2. Food lead, tap water lead and other factors are treated here.

### 6.1. Presence and origin of lead in food

Lead in food is a potential confounder of associations between environmental lead and blood lead in a limited sense only. As will be discussed later, some lead in food originates from environmental pollution. In industrialized countries, however, the food that people consume is usually not grown at or near places where people live and where people may be exposed to environmental pollution. It is consequently defensible to assume that associations between food lead and environmental lead are non-causal if these are found to exist in an urban study area. As mentioned in Chapter 1, Section 1.2, a child is born with a blood lead level somewhat lower than its mother's. After birth, breast milk, bottled milk and children's formulae are the main sources of lead in the first months of life.

A recent review on chemical contaminants in human milk suggests that the concentration of lead in breast milk is mostly in the range of 5-20 μg $\ell^{-1}$ in women living in industrialized countries (Jensen 1983). A more recent study in a British urban population has shown that at maternal PbB levels of about 10 μg 100 $m\ell^{-1}$, the lead content of breast milk was only 2 μg $\ell^{-1}$ (Kovar, Strehlow, Richmond and Thompson 1984) and in a study among urban and rural women living in Arizona, U.S.A., it was only 3 μg $\ell^{-1}$ (Rockway, Weber, Lei and Kimberling 1984).

Recent data on lead intake through food by young children are compiled in Table 6.1. Most estimates are based on market basket studies, i.e. studies in which the lead content of individual food items of a representative diet is being measured. There are some indications that market basket studies tend to overestimate 'real' lead intake, as estimated by duplicate diet studies. In a study in the U.K., Sherlock et al. (1983) estimated the dietary lead intake of adults in the area under study at 770 μg $w^{-1}$, whereas a duplicate diet study in the same area resulted in an estimated lead intake of 500 μg $w^{-1}$. A recent market basket study from Belgium estimated total daily lead intake for adults to be 282 μg $d^{-1}$ (Fouassin and Fondu 1981) whereas a duplicate diet study, performed at the same time, resulted in an estimated daily lead intake of 96 μg (Buchet, Lauwerys, Vandevoorde and Pycke 1981, 1983).

In The Netherlands, one market basket study performed in 1974-1975 resulted in an estimated daily lead intake for adults of 135 μg (Ellen 1977). In a later publication containing data on the period 1974-1978, this figure was reduced to 92 μg $d^{-1}$. Both estimates did not take lead intake via drinking water into account. A duplicate meal study was performed in the years 1976-1978, and resulted in an average intake of 107 μg $d^{-1}$, including drinking water (Anonymous 1980). The data in Table 6.1 range from a very low intake of only a few μg per day for breast-fed infants to somewhat over 100 μg per day for children of ages well into their teens from the Federal Republic of Germany. The other 11 studies all indicate daily lead intakes of about 20-80 μg $d^{-1}$.

At present, it is not difficult to find populations of children in industrial countries with an average blood lead level below 10 μg 100 $m\ell^{-1}$ (Taskinen, Nordman and Hernberg 1981; Brunekreef et al. 1983; Rabinowitz and Needleman 1984). Although this is a matter of speculation in view of the limited available evidence, the data from the studies by Ryu et al. (1983) and by the U.K. Department of the Environment (1982) suggest that in these populations dietary lead intake may even be well below 50 μg $d^{-1}$.

Table 6.1 Daily lead intake via food by young children

| Reference | Daily dietary lead intake (μg) | Remarks |
|---|---|---|
| Bander, Morgan and Zabik 1983 | 49 ± 38 (SD) | Children less than 1 year U.S.A. |
| | 55 ± 21 | 1-2 years |
| | 56 ± 22 | 2-3 years |
| | 65 ± 24 | 3-4 years |
| | 65 ± 29 | 4-5 years |
| | 74 ± 33 | 5 years |
| | | Market basket study |
| Biddle 1982 | 21 - 36 | Infants, U.S.A. 1975-1980 |
| | 28 - 46 | Toddlers, U.S.A. 1975-1980 |
| | | Market basket studies |
| Boppel 1975 | 45 | Infant formulae, F.R.G. |
| Department of the Environment 1982 | 10 - 160 | Bottle-fed infants Intake depends on water lead concentration in area under study (Glasgow, U.K.) |
| Haschke and Steffan 1981 | 50 - 80 | Children 1-6 months Austria |
| Johnson, Manske, New and Podrebarac, 1981, 1984 | 20 - 30 | Infants and toddlers U.S.A. market basket studies, 1975-1977 |
| Kirkpatrick et al. 1980 | 17 - 81 | Children of <1 year Market basket study Canada |
| Kovar et al. 1984 Larsson, Slorach, Hagman and Hofvander 1981 | 2 - 3 | On the basis of lead in breast milk (± 2 μg $kg^{-1}$) in Sweden and the U.K. |

Table 6.1 (continued) Daily lead intake via food by young children

| Reference | Daily dietary lead intake (µg) | Remarks |
|---|---|---|
| Reith, Engelsman and van Ditmarsch 1974 | 42 | Children 1-4 years<br>The Netherlands<br>Market basket study |
| Stolley, Kersting and Droese 1981 | 95 - 142 | Children 2-14 years<br>F.R.G.<br>Market basket study |
| Woidich and Pfannhauser 1980 | 6 - 80 | Infants and toddlers<br>F.R.G. |
| Ryu et al. 1983 | 16 - 17 | Infants under 1 year<br>U.S.A.<br>Infant formulae and cow's milk<br>Canned formulae and canned milk |

Whether lead in food is an actual confounder in studies on the relationship between environmental lead and blood lead in children depends on its association with environmental lead. To the author's knowledge, no study has ever systematically compared the lead content of diets consumed in urban and suburban areas. In The Netherlands, food consumption patterns have been compared for different categories of workers' families (Centraal Bureau voor de Statistiek 1979). In the years 1974/1975, workers' families tended to buy more food per person in the major lead containing food groups when their level of income was higher. It was reported (Anonymous 1980) that almost 80 per cent of total dietary lead intake in The Netherlands came from bread, cereals, potatoes, vegetables, fruits, wine and spirits, meat, milk and milk products. When it is assumed that wine and spirits are not consumed by pre-school children, the differences in the amounts of lead in food bought per person would amount to 10 per cent at most between the income strata of workers' families and higher income categories, who purchase food with higher lead levels.

The origins of lead in food have not been quantified in detail. Chamberlain (1983b) has argued that on the basis of $^{210}$Pb/stable Pb ratios of outdoor lead deposition and human diets, probably only 13 µg of lead per day in an adult diet in the U.K. comes from vehicular traffic. For children, this would then probably amount to no more than 7 µg per day, and the relative contribution of traffic lead to dietary lead for children would then come to depend on how much lead a child actually ingests with food. A study from Italy (Facchetti and Geiss 1982) has suggested that at least 46 per cent of the lead in children's blood originates from automobile traffic. In this study, the isotopic ratio of lead in gasoline in the Turin area was changed for a number of years, with the explicit goal to evaluate the importance of gasoline lead as a source of lead in human blood. Samples of air, food, blood, etc. were taken to evaluate the contribution of gasoline lead to blood lead. Pre-school children became involved in the study only at the halfway stage and numbered less than ten (Elwood 1983b). For this reason, the estimated percentage for children cannot be considered as very reliable. Human populations living in remote, non-industrial areas have been shown to have average blood lead levels between 1 and 5 µg 100 mℓ$^{-1}$, although in one study the PbB value was much higher. Hecker, Allen, Dinman and Neel (1974) studied a number of Yanomamo Indians living in the area drained by the Upper Orinoco River and its tributaries in southern Venezuela. Their average blood lead concentration was only 0.83 µg 100 mℓ$^{-1}$, and significantly lower than the average blood lead concentration (14.6 µg 100 mℓ$^{-1}$) of a control population living in the U.S.A. which was studied using the same methods of sampling and analysis.

Poole, Smythe and Alpers (1980) studied a population of seven- to ten-year-old children living in the remote Eastern Highlands Province of Papua New Guinea; the children's diet contained small quantities of canned food, and their average blood lead concentration was 5.2 µg 100 mℓ$^{-1}$.

Piomelli et al. (1980) studied a population of children and adults living in the remote Manang district of Nepal and found a mean blood lead concentration of 3.4 µg 100 mℓ$^{-1}$ without apparent differences between children and adults. Hansen, Kromann, Wulf and Albøge (1983) studied a population living in the isolated district of Angmagssalik in East Greenland; males were found to have an average PbB value of 14.8 µg 100 mℓ$^{-1}$, and females an average of 12.8 µg 100 mℓ$^{-1}$. For Danes living in the Århus (urban) area, values of 10.5 and 7.7 µg 100 mℓ$^{-1}$ respectively were found, using the same methods. There was no explanation for this unexpected finding.

Thus in some remote populations, PbB values were so low that it is most probable that their food contained much less lead than the food of people living in industrialized countries.

Sources other than vehicular traffic contribute to lead in food, notably lead soldered cans (Crowell 1980; Schaffner 1981; Ludwigsen 1982; Moore 1984). These containers, however, are now being replaced in most countries by cans which do not contribute lead to the food to the same extent. It is unclear to what extent other industrial food preparation processes contribute to lead in food. Scattered references indicate that the contribution is negligible from mechanical deboning of meat (Forschner and Wolff 1981) and other industrial meat handling processes (Hecht, Schramel, Moreth and Schinner 1981) and that some processes may even decrease the lead content of food (Bielig and Hofsommer 1980). In urban areas, food may become polluted with lead during transport, handling, storage and display (Beaud, Rollier and Ramuz 1982), or during preparation (Gallacher et al. 1984c) and cooking when the water used contains lead (Moore, Hughes and Goldberg 1979b; Little, Fleming and Heard 1981; Smart, Warrington and Evans 1981; Smart, Warrington, Dellar and Sherlock 1983; Haring 1984); if the lead concentration of the water is not elevated, then the cooking process does not change the lead content of food (Schelenz and Boppel 1982); in fact, cooking may even decrease the lead content if soft water is being used (Haring 1984). (Soft water contains less than 3 milli-equivalents of cations per litre).

All of this means that the proportion of lead in the diet originating from traffic will vary from situation to situation, and it is probably naive to try to attribute any precise number to this proportion, as Moore (1983) has aptly pointed out.

## 6.2. Lead in tap water

If lead is present in a water supply system, the concentration of lead in tap water may be greatly elevated (Beattie et al. 1972; Goldberg 1974; Elwood, St Leger and Morton 1976; Moore 1977; Haring 1978, 1984; Moore et al. 1978, 1979a; Thomas, Elwood, Welsby and St Leger 1979; Sartor and Rondia 1980, 1981; Thomas 1980; Moore, Goldberg, Fyfe and Richards 1981; Sartor, van Beneden and Rondia 1981; Thomas, Elwood, Toothill and Morton 1981; McIntosh et al. 1982; Moore et al. 1982; Sharrett, Carter, Orheim and Feinleib 1982a; Sharrett et al. 1982b; Moore 1983; Pocock et al. 1983; Sartor, Manuel, Rondia and Geubelle 1983; Elwood 1984).

Studies from Belgium and the U.K. especially have shown that in

some areas blood lead levels in adults as well as in children may rise well above accepted standards due to a high lead concentration in tap water (Sartor et al. studies; Moore et al. studies).

The plumbosolvency of drinking water has been shown to depend largely on pH (Moore 1973, 1983; Haring 1983, 1984) so that in areas where pH is low, much lead is dissolved from pipes and storage tanks. Alterations of pH by adding lime have shown a great reduction in the lead concentrations in tap water even if lead pipes are not being replaced and it has been shown that these alterations have produced marked reductions in blood lead levels as well (Moore 1983).

It has been suggested that the reduction in blood lead levels can partly be caused by an increased Ca intake with water, and that this has led to some overestimation of the contribution of water lead to total lead intake (Bryce Smith and Stephens 1981; Elwood and Gallacher 1984). In the Glasgow study, lime was increased to a concentration of about 5 mg $\ell^{-1}$. At a normal Ca intake of about 500-800 mg $d^{-1}$, however, this would not seem to make a significant contribution to total Ca intake (Mahaffey 1974; Koivistoinen 1980; de Wijn and van Staveren 1980). In The Netherlands, the Ca content of drinking water was shown to range from 20 to 117 mg $\ell^{-1}$ in a survey conducted in 19 different communities (Haring 1984). In Glasgow, however, the Ca content of drinking water was originally only 0.33 mg $\ell^{-1}$ (Moore 1973).

The higher absorption rate of lead administered via water compared with lead administered via food makes tap water lead a potentially much more important contributor to total lead uptake, even at relatively low levels of water lead, than seems to have been realized. Elwood (1984) has remarked that the omission of water lead from epidemiological studies on blood lead/environmental lead relationships in children raises serious questions about the validity of the resulting equations.

### 6.3. Other potential confounders

Alcohol consumption and tobacco smoking have been shown to be related to blood lead levels of adults (Wibowo, del Castilho and Zielhuis 1977; Ducoffre et al. 1980; Awad, Huel, Lazar and Boudène 1981; Grandjean, Olsen and Hollnagel 1981; Shaper et al. 1982; Bortoli et al. 1983; Brockhaus et al. 1983; Pocock et al. 1983; Perrelli et al. 1984).

Neither habit is generally present in young children, however, and the fact that the smoking effect on adult blood lead levels has been small in the majority of studies suggests that 'passive smoking'

by children is not an important pathway.

Objects like glazed pottery (Acra, Dajani, Raffoul and Karahogopian 1981), printed matter (Bogden, Joselow and Singh 1975; Eaton, Fowles, Thomas and Turnbull 1975), household articles in general (Horiguchi, Kurono and Teramoto 1982), electric kettles (Wigle and Charlebois 1978), toothpaste (Berman and McKiel 1972) and cosmetics (Anonymous 1979) have been mentioned as potential sources of lead for children. Do-it-yourself enthusiasts have been warned that, for example, improper removing of old paint layers in old homes may cause elevated air lead and dust lead concentrations (Inskip and Atterbury 1983). Although these factors may be significant for individuals, they do not usually seem to have a detectable influence on average population blood lead levels.

In the U.S.A., children of a different race have repeatedly been shown to have different blood lead levels (Billick et al. 1979, 1980; Quah, Stark, Meigs and Delouise 1982; Stark et al. 1982a; Annest et al. 1983). As race, socio-economic status and living conditions in general are related, it is not clear whether these PbB differences are caused by innate factors or mostly by external factors. In the U.K. as well, higher blood lead levels have been reported in children of Asian origin, compared with Caucasian children (Josephs 1977; Archer, Giltrow and Waldron 1980; Strehlow and Barltrop 1982). It has been suggested that the use of surma, a lead-containing cosmetic, by Asian women may contribute to this (Josephs 1977) but dietary factors may be more important (Strehlow and Barltrop 1982).

Shortly after birth, children of different gender generally do not have different PbB levels (cf. for example Rabinowitz and Needleman 1984), but when children grow older, boys and girls may have different blood lead levels. Age is related to a number of factors which influence blood lead levels and, as a consequence, PbB levels exhibit a peak at ages of about 3-6 years in some populations, but not in others (Duggan 1983a).

Several factors which tend to increase the blood lead concentration at a given exposure level, like mouthing, Ca deficiency, inadequate child care, etc. may very well be more prevalent in areas where lead pollution is also more severe, as people of low socio-economic status will have less opportunity to move away from polluted living areas near industrial lead sources or in inner cities with high traffic densities.

The impact of a given amount of lead in the environment on children's blood lead may consequently be larger in inner cities than in suburbs.

# 7. Epidemiology of lead intake from the environment by children

## 7.1. Preface

Experimental studies on lead intake from the environment by children have not been performed. Therefore, to investigate the associations between environmental lead and blood lead in children, mainly observational studies must be relied upon (although it is sometimes possible to take advantage of changes like emission reductions, clean-up operations and the opening of new roads or factories). Such studies are of an epidemiological nature.

In the past 20 years, concern over the potential health effects of environmental pollutants has reached a high level in many developed countries. The resulting pressure to do agent-orientated epidemiological studies has emphasized the general problem of how to decide that an agent-orientated study has any chance of detecting a specified health effect in environmental epidemiology in particular (Lyon, Klauber, Graff and Chin 1981; Stebbings 1981; Stinett, Buffler and Eifler 1981). In studies on the relationship between environmental lead and blood lead in children, the concern is not so much with some specific health effect of lead, but with the concentration of lead in blood as an indicator of internal exposure and risk to health. In making quantitative estimates of relationships between environmental lead and blood lead in children there are some specific issues which merit attention - curvilinearity of the blood lead/lead exposure relationship, the causal structure of the exposure/response system and the reliability of the exposure variables. A tabulated summary of quantitative exposure-response estimates from observational studies concludes this chapter.

## 7.2. Curvilinearity of the relationship between environmental lead and blood lead

For children as well as adults, the relationship between blood lead and environmental lead has repeatedly been shown to be curvilinear in the sense that $\Delta PbB/\Delta exposure$ is smaller at high levels of PbB than at low levels of PbB (Hammond, O'Flaherty and Gartside 1981; Chamberlain 1983a; Laxen 1983; cf. Figure 7.1). The mechanisms behind this are not fully understood, and could include reduced absorption from the gut, altered distribution within the body and increased excretion (Hammond et al. 1981).

It has been suggested that the departure from linearity is not great at low levels of PbB (Chamberlain 1983a), but the recent results of the study by Ryu et al. (1983) seem to contradict this, as discussed in Chapter 4. The curvilinearity of the relationship can be taken into account by relating log PbB to log exposure, or by relating PbB to some exponential of the exposure variables (Moore et al. 1982).

If downward curvilinearity is present in the data, a log/log relationship results in which the regression coefficient of log PbB on log (exposure variable) is less than one. A straight line relationship results in a log/log relationship with a regression coefficient of exactly one, and a curvilinear upward relationship results in a regression coefficient >1. The general consequence of the downward curvilinearity is that ΔPbB/Δexposure relationships obtained at different levels of PbB cannot be directly compared; one may expect a stronger effect of a given exposure change at low levels of PbB than at high levels of PbB.

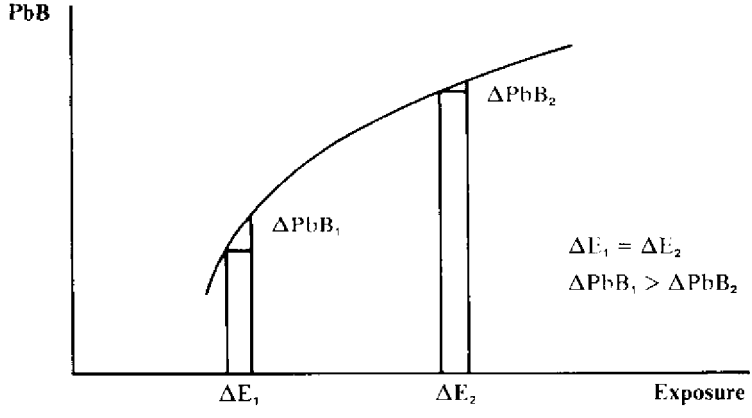



Figure 7.1 Curvilinear dependence of blood lead on lead exposure.

## 7.3. The causal structure of the exposure-response system

From the preceding sections it is clear that many variables potentially influence the concentration of lead in blood, and that many of these are interrelated. In the analysis of the data, the

presumed causal ordering of the variables must be carefully taken into account. If, for example, more lead piping is present in old homes than in new ones, the age of the home and the concentration of lead in tap water will be related. If both are evaluated together as determinants of blood lead, one may find that water lead becomes insignificant after adjustment for home age. This is an artefact, as it does not mean that water lead has no influence; it is merely represented already by home age. Usually some environmental exposure variables will also be correlated with each other. Sometimes several exposure variables are entered into an equation as explanatory variables together (Angle and McIntire 1979; Snee 1982; EPA 1983). This is justifiable as an attempt to separate their respective effects on blood lead, but the partial regression coefficients obtained do not adequately describe what will happen to the blood lead concentration when the input of lead into the system is changed. If, for example, lead in air changes because of a reduction of lead in petrol, in the long run lead in dust will be reduced as well. The partial regression coefficients of blood lead on air lead (PbA) cannot be used to predict the effect on blood lead of such a reduction in petrol lead without also evaluating the pathway through dust. The partial $\Delta PbB/\Delta PbA$ underestimates, in other words, the $\Delta PbB/\Delta$petrol lead relationship. It is therefore questionable to use partial $\Delta PbB/\Delta PbA$ relationships for setting air lead standards (as, for example, was done in the U.S.A., cf. EPA 1978), as such a procedure tacitly assumes that air lead can be manipulated without affecting lead in other environmental pathways.

It should be emphasized that evaluating the structure of the exposure response system is a largely non-statistical issue which requires detailed knowledge of the specific research area.

### 7.4. Variability of exposure and outcome variables

It is well known from regression theory that the results of regression analyses are affected by random errors in both the exposure and the outcome variables (Snedecor and Cochran 1967; Cochran 1968; Draper and Smith 1981). Generally, random errors in the outcome variable reduce the correlation coefficient, but not the regression coefficient of the outcome variable on some predictor. In other words, an association which is significant in reality may go undetected, but the size of the regression coefficient is none the less an unbiased though unstable estimate of the size of the effect.

Random errors in an explanatory variable not only decrease the correlation coefficient, but bias the regression coefficient toward

zero as well (Cochran 1968; Draper and Smith 1981). It is therefore of interest to reduce as much as possible random errors in both the outcome and the explanatory variables.

An interesting observation at this point is that, in the past, considerable effort has been devoted especially to reducing the error of the blood lead determination - but that this error has been rather narrowly defined as the error associated with sampling and analysis. Likewise, in lead exposure studies the error analysed and reported (if at all) is usually the error associated with sampling and analysis.

A typical exposure-response study may thus consist, for each subject, of a single blood lead determination, an air lead study of some duration and single or duplicate samples of soil, dust, drinking water, etc. taken on one occasion only. It is assumed that the values obtained are representative for periods of one to a few months as the outcome variable, blood lead, is usually taken to represent recent exposure in terms of one to a few months (cf. Chapter 4).

It would therefore be more useful to define the 'random error' of the outcome and the explanatory variables as the within-person variability over some period of time. In order to obtain an estimate of this type of error in the exposure variables, it is necessary to repeat the exposure measurements for a number of individuals, at least once in space, or in time, or in both. The type of exposure information which is required determines which is the best way to repeat the measurements. If, for example, variations in time are of less interest because some time-integrated measurement like long-term outdoor deposition has been performed, it is most useful to perform the measurements in the locations most frequently visited by the study subjects. For outdoor deposition, the measurements might then be performed in a few locations near the homes of the study subjects. An analysis of variance can then be performed, to estimate the 'within-subjects' and 'between-subjects' variance of the exposure indicator under study (Snedecor and Cochran 1967). The correlation coefficient between repeated measurements (cf. correlations between serial blood lead levels in children in papers by David et al. 1982 and Rabinowitz et al. 1984) can also be used to estimate the 'between-subjects' variance relative to total variance (Cochran 1968). In Chapter 4 it has already been shown that the limited evidence available suggests that this type of error may very well be 20-40 per cent of total blood lead variance.

Although some information on variability of environmental lead exposure variables over space and time has recently become available, systematic evaluation of within- and between-person variability of lead exposure variables in epidemiological studies has

not been performed to date.

This is unfortunate as regression coefficients from environmental exposure-response studies are currently being used as basic information for the derivation of air lead standards (EPA 1978, 1983), and it would not seem in the interest of public health to use systematic underestimates of the 'true' blood lead/environmental lead relationship.

In Appendix 1, a brief mathematical treatment is given of this type of error, and the required analysis to estimate it.

## 7.5. Summary of quantitative estimates of the impact of environmental lead exposure on blood lead levels in children

In the literature, a number of studies have been published which contain data on environmental lead exposure variables and blood lead concentrations in children. These studies were usually not explicitly meant to produce quantitative estimates of blood lead/lead exposure relationships. In trying to obtain such estimates from them, a varying number of limitations must usually be accepted, such as incomplete or absent adjustments for confounders, mis-matching of exposure and response data, incomparability of exposure and/or response measurement methods across studies, etc. A detailed review of the studies used for compiling the tables presented in this section is given elsewhere (Brunekreef 1984, 1985). Where appropriate, short comments on individual studies will be supplied in the 'Remarks' sections of the Tables.

The studies were divided into three groups - studies conducted near industrial lead sources (Table 7.1); studies conducted in urban areas without major industrial lead sources (Table 7.2); and other studies, usually concerning exposure to soil and dust contaminated with lead from paint or from lead workers' clothes and shoes (Table 7.3).

In Section 7.2, it has been argued that the relationship between environmental lead and blood lead is curvilinear in the sense that a given exposure increment results in a larger increase of the blood lead concentration at low levels of exposure than at high levels of exposure. In principle, therefore, it is preferable to compare curves rather than linear relationships. But from most studies, curvilinear relationships could not be calculated, so it was decided to express the relationship between environmental lead and blood lead on a linear scale.

The consequence of this is that results from studies performed at widely differing levels of exposure cannot be readily compared.

Where appropriate, the reader will be reminded of this when study results are likely to have been heavily influenced by unusually high or low overall exposure conditions. The relationship between environmental lead and blood lead will be expressed as $\alpha$ when the concentration of lead in air is the prime indicator of environmental lead pollution and $\alpha$ will be expressed as $\mu g\ 100\ m\ell^{-1}$ (PbB) per $\mu g\ m^{-3}$ (lead in air PbA). If lead in dust or soil is the prime lead exposure indicator, the relationship between blood lead and environmental lead will be expressed as $\beta$. Usually, $\beta$ will be expressed as $\mu g\ 100\ m\ell^{-1}$ (PbB) per $g\ kg^{-1}$ (lead in soil, dust), although occasionally the $mg\ m^{-2}$ unit will be used for lead in dust. The units were chosen such that the $\alpha$ as well as the $\beta$ values would mostly fall in the 1-10 range.

## 7.6. Summary of results from smelter studies

Table 7.1 contains a summary of the findings from 11 different smelter studies. The studies are numbered, and the references are given at the foot of the Table.

Table 7.1 Summary of findings from smelter studies

| Study No. (I) | $\alpha$ estimate (II) | $\beta$ estimate (III) | Remarks |
|---|---|---|---|
| 1 | 3.3 | | unadjusted; children 3-6 years |
| | 4.0 | | unadjusted; 8-11 years |
| 2 | 1.1-7.2 | | unadjusted; 2-14 years; depending on season |
| | | 0.4-2.5 (ld) | unadjusted; depending on season |
| 3 | 4.0 | | unadjusted; 2-3 years; |
| | 3.6 | | adjusted for parental education |
| | | 12.6 (s) | 1-3 years; adjusted for parental education |

Table 7.1 (continued) Summary of findings from smelter studies

| Study No. (I) | α estimate (II) | β estimate (III) | Remarks |
|---|---|---|---|
| 4 | 2.6-3.7 | 11.7 (s)<br>0.8 (hd) | 1-19 years; unadjusted based on reduction of PbB and PbA over time |
| 5 | 1.7<br>1.6 | | 0-10 years; unadjusted<br>10-15 years; unadjusted |
| 6 | 1.8<br>1.9 | | pre-school age; unadjusted<br>school age; unadjusted |
| 7 | 3.9 | 5.3 (s)<br>5.7 (sd)<br>10.2 (hd)<br>1.9 (ld) | 0-15 years; unadjusted |
| 8 | 5.3 | 3.5 (pd) | 10-15 years; adjusted for tap water lead and parental education |
| 9 | 5.3<br>0.7 | 11.2 (s)<br>1.4 (s)<br>8.3 (s)<br>4.8 (s) | 0-6 years; unadjusted<br>13-14 years; undjusted<br>0-3 years; Trail only<br>6 years; Trail only |
| 10 | 12.5<br>17.6 | | girls of 10-15 years; unadjusted<br>boys of 10-15 years; unadjusted |
| 11 | 2.4-3.3<br>1.0-2.5 | 5.2-7.3 (s)<br>0.6 (s) | 1-9 years; unadjusted<br>1-9 years; adjusted for parental occupation, house dustiness, age and one other lead exposure variable |

(I) Study No.1. Cavalleri et al. (1981); 2. Einbrodt et al. (1975), Rosmanith et al. (1975a, 1975b, 1976); 3. Krajnc, Helleman, van Logten and van Esch (1977), Zielhuis et al. (1979), Brunekreef et al. (1981), Diemel et al. (1981); 4. Landrigan et al. (1975), Morse et al. (1979); 5. Popovac et al. (1982); 6. Prpic-Majic et al. (1983, 1984); 7. Roberts et al. (1974a, 1974b, 1975); 8. Roels et al. (1976, 1978b, 1980); 9. Neri et al. (1978), Schmitt et al. (1979); 10. Wagner et al. (1981); 11. Yankel et al. (1977), Walter et al. (1980).

(II) $\alpha$ = ug 100 $m\ell^{-1}$ (PbB) per ug $m^{-3}$ (Pb air)

(III) $\beta$ = ug 100 $m\ell^{-1}$ per mg $m^{-2}$ $d^{-1}$
ld = lead deposition

$\beta$ = ug 100 $m\ell^{-1}$ per g $kg^{-1}$
s = soil
hd = house dust
sd = street dust
pd = playground dust

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From the data in the Table it is clear that a wide range of values can be calculated from the different studies. Adjustment for confounders has been weak or absent in most studies. In studies 3 and 8, adjustment for at least some confounders did not reduce the estimates much, but in view of the many differences between studies, it cannot be assumed that this is the general rule. Unadjusted values below 2 generally stem from areas where PbB values were high (studies 5, 6, 11) or from older children (study 9). The majority of values are in the 2.4-5.3 range; the results of the Wagner et al. (1981) study (no.10) are evidently out of range.

For soil lead, the unadjusted $\beta$ values range from 4.8-12.6 ug 100 $m\ell^{-1}$ per g $kg^{-1}$, if we exclude the low 1.4 value for 13- to 14-year-olds in study 9. For house dust, the two available $\beta$ values are very different (10.2 and 0.8 ug 100 $m\ell^{-1}$ per g $kg^{-1}$). The two street and playground dust $\beta$s, on the contrary, are close to each other (5.7 and 3.5 ug 100 $m\ell^{-1}$ per g $kg^{-1}$ respectively) and only somewhat lower than the soil lead $\beta$s.

## 7.7. Summary of results from urban studies

Table 7.2 contains a summary of the findings from eight different urban studies. The references are at the foot of the Table.

Table 7.2 Summary of findings from urban studies

| Study No. (I) | α estimate (II) | β estimate (III) | Remarks |
|---|---|---|---|
| 12 | -3.4 | 15.5 (s)<br>12.8 (hd) | Children 1-5 years; Unexplained negative α result of unadjusted analysis |
| | 2.6. | 10.6 (s)<br>12.6 (hd) | 6-18 years; unadjusted |
| | 1.0 | 10.5 (s)<br>10.8 (hd) | 1-18 years combined; unadjusted |
| | 1.92 | 6.8 (s)<br>7.2 (hd) | 1-18 years; linear model; adjusted for other exposure variables |
| | 4-7 | | 1-18 years; unadjusted |
| 13 | 2.0 | | 0-10 years; unadjusted |
| 14 | 2.9 | | 0-6 years; adjusted for age and race |
| 15 | | 5.8 (ld)<br>61.2 (hd)<br>11.3 (s) | 4-6 years; adjusted for tap water lead and other confounders; hd expressed as $\mu g\ m^{-2}$ |
| 16 | 1.8 | | 1-16 years; boys; unadjusted |
| | 0.9 | | 1-16 years, girls; unadjusted |
| 17 | - | | no association between PbB and air lead |
| 18 | >10 | | 4-18 years; unadjusted; time lag not taken into account |
| 19 | 6.5 | | 2-14 years, unadjusted |

(I) Study No.12. Angle and McIntire (1979), Angle, McIntire and Colucci (1974, 1984); 13. Berode et al. (1980); 14. Billick et al. (1979, 1980), Billick (1983); 15. Brunekreef et al. (1983), Brunekreef (1985); 16. Johnson et al. (1975, 1976); 17. Johnson et al. (1978); 18. Okubo et al. (1978, 1983); 19. Rosmanith et al. (1977a, 1977b).

(II) and (III) cf. Table 7.1

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The available information from city environments is even more scant than from smelter areas. Air lead determinations in these studies were more restricted than in the smelter studies with only one or a few sites, or were practically useless due to selection of sampling location and period (study 16). Estimates of $\beta$ for soil and house dust could be obtained from study 12. Although these estimates are reasonably in line with those from the smelter studies, the instability of the $\alpha$ and $\beta$ estimates from this study and the remarkable difference between the regression analysis results and the group comparisons render the size of the estimates unreliable. The $\beta$ estimate for soil from study 15 is also in line with the results from the majority of smelter studies. The range of $\alpha$ values from urban studies would be about 2 to 6.5 if the more obvious outliers are excluded. This range is somewhat larger than the range obtained from smelter studies, and probably reflects the paucity of exposure information in urban studies.

## 7.8. Summary of results from other studies

Table 7.3 contains a summary of the findings from the other studies. References are at the foot of the Table.

The results of these studies indicate a $\beta$ for soil lead between 0.6 and 10.2 $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$. The low 0.6 value is evidently out of line with the other values which range from 3.9 to 10.2 and which are only slightly lower than those reported in Tables 7.1 and 7.2.

For house dust lead, the $\beta$ estimates in Table 7.3 range from 4.0 to 19.8. This is in line with the results in Tables 7.1 and 7.2. Only in one study (No.23) was house dust lead reported as $\mu g\ m^{-2}$ instead of $mg\ kg^{-1}$. The results of this study are lower than those of study No.15 (61.2 $\mu g\ 100\ m\ell^{-1}$ per $\mu g\ m^{-2}$).

## 7.9. Discussion of pathway impact estimates

It must be stressed that none of the 26 reviewed studies had as its

Table 7.3 Summary of findings from other studies

| Study No. (I) | β-estimate (II) | Remarks |
|---|---|---|
| 20 | 8.6-19.8 (hd) | 1-6 years; children of lead workers |
| 21 | 0.6 (s)<br>4.0 (hd) | 2-3 years children from high soil lead area (mining) compared with controls; faecal lead suggested little ingestion of dust and soil |
| 22 | 4.9 (s) | Black pre-school children; soil lead related to paint lead and traffic density; unadjusted estimate |
| 23 | 8.1 (s)<br>38.0 (hd) | 1-3 years children; soil and house dust contaminated by paint lead; house dust expressed as mg $m^{-2}$ |
| 24 | 3.9 (s) | 1-5 years children; soils contaminated by paint lead |
| 25 | 11.0 (hd)<br>10.2 (s) | 0-6 years children living in homes with high lead paint levels |
| 26 | 6.8 (hd) | Pre-school age children of lead workers |

(I) Study No.20. Baker et al. (1977); 21. Barltrop et al. (1974, 1975), Barltrop (1975); 22. Galke, Hammer, Keil and Lawrence (1975); 23. Reeves et al. (1982); 24. Shellshear, Jordan, Hogan and Shannon (1975); 25. Stark et al. (1982b); 26. Watson, Witherell and Giguere (1978).

(II) For units cf. Table 7.1

primary goal to establish quantitatively the relationship between environmental lead and blood lead in children. As a consequence, most studies do not permit straightforward calculation of $\alpha$ and $\beta$ values, which are properly adjusted for the relevant confounders.

In the preceding sections, the central tendency of the $\alpha$ and $\beta$ values has been noted rather than any attempt to separate acceptable from unacceptable studies. The criteria to do so must necessarily remain arbitrary to a certain extent, if only because published study results often do not permit clear cut application of even well-defined criteria. If a descrimination is to be made, miniumum criteria are proposed -

a. environmental lead and blood lead measured at the same time and place; for soil and house dust, sampling at individual homes;
b. venous blood samples, with reference to a quality control programme.

Of the 11 industrial studies, this would leave the studies 1, 3, 5 and 8 with $\alpha$ values of 1.7 (measured at high level of exposure) and 3.3-5.3 $\mu g\ 100\ m\ell^{-1}$ per $\mu g\ m^{-3}$ for lower levels of exposure, a playground dust $\beta$ of 3.5 $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$ and a soil lead $\beta$ of 12.6 $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$. Of the urban studies, 14 and 15 would remain with an $\alpha$ value of 2.9 and $\beta$ values of 5.8 (lead deposition $\mu g\ 100\ m\ell^{-1}$ per $\mu g\ m^{-2} d^{-1}$), 61.2 (house dust $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$) respectively. No other studies fulfilled even these relatively lenient criteria.

When the requirement of reference to a quality control programme for the blood lead analysis is omitted, studies 4, 10, 11, 21 and 22 would become acceptable too. This would add $\alpha$ values of 2.4-3.7 and 12.5-17.6 (from the study by Wagner et al. (1981), and $\beta$ values of 0.6 (from Barltrop's study) and 4.9-11.7 for soil and 0.8 and 4.0 for house dust.

Application of these criteria evidently does not change the general picture, which puts most $\alpha$ values between 3 and 5 $\mu g\ 100\ m\ell^{-1}$ per $\mu g\ m^{-3}$, with some clear outliers on both sides of this range, and which puts $\beta$ for soil lead between 5.0 and 10.0 $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$.

For adults, who do not generally ingest dust or soil particles, experimental studies have sufficiently demonstrated that $\alpha$ is about 1-2 $\mu g\ 100\ m\ell^{-1}$ per $\mu g\ m^{-3}$ (Azar, Snee and Habibi 1975; Griffin et al. 1975; Chamberlain et al. 1978; Gross 1981). Earlier reviews have suggested that $\alpha$ may be somewhat larger in children than in adults (Hammond et al. 1981; Ratcliffe 1981; Snee 1981; Chamberlain

1983a; Jones and Stephens 1983) and the present review suggests that the difference may be as much as two- to threefold. It must be stressed that probably the major part of this difference is caused by the fact that in the case of children, additional pathways such as dust and soil are much more important than in the case of adults. The $\alpha$ values consequently represent total lead intake from the environment rather than via inhalation alone, as no adjustment was made for other environmental pathways.

For soil lead, the unadjusted $\beta$ values range from 0.6 to 15.5 $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$. The 0.6 value is evidently an outlier, as the remaining values are all between 3.9 and 15.5. The 0.6 value (Barltrop et al. 1974; Barltrop 1975) comes from the only study area where soils were polluted by historical mining activities, whereas in all other cases contamination of the soil surface was actuallly going on or had only been stopped or reduced shortly before the study. It may be that the surface soil particles which were actually available for intake had a different lead content, compared with the lead content in the sample actually taken in the Barltrop study. This seems to be supported by the observation that the $\beta$ for house dust was much less out of line with the results from other studies.

Studies performed in areas where soils were predominantly contaminated by paint gave $\beta$ estimates for soil between 3.9 and 8.1 whereas studies near industrial sources in urban areas gave $\beta$ estimates for soil between 4.8 and 15.5. It may be that in the latter two types of studies, other pathways, such as air, which were more or less absent in the 'paint' studies were of influence in the $\beta$ estimates.

For house dust lead, $\beta$ values ranged from 0.8 to 19.8 $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$. The 0.8 value is an outlier, as the rest of the values were between 4.0 and 19.8. The 4.0 value was from the Barltrop et al. (1974) study which also gave a low $\beta$ for soil lead, and in which, judging from the faecal lead data that were reported, children with a low intake of dust and soil were studied. The next lowest value was 6.8.

Excluding some outlying values, the $\beta$ values for soil and house dust lead are generally within a range of 3-4 from each other. All differences between groups in age, race, mouthing, exposure through other pathways, sampling and analysis methods, etc. evidently were not able to push the $\beta$ estimates further apart. The few $\beta$ values derived for street and playground dust are also within the general range for soil and house dust lead.

For soil lead, $\beta$ values clearly above 10.0 come from the Omaha study (No. 12) (lack of adjustment for race probably inflated this estimate); from the Arnhem study (No. 3), in which the overall level

of exposure was low; from the Trail study, but only when Trail was compared with a control town (within Trail, β values were lower) and from the El Paso study (No. 4) in which the β values were estimated from a reduction of PbB and lead in soil over time which was probably not yet completed. Nine other β estimates from seven different studies were all in the 3.9-10.2 range.

For house dust lead, β values above 10.0 again come from the Omaha study (No. 12); from one of the studies of lead workers' children (No. 20) in which, however, only a few children were studied and from which β values had to be estimated from exposure categories rather than averages; and from one of the paint studies (No. 26). Generally, the 5.0-10.0 range is where most of the β values for lead in soil, house dust, street dust and playground dust can be found.

Earlier reviews by Duggan (1980, 1983b) have suggested that a reasonable mid-point for β might be 5.0. These reviews, however, have relied more heavily on studies in which one or more of the other pathways was excluded, and in some cases adjusted rather than unadjusted β values were calculated.

As mentioned earlier, the size of the α values was more or less unrelated to age, blood lead level and type of blood sampling. For the β estimates, the presented evidence suggests the same. This is not to imply that the blood lead/lead exposure relationship is independent of age, that curvilinearity does not exist and/or that type of blood sampling is irrelevant to blood lead level; it merely indicates that within the scatter of values found, the influence of age, blood lead level and method of blood sampling cannot be detected.

## 8. The scientific basis of standards for environmental lead

From the previous sections it will be clear that it is not easy to give an exact, quantitative picture of the impact of environmental lead pollution on children's blood lead. It is equally clear that public health authorities would like to have such a picture to derive standards for lead in air, soil, dust or other environmental media. The ambient air quality standard for lead as adopted in the U.S.A. (EPA 1978) can be used to illustrate the complications involved.

The 1978 standard uses an $\alpha$ estimate of 2, which is mainly based on the Silver Valley lead study (Yankel et al. 1977), and is derived after adjustment for soil lead. This, in fact, means that a standard was adopted which underestimates the effect on children's blood lead when the concentration of lead in air is changed, as this will ultimately change the concentration of lead in other media as well, which is assumed not to happen by the adjustment procedure (cf. Section 7.3).

The standard is currently under review; drafts of the Criteria Document issued in 1983 have emphasized three studies - the Silver Valley lead study (Yankel et al. 1977), the Omaha study (Angle and McIntire 1979) and the Belgian smelter study (Roels et al. 1980). In the drafts, secondary analyses of the data from these studies were presented in which the blood lead/air lead relationship was adjusted for soil lead and/or hand lead; the resulting $\alpha$ was now correctly interpreted as representing an inhalation slope; again, the impossibility of manipulating air lead without affecting lead in soil, dust, etc. was not adequately discussed, although it was correctly remarked that once soil and dust are polluted, other methods of control might be necessary apart from reducing lead in the air (Charney, Kessler, Farfel and Jackson 1983; Marcus 1984). If this remark can be interpreted to mean that keeping soil lead and dust lead not only statistically but factually constant is considered possible in areas where air lead is allowed to increase up to the standard, the adjusted relationship can indeed be used to predict the resulting blood lead rise. It is obvious, however, that this would be a somewhat impractical procedure.

An update of the review draft issued in September 1984 (EPA 1984) suggests that it may be better to adopt an aggregate approach, which would emphasize air lead as an indicator of general multi-media environmental pollution. If this approach were accepted, $\alpha$ would have to be approximately doubled. At present, it is not yet clear which approach EPA will adopt when it finally publishes its new air lead standard. In the new draft, a $\beta$ for soil and house dust of 2.0 $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$ is suggested, which is rather lower than the 5.0-10.0 range mentioned in the previous chapter. The review draft mixes adjusted and unadjusted values, however, and uses an adjusted value from the Stark et al. (1982b) study as an 'acceptable' mid-point value. As mentioned earlier, unadjusted $\beta$ values from the same study are of the order of 10.0 $\mu g\ 100\ m\ell^{-1}$ per $g\ kg^{-1}$.

The scatter in the $\alpha$ values as well as the $\beta$ values further stresses the importance of using safety factors. One single mid-point value is

evidently not sufficient to protect specific population groups which may differ in important ways from the average. In other areas of the environmental health field, it is more or less common practice to use safety factors of 2 or more when using epidemiological data, applied to the lowest exposure level where effect has been demonstrated (or to the highest where it has not), to derive a standard (WHO 1977b, 1978). It is quite remarkable that such a line of reasoning has seldom been applied to the environmental exposure impact estimate of lead. It is evident that a safety factor of 2, applied, for example, to the 90-percentile of the $\alpha$ or $\beta$ estimates alone would be sufficient to arrive at standards which are at least four times lower than the one currently in use in the U.S.A. This is even more important when it is realized that in establishing currently accepted safe levels of lead in blood, safety factors were only marginally used or not used at all (cf. Chapter 1).

On the basis of the observation that the current level of exposure to lead is quite close to the level where adverse health effects have been demonstrated in man and in animal experiments, Rostron (1982b) has remarked that if it were decided now to which levels lead could be introduced in our environment, these levels would preferably be lower than the ones currently encountered. Further stress is given to this point in observing that safety factors were not applied to the $\alpha$ estimates used in most existing standards for air lead.

## 9. Concluding remarks

Despite the great research effort which has been devoted to the environmental health aspects of lead in the past, it is still difficult to give an exact description of the relationship between environmental lead and blood lead in children. This is partly due to the differences in circumstances in which different child populations grow up. There is no unique relationship between concentrations of lead in the environment and lead in children's blood. Depending on local circumstances like accessibility of environmental media, play habits and the nutritional status of the involved populations, the blood lead levels of children are more or less affected by a given level of lead in the environment.

Also, there has been no standardization of the methods used for investigating the exposure of children to lead in the environment. In

addition, there are several key topics which have not been investigated in detail. These include the relationship between total lead intake and blood lead in children, and the amounts of dust and dirt which are ingested during normal play. Quantitative estimates of relationships between environmental lead and blood lead in children - including the ones given in this report - therefore need to be interpreted with care.

It is not yet possible to predict blood lead levels in children precisely from their exposure to lead in the environment. As a consequence, it remains necessary to measure blood lead if an adequate assessment of health risks is sought in any situation in which environmental lead concentrations are elevated.

The uncertainty which surrounds the estimates of the impact of environmental lead exposure on children's blood lead emphasizes the need to use a margin of safety when establishing environmental quality standards for lead. In the interests of public health it seems prudent to reduce or eliminate lead in gasoline rather than trying to establish detailed quality standards for the concentration of lead in different environmental media.

# APPENDIX I

## Variability of exposure measurements and its effects on regression analyses in epidemiology

A common assumption in regression analysis is that the X or independent variable is measured without error. In environmental epidemiology, however, it is usually not possible to do so. In measuring exposure to environmental agents, a sometimes large variability in time and space may be encountered which makes it difficult to define exactly the exposure level of each individual of a study population. If, for example, we define the relevant house dust lead exposure of an individual child as the average amount of lead on the floor of the living room, over the months prior to blood sampling, it will be clear that one sample from one spot at one point in time within that month yields an estimate of the relevant exposure, the reliability of which depends on the variability of the amount of lead on living room floors in time and space.

It is well known that a random error in the X or independent variable leads to a biased estimate of the regression coefficient of the Y or dependent variable on X (Cochran 1968; Draper and Smith 1981). In the bivariate case, the bias is consistently towards zero, and one of the methods to estimate the size of the bias is to obtain estimates of the error variance and the true variance of the X variable. These estimates can be obtained from an analysis of variance; an analysis of variance can be performed when there has been some repetition of the exposure measurements in time and/or space. A correction of the observed regression coefficient of Y on X may then be defined as $b = B(1+\lambda)^{-1}$, with

| | |
|---|---|
| $b$ | = observed regression coefficient |
| $B$ | = 'true' regression coefficient |
| $\lambda$ | = $\sigma_e^2/\sigma_t^2$ |
| $\sigma_e^2$ | = error variance |
| $\sigma_t^2$ | = true variance |

From an analysis of variance, estimates of the error variance and true variance can be obtained as the within-subjects variance and the between-subjects variance, respectively. From a standard analysis of variance table, these can be obtained from the within-subjects Mean Square and the between-subjects Mean Square (Snedecor and Cochran 1967).

| Sum of Squares | Degrees of freedom | Mean Square |
|---|---|---|
| Between subjects | n-1 | $SS_b/n-1$ |
| Within subjects | k | $SS_w/k$ |
| Total | n + k-1 | $SS_t/n+k-1$ |

n is the number of subjects; n+k is the total number of observations, which is equal to nq in which q is the number of repetitions of the exposure measurements.

$SS_w/k$ is an estimate of the error variance;
$SS_b/n-1$ is an estimate of the (error variance + q true variance).

We may now define $\lambda$ as a reliability coefficient. If it is zero, there is no error variance, and the regression coefficient of Y on X is not biased. If it deviates much from zero (because $\sigma_e^2$ is large compared to $\sigma_t^2$) the bias in the regression coefficient becomes large.

The SPSS programme Reliability (Parallel option) can be used to obtain the required analysis of variance table. The programme has the property that it estimates the error variance and true variance after adjustment for systematic differences between measurements due to time sequence effects, etc. The analysis of variance table which is produced also permits calculation of unadjusted components of variance. The programme also produces a reliability coefficient defined as

$\sigma_c^2/\sigma_t^2$, for the sum of the repeated measurements.

The variance of the sum of q measurements is equal to $q^2$ times the variance of the mean of these q measurements. This is also true for the components of variance $\sigma_e^2$ and $\sigma_t^2$ so that $\sigma_e^2/\sigma_t^2$ for the sum is equal to $\sigma_e^2/\sigma_t^2$ for the mean. The latter reliability coefficient can thus be used to establish how much better the exposure was estimated by the mean of q measurements than by one single measurement, by comparing this reliability coefficient to the one based on single measurements. In multivariate regression analysis, the simple correction formula for obtaining the 'true' regression coefficient no longer holds (Cochran 1968). The calculations become complicated, and, depending on the size of the error in the different independent variables, the bias in the regression coefficients may be away from as well as toward zero.

## REFERENCES


ACRA, A., Dajani, R., Raffoul, Z. and Karahagopian, Y. 1981 Lead glazed pottery: a potential health hazard in the Middle East, Lancet i, 433-434.

AGRAWAL, Y. K., Patel, M. P. and Merh, S. S. 1981 Lead in soils and plants: its relationship to traffic volume and proximity to highway, Int. J. Environ. Stud. 16, 222-224.

ALEXANDER, F. W., Delves, H. T. and Clayton, B. E. 1972 The uptake and excretion by children of lead and other contaminants, Proc. Int. Symp. Environ. Health Aspects of Lead, Amsterdam, 319-330.

ALEXANDER, F. W., Clayton, B. E. and Delves H. T. 1974 Mineral and trace metal balances in children receiving normal and synthetic diets, Q. J. Med. 43, 89-111.

ALEXANDER, F. W. and Delves, H. T. 1981 Blood lead levels during pregnancy, Int. Arch. Occup. Environ. Health 48, 35-39.

ALZONA, J., Cohen, B. L., Rudolph, H., Jow, H. N. and Frohliger, J. O. 1979 Indoor-outdoor relationships for airborne particulate matter of outdoor origin, Atmos. Environ. 13, 55-60.

ANAGNOSTOPOULOS, A. 1983 Air lead and dust in Thessaloniki, In: Lead versus Health, M. Rutter and R. R. Jones (Eds), John Wiley and Sons, New York, 107-113.

ANDERSON, D. G. and Clark J. L. 1974 Neighbourhood screening in communities throughout the nation for children with elevated blood lead levels, Environ. Health Perspect. 7, 3-6.

ANGLE, C. R., McIntire, M. S. and Colucci, A. V. 1974 Lead in air, dust fall, soil, house dust, milk and water: correlation with blood lead of urban and suburban school children, Trace Subst. Environ. Health VIII, 23-29.

ANGLE, C. R. and McIntire, M. S. (1979) Environmental lead and children: the Omaha study, J. Toxicol. Environ. Health 5, 855-870.

ANGLE, C. R., Marcus, A., Cheng, I-H. and McIntire, M. S. 1984 Omaha childhood blood lead and environmental lead: a linear total exposure model, Environ. Res. 35, 160-170.

ANNEST, J. L., Pirkle, J. L., Makuc, D., Neese, J. W., Bayse, D. D. and Kovar, M. G. 1983 Chronological trends in blood lead levels between 1976 and 1980, New Engl. J. Med. 308, 1373-1377.

ANONYMOUS 1979 Surma and lead poisoning, Lancet i, 28.

ANONYMOUS 1980 Surveillance programme "Man and Nutrition", Dutch Dept of Public Health, Government Publishing Office, The Hague (in Dutch).

ANONYMOUS 1982a Lead in petrol, Brit. Med. J. 284, 529.
ANONYMOUS 1982b Lead in petrol: again, Brit. Med. J. 284, 1506.
ANONYMOUS 1982c Lead in petrol and elsewhere, Lancet i, 1337-1338.
ANONYMOUS 1984 Measures for lead in petrol announced, EC Publication C. 178, 06-07.
ARCHER, A, Giltrow, J. P. and Waldron, H. A. 1980 Blood lead concentrations in pre-school children in Birmingham, J. R. Soc. Med. 73, 328-332.
AURAND, K., Drews, M. and Seifert, B. 1983 A passive sampler for the determination of the heavy metal burden of indoor environments, Environ. Technol. Lett. 4, 433-440.
AWAD, L., Huel, G., Lazar, P. and Boudène, C. 1981 Factors explaining population blood lead level variability, Revue Epidem. et Santé Publ. 29, 113-124 (in French).
AZAR, A., Snee, R. D. and Habibi, K. 1975 An epidemiologic approach to community air lead exposure using personal air samplers, Environ. Qual. Saf. Suppl. II: Lead, 254-290.
BABICH, H. and Davis, D. L. 1981 Food tolerances and action levels: do they adequately protect children?, Bioscience 31, 429-438.
BAKER, E. L., Folland, D. S., Taylor, T. A., Frank, M., Peterson, W., Lovejoy, G., Cox, D., Housworth, J., Landrigan, P. 1977 Lead poisoning in children of lead workers, New Engl. J. Med. 296, 260-261.
BANDER, L. K., Morgan, K. J. and Zabik, M. E. 1983 Dietary lead intake of pre-school children, Am. J. Public Health 73, 789-794.
BARLTROP, D. 1966 The prevalence of pica, Am. J. Dis. Child 112, 116-123.
BARLTROP, D. 1972 Sources and significance of environmental lead for children, Proc. Int. Symp. Environ. Health Aspects of Lead, Amsterdam, 675-681.
BARLTROP, D., Strehlow, C. D., Thornton, I. and Webb, J. S. 1974 Significance of high soil lead concentrations for childhood lead burdens, Environ. Health Perspect. 7, 75-82.
BARLTROP, D., Strehlow, C. D., Thornton, I. and Webb, J. S. 1975 Absorption of lead from dust and soil, Postgrad. Med. J. 51, 801-804.
BARLTROP, D. 1975 Significance of lead contaminated soils and dusts for human populations, Arch. Ind. Hyg. Toxicol. 26, Suppl. 81-96.
BARLTROP, D. and Meek, F. 1975 Absorption of different lead compounds, Postgrad Med. J. 51, 805-809.
BARLTROP, D. and Khoo, H. E. 1976 The influence of dietary minerals and fat on the absorption of lead, Sci. Total Environ. 6, 265-273.
BARLTROP, D. and Meek, F. 1979 Effect of particle size on lead

absorption from the gut, Arch. Environ. Health 34, 280-285.
BARRY, P. S. I. 1978 Distribution and storage of lead in human tissues, In: The biogeochemistry of lead in the environment, J. O. Nriagu (Ed.), B. Biol. Effects, Elsevier, Amsterdam, 97-150.
BARRY, P. S. I. 1981 Concentrations of lead in the tissues of children, Brit. J. Ind. Med. 38, 61-71.
BARTON, J. C., Conrad, M. E., Harrison, L. and Nuby, S. 1978 Effects of calcium on the absorption and retention of lead, J. Lab. Clin. Med. 91, 366-376.
BEATTIE, A. D., Dagg, J. H., Goldberg, A., Wang, I. and Ronald, J. 1972 Lead poisoning in rural Scotland, Brit. Med. J. 264, 488-491.
BEAUD, P., Rollier, H. and Ramuz, A. 1982 Contamination of foods in display windows by traffic, Trav. Chim. Aliment. Hyg. 73, 196-207 (in French).
BELL, R. R. and Spickett, J. T. 1981 The influence of milk in the diet on the toxicity of orally ingested lead in rats, Fd. Cosmet. Toxicol. 19, 429-436.
BELL, R. R. and Spickett, J. T. 1983 The influence of dietary fat on the toxicity of orally ingested lead in rats, Fd. Chem. Toxicol. 21, 469-472.
BERLIN, A. 1982 Assessment of exposure to lead of the general population in the European Community through biological monitoring, Environ. Monit. Assess. 2, 225-231.
BERMAN, E. and McKiel, K. 1972 Is that toothpaste safe?, Arch. Environ. Health 25, 64-65.
BERODE, M., Guillemin, M., Lejeune, M., Bovet, P. and Lob, M. 1980 Evaluation of lead exposure of a child population in Lausanne, Helv. Paediatr. Acta 35, Suppl. 43, 1-63 (in French).
BEVAN, M. G., Colwill, D. M. and Hogbin, L. E. 1974 Measurements of particulate lead on the M4 motorway at Harlington, Transport and Road Research Lab. Report, 626 (as cited by Chamberlain et al. 1978).
BIDDLE, G. N. 1982 Toxicology of lead; a primer for analytical chemists, J. Assoc. Off. Anal. Chem. 65, 947-952.
BIELIG, H. J. and Hofsommer, H. J. 1980 Influencing the heavy metal content of foodstuffs, Ind. Obst- und Gemuseverwert. 65, 1-7 (in German).
BILLICK, I. H., Curran, A. S. and Shier, D. R. 1979 Analysis of pediatric blood lead levels in New York City for 1970-1976, Environ. Health Perspect. 31, 183-190.
BILLICK, I. H., Curran, A. S. and Shier, D. R. 1980 Relation of pediatric blood lead levels to lead in gasoline, Environ. Health Perspect. 34, 213-217.
BILLICK, I. H. 1983 Sources of lead in the environment, In; Lead

versus Health, M. Rutter and R. R. Jones (Eds), John Wiley and Sons, New York, 59-77.
BLAKE, K. C. H. 1976 Absorption of $^{203}Pb$ from gastro-intestinal tract of man, Environ. Res. 11, 1-4.
BLAKE, K. C. H. and Mann, M. 1983 Effect of calcium and phosphorus on the gastro-intestinal absorption of $^{203}Pb$ in man, Environ. Res. 30, 188-194.
BLAKE, K. C. H., Barbezat, G. O. and Mann, M. 1983 Effect of dietary constituents on the gastro-intestinal absorption of $^{203}Pb$ in man, Environ. Res. 30, 182-187.
BLOOM, H. and Smythe, L. E. 1984 Environmental lead and its control in Australia, Search 14, 315-319.
BOGDEN, J. D., Joselow, M. M. and Singh, N. P. 1975 Extraction of lead from printed matter at physiological values of pH, Arch. Environ. Health 30, 442-444.
BOPPEL, B. 1975 Lead content of foodstuffs, 4 Lead content of infant formula, Z. Lebensm. Unters. Forsch. 158, 291-294 (in German).
BORNSCHEIN, R., Pearson, D. and Reiter, L. 1980a Behavioral effects of moderate lead exposure in children and animal models, 1 Clinical studies, CRC Critical Reviews Toxicol. 8, 43-99.
BORNSCHEIN, R., Pearson, D. and Reiter, L. 1980b Behavioral effects of moderate lead exposure in children and animal models, 2 Animal studies, CRC Critical Reviews Toxicol. 8, 101-152.
BORTOLI, A., Mattiello, G., Zotti, S., Bonvicini, P., Trabuio, G. and Fazzin, G. 1983 Blood lead levels in patients with chronic liver diseases, Int. Arch. Occup. Environ. Health 52, 49-57.
BRESLOW, N. E. and Day, N. E. 1978 Statistical methods in cancer research, I The analysis of case-control studies, IARC Scientific Publications No.32, IARC Lyon.
BROCKHAUS, A., Freier, I., Ewers, U., Jermann, E. and Dolgner, R. 1983 Levels of cadmium and lead in blood in relation to smoking, sex, occupation and other factors in an adult population of the FRG, Int. Arch. Occup. Environ. Health 52, 167-175.
BRUNEKREEF, B., Smit, J., Dieckman, N. and Heemskerk, J. (Eds), 1978 Environmental evaluation of the impact of lead from a secondary lead smelter in Arnhem, Department of Environmental and Tropical Health/Department of Air Pollution/Department of Soil Pollution, Agricultural University Wageningen, The Netherlands (in Dutch).
BRUNEKREEF, B., Veenstra, S. J., Biersteker, K. and Boleij, J. S. M. 1981 The Arnhem lead study. I Lead uptake by 1- to 3-year old children living in the vicinity of a secondary lead smelter in Arnhem, The Netherlands, Environ. Res. 25, 441-448.

BRUNEKREEF, B., Noij, D., Biersteker, K. and Boleij, J. S. M. 1983 Blood lead levels of Dutch city children and their relationship to lead in the environment, J. Air Pollut. Control Assoc. 33, 872-876.
BRUNEKREEF, B. 1984 The relationship between air lead and blood lead in children: a critical review, Sci. Total Environ. 38, 79-123.
BRUNEKREEF, B. 1985 The relationship between environmental lead and blood lead in children. Thesis, Department of Environmental and Tropical Health, Agricultural University Wageningen, The Netherlands.
BRYCE SMITH, D. and Stephens, R. 1981 Exposure to lead (letter), Lancet ii, 877.
BUCHET, J. P., Roels, H., Hubermont, G. and Lauwerys, R. 1978 Placental transfer of lead, mercury, cadmium and carbon monoxide in women, II Influence of some epidemiological factors on the frequency distributions of the biological indices in maternal and umbilical cord blood, Environ. Res. 15, 494-503.
BUCHET, J. P., Lauwerys, R., Vandevoorde, A. and Pycke, J. M. 1981 Evaluation of the daily ingestion of Cd, Pb, Mn, Cu, Cr, Hg, Ca, Zn and As by the Belgian population, Arch. Belg. de Med. Soc. Hyg. Med. du Travail et Med. Leg. 39, 465-480 (in French).
BUCHET, J. P., Lauwerys, R., Vandevoorde, A. and Pycke, J. M. 1983 Oral daily intake of cadmium, lead, manganese, copper, chromium, mercury, calcium, zinc and arsenic in Belgium: a duplicate meal study, Fd. Chem. Toxicol. 21, 19-24.
BUSHNELL, P. J. and DeLuca, H. F. 1981 Lactose facilitates the intestinal absorption of lead in weanling rats, Science 211, 61-63.
BUSHNELL, P. J. and DeLuca, H. F. 1983 The effects of lactose on the absorption and retention of dietary lead, J. Nutr. 113, 365-378.
BYRD, D. S., Gilmore, J. T. and Lea, R. H. 1983 Effect of decreased use of lead in gasoline on the soil of a highway, Environ. Sci. Technol. 17, 121-123.
CAVALLERI, A., Baruffini, A., Minoia, C. and Bianco, L. 1981 Biological response of children to low levels of inorganic lead, Environ. Res. 25, 415-423.
CENTRAAL Bureau voor de Statistiek 1979 Workers' Budget Survey 1974/1975 4: Amount and price of food items bought, Staatsuitgeverij, The Hague (in Dutch).
CHAMBERLAIN, A. C., Clough, W. S., Heard, M. J., Newton, D., Stott, A. N. B. and Wells, A. C. 1975 Uptake of lead by inhalation of motor exhaust, Proc. R. Soc. London B. 192, 77-110.
CHAMBERLAIN, A. C., Heard, M. J., Little, P., Newton, D., Wells, A. C. and Wiffen, R. D. 1978, Investigations into lead from motor vehicles, AERE report R9198, AERE Harwell, U.K.

CHAMBERLAIN, A. C. 1981 Contribution of lead in dust to lead in blood, EMSc Division, AERE Harwell, U.K.
CHAMBERLAIN, A. C. 1983a Effect of airborne lead on blood lead, Atmos. Environ. 17, 677-692.
CHAMBERLAIN, A. C. 1983b Fallout of lead and uptake by crops, Atmos. Environ. 17, 693-706.
CHARNEY, E., Sayre, J. W. and Coulter, M. 1980 Increased lead absorption in inner city children - where does the lead come from?, Pediatrics 65, 226-231.
CHARNEY, E. 1982 Lead poisoning in children: the case against household lead dust, In: Lead absorption in children, J. J. Chisholm and D. M. O'Hara (Eds), Urban and Schwarzenberg, Baltimore/Münich, 79-88.
CHARNEY, E., Kessler, B., Farfel, E. and Jackson, D. 1983 Childhood lead poisoning - a controlled trial of the effect of dust-control measures on blood lead levels, New Engl. J. Med. 309, 1089-1093.
CHESNEY, R. W., Rosen, J. F., Hamstra, A. J., Smith, C., Mahaffey, K. and DeLuca, H. F. 1981 Absence of seasonal variation in serum concentrations of 1,25-dihydroxyvitamin-D despite a rise in 25-hydroxyvitamin-D in summer, J. Clin Endocrinol. Metabol. 53, 139-142.
CHISHOLM, J. J. 1973 Lead poisoning, In: Cities: their origin, growth and human impact, K. Davis (Ed.), Readings from Scientific American 123-131.
CHISHOLM, J. J. 1982 Management of increased lead absorption - illustrative cases, In: Lead absorption in children, J. J. Chisholm and D. M. O'Hara (Eds), Urban and Schwarzenberg, Baltimore/Münich, 171-188.
COCHRAN, W. G. 1968 Errors of measurement in statistics, Technometrics 10, 637-666.
COHEN, A. F. and Cohen, B. L. 1980 Protection from being indoors against inhalation of suspended particulate matter of outdoor origin, Atmos. Environ. 14, 183-184.
COLINET, E. 1983 European interlaboratory trial for the assays of lead and cadmium in blood, Proc. Int. Conf. Heavy Metals in the Environ., Heidelberg, 586-589.
COOL, M., Marcoux, F., Paulin, A. and Mehra, M. C. 1980 Metallic contaminants in street soils of Moncton, New Brunswick, Canada, Bull. Environ. Contam. Toxicol. 25, 409-415.
CROWELL, R. H. 1980 Lead in foods, Q. Bull. Assoc. Food Drug Off. 44, 168-174.
CULBARD, E., Thornton, I., Watt, J., Moorcroft, S. and Brooks, K. 1983a Sources and distribution of lead and cadmium in United

Kingdom dusts and soils, Proc. Int. Conf. Heavy Metals in the Environ., Heidelberg, 426-429.
CULBARD, E., Thornton, I., Watt, J., Moorcroft, S. and Brooks, K. and Thompson, M. 1983b Metal contamination of dusts and soils in urban and rural households in the United Kingdom, Trace Subst. Environ. Health, XVII, 236-241.
DAINES, R. H., Motto, H. and Chilko, D. M. 1970 Atmospheric lead; its relationship to traffic volume and proximity to highways, Environ. Sci. Technol. 4, 318-322.
DAINES, R. H., Smith, D. W., Feliciano, A. and Trout, J. R. 1972 Air levels of lead inside and outside of homes, Ind. Med. 41, 26-28.
DARROW, D. K. and Schroeder, H. A. 1974 Childhood exposure to environmental lead, Adv. Exp. Med. Biol. 48, 425-445.
DAVID, O. J., Wintrob, H. L. and Arcoleo, C. G. 1982 Blood lead stability, Arch. Environ. Health 37, 147-150.
DAVIDSON, C. I., Miller, J. M. and Pleskow, M. A. 1982 The influence of surface structure on predicted particle dry deposition to natural grass canopies, Water, Air and Soil Pollut. 18, 25-43.
DAVIES, B. E. and Roberts, L. J. 1978 The distribution of heavy metal contaminated soils in North East Clwyd, Wales, Water, Air and Soil Poll. 9, 507-518.
DAVIES, B. E and White, H. M 1981a Environmental pollution by wind-blown lead mine waste; a case study in Wales, U.K. Sci. Total Environ. 20, 57-74.
DAVIES, B. E. and White, H. M. 1981b Trace elements in vegetables grown on soils contaminated by base metal mining, J. Plant Nutr. 3, 387-396.
DAVIES, B. E., Ginnever, R. C. and Lear, J. M. 1981c Cadmium and lead contaminated soils in some British metal mining areas, Trace Subst. Environ. Health XV, 323-332.
DAVIES, B. E. 1983 A graphical estimation of the normal lead content of some British soils, Geoderma 29, 67-75.
DAY, J. P., Fergusson, J. E. and Chee, T. M. 1979 Solubility and potential toxicity of lead in urban street dust, Bull. Environ. Contam. Toxicol. 23, 497-502.
DELVES, H. T., Sherlock, J. C. and Quinn, M. J. 1984 Temporal stability of blood lead concentrations in adults exposed only to environmental lead, Human Toxicol. 3, 279-288.
DEN TONKELAAR, W. 1983 Exposure of car passengers to CO, NO, $NO_2$, benzene, toluene and lead, Proc. VIth World Congr. on Air Quality, Paris, Vol.2, 329-335.
DEPARTMENT of the Environment (U.K.) 1982 The Glasgow duplicate diet study (1979/1980), Pollution Report No. 11, HM Govt.

Printing Office, London.
DIEHL, J. F. 1982 Heavy metals in food - are tolerance levels exceeded?, Landwirt. Forsch. 39, (Sonderheft), 35-59 (in German).
DIEMEL, J. A. L., Brunekreef, B., Boleij, J. S. M., Biersteker, K. and Veenstra, S. J. 1981 The Arnhem lead study. II Indoor pollution and indoor/outdoor relationships, Environ. Res. 25, 449-456.
DRAPER, N. R. and Smith, H. 1981, Applied Regression Analysis, John Wiley and Sons, New York.
DUCOFFRE, G., Bruaux, P., Claeys-Thoreau, F., Lafontaine, A., Schifflers, E. and Smans, M. 1980 Statistical study of some parameters able of influencing blood lead levels, In; Mechanisms of toxicity and hazard evaluation, B. Holmstedt et al. (Eds), Elsevier, Amsterdam, 607-611.
DUGGAN, M. J. and Williams, S. 1977 Lead in dust in city streets, Sci. Total Environ. 7, 91-97.
DUGGAN, M. J. 1980 Lead in urban dust; an assessment, Water, Air and Soil Pollut. 14, 309-321.
DUGGAN, M. J. 1983a The uptake and excretion of lead by young children, Arch. Environ. Health 38, 246-247.
DUGGAN, M. J. 1983b Contribution of lead in dust to children's blood lead, Environ. Health Perspect. 50, 371-381.
DUGGAN, M. J. 1983c Lead in dust as a source of children's body lead, In; Lead versus health, M. Rutter and R. R. Jones (Eds), John Wiley and Sons, New York, 115-139.
DUGGAN, M. J. 1984 Temporal and spatial variation of lead in air and in surface dust - implications for monitoring, Sci. Total Environ. 33, 37-48.
EATON, D. F., Fowles, G. W. A., Thomas, M. W. and Turnbull, G. B. 1975 Chromium and lead in colored printing inks used for children's magazines, Environ. Sci. Technol. 9, 768-770.
EINBRODT, H. J., Rosmanith, J., Dreyhaupt, F. J. and Schröder, A. 1975 The influencing factors of selection of collective (study group) upon the assessment in epidemiological studies in the example of blood lead levels in children, Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Hyg., Abt. 1 Orig. Reihe B. 161, 38-45 (in German).
ELLEN, G. 1977 Presence of heavy metals in food, Voeding 38, 443-460 (in Dutch).
ELLIS, J. B. and Revitt, D. M. 1982 Incidence of heavy metals in street surface sediments; solubility and grain size studies, Water, Air and Soil Pollut. 17, 87-100.
ELWOOD, P. C., St Leger, A. S. and Morton, M. 1976 Dependence of blood lead on domestic water lead, Lancet i, 1295.
ELWOOD, W. J., Clayton, B. E., Cox, R. A., Delves, H. T., King, E.,

Malcolm, D., Ratcliffe, J. M., Taylor, J. F. 1977 Lead in human blood and in the environment near a battery factory, Brit. J. Prev. Soc. Med. 31, 154-163.
ELWOOD, P. C. 1983a Changes in blood lead concentrations in women in Wales 1972-1982, Brit. Med. J. 286, 1553-1555.
ELWOOD, P. C. 1983b Turin isotopic lead experiment (letter), Lancet i, 869.
ELWOOD, P. C. 1984 Abuses of epidemiology in environmental research, Proc. Int. Conf. on Environ. Pollut., London, 249-256.
ELWOOD, P. C. and Gallacher, J. E. J. 1984 Effect of dust control on blood lead (letter), New Engl. J. Med. 310, 924-925.
ELWOOD, P. C. and Gallacher, J. E. J., Phillips, K. M., Davies, B. E. and Toothill, C. 1984 Greater contribution to blood lead from water than from air, Nature 310, 138-140.
EPA 1978 National Primary and Secondary Ambient Air Quality Standards, Fed. Register 43, 46246-46277.
EPA 1983 Air Quality Criteria for Lead - Review Draft, EPA 600/8-83-028 A (4 volumes).
EPA 1984 Air Quality Criteria for Lead - Review Draft, EPA 600/8-83-028 B (4 volumes).
FACCHETTI, S. and Geiss, F. 1982 Isotopic lead experiment - status report, CEC Luxembourg.
FARMER, J. G. and Lyon, T. D. B. 1977 Lead in Glasgow street dirt and soil, Sci. Total Environ. 8, 89-93.
FERGUSSON, J. E., Hayes, R. W., Yong, T. S. and Thiew, S. H. 1980 Heavy metal pollution by traffic in Christchurch, New Zealand: lead and cadmium content of dust, soil and plant samples, N.Z. J. Sci. 23, 293-310.
FERGUSSON, J. E. 1981 Lead additives - a survey of environmental effects, Chem. Aust. 48, 87-90.
FERGUSSON, J. E. and Ryan, D. E. 1984 The element composition of street dust from large and small urban areas related to city type, source and particle size, Sci. Total Environ. 34, 101-116.
FORSCHNER, E. and Wolf, H. O. 1981 Mechanically deboned meat and poultry - contamination with lead, cadmium and mercury, Arch. Lebensm. Hyg. 32, 200-203 (in German).
FOUASSIN, A. and Fondu, M. 1981 Evaluation of the average lead and cadmium content in Belgian food, Arch. Belg. de Med. Soc. Hyg. Med. du Trav. et Med. Leg. 39, 1-14 (in Dutch).
FRANZ, D. A. and Hadley, W. M. 1981 Lead in Albuquerque street dirt and the effect of curb paint, Bull. Environ. Contam. Toxicol. 27, 353-358.
GALKE, W. A., Hammer, D. I., Keil, J. E. and Lawrence, S. W. 1975

Environmental determinants of lead burdens in children, Proc. Int. Conf. Heavy Metals in the Environ., Toronto, 53-74.
GALLACHER, J. E. J., Elwood, P. C., Phillips, K. M., Davies, B. E. and Toothill, C. 1984a Relationship between blood lead and lead in air, water and dust in representative population samples in Wales, Proc. Int. Conf. Environ. Pollut., London, 263-266.
GALLACHER, J. E. J., Elwood, P. C., Phillips, K. M., Davies, B. E. and Jones, D. T. 1984b Relation between pica and blood lead in areas of differing lead exposure, Arch. Dis. Childhd. 59, 40-44.
GALLACHER, J. E. J., Elwood, P. C., Phillips, K. M., Davies, B. E., Ginnever, R. C., Toothill, C., Jones, O. T. 1984c Vegetable consumption and blood lead concentrations, J. Epidemiol. Comm. Health 38, 173-176.
GALLOWAY, J. N., Thornton, J. D., Norton, S. A., Volchok, H. L. and McLean, R. A. N. 1982 Trace metals in atmospheric deposition: a review and assessment, Atmos. Environ. 16, 1677-1700.
GARCIA-MIRAGAYA, J., Castro, S. and Paolini, J. 1981 Lead and zinc levels and chemical fractionation in road side soils of Caracas, Venezuela, Water, Air and Soil Pollut. 15, 285-297.
GIBSON, M. J. and Farmer, J. G. 1984 Chemical partitioning of trace metal contaminants in urban street dirt, Sci. Total Environ. 33, 49-57.
GOLDBERG, A. 1974 Drinking water as a source of lead pollution, Environ. Health Perspect. 7, 103-105.
GRAF, W., Baars, U., Grote, S. and Ubelmesser, W. J. 1980 Effect of the lead-in-petrol law on the concentration of lead and 3-4 benzopyrene in urban dust, Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Hyg., Abt. 1 Orig. Reihe B. 170, 388-401.
GRANDJEAN, P., Olsen, N. B. and Hollnagel, H. 1981 Influence of smoking and alcohol consumption on blood lead levels, Int. Arch. Occup. Environ. Health 48, 391-397.
GRANDJEAN, P. 1981 Blood lead concentrations reconsidered, Nature 291, 188.
GREEN, V. A., Wise, G. W. and Callenbach, J. 1976 Lead poisoning, Clin. Toxicol. 9, 33-51.
GRIFFIN, T. B., Coulston, F., Wills, H., Russel, J. C. and Knelson, J. H. 1975 Clinical studies of men continuously exposed to airborne particulate lead, Environ. Qual. Safety Suppl. II - Lead, 221-240.
GROSS, S. B. 1981 Human oral and inhalation exposures to lead: summary of Kehoe balance experiments, J. Toxicol. Environ. Health 8, 333-377.
HAAS, T., Mache, K., Schaller, K., Wieck, A., Mache, W. and Valentin, H. 1972 Investigations into ecological lead burden in childhood, Proc. Int. Symp. Environ. Health Aspects of Lead,

Amsterdam, 741-748 (in German).
HABIBI, K. 1970 Characterization of particulate lead in vehicle exhaust - experimental techniques, Environ. Sci. Technol. 4, 239-248.
HAMILTON, R. S., Revitt, D. M. and Warren, R. S. 1984 Levels and physicochemical associations of Cd, Cu, Pb and Zn in road sediments, Sci. Total Environ. 33, 59-74.
HAMMOND, P. B., O'Flaherty, E. J. and Gartside, P. S. 1981 The impact of air lead on blood lead in man - a critique of the recent literature, Fd. Cosmet Toxicol. 19, 631-638.
HAMMOND, P. B. 1982 Metabolism of lead, In: Lead absorption in children, J. J. Chisholm and D. M. O'Hara (Eds), Urban and Schwarzenberg, Baltimore/Münich, 11-20.
HANSEN, J. C., Kromann, N., Wulf, H. C. and Alboge, K. 1983 Human exposure to heavy metals in east Greenland, II Lead, Sci. Total Environ. 26, 245-254.
HARING, B. J. A. 1978 Human exposure to metals released from water distribution systems, with particular reference to water consumption patterns, La Trib. au Cebedeau 419, 349-355.
HARING, B. J. A. 1983 Lead in drinking water and water conditioning, RID report 83-2 Voorburg, The Netherlands (in Dutch).
HARING, B. J. A. 1984 Lead in drinking water, Thesis Amsterdam, The Netherlands.
HARRISON, R. M. 1979 Toxic metals in street and household dusts, Sci. Total Environ. 11, 89-97.
HARRISON, R. M. and Laxen, D. P. H. 1977 A comparative study of methods for the analysis of total lead in soils, Water, Air and Soil Pollut. 8, 387-392.
HARRISON, R. M. and Laxen, D. P. H. 1984 Lead pollution - causes and control, Chapman and Hall London.
HASCHKE, F. and Steffan, I. 1981 Lead uptake of infants with food in the years 1980-1981, Wiener Klin. Wochenschr. 93, 613-616 (in German).
HEALY, M. A. and Aslam, M. 1980 The distribution of lead in a roadside environment and its consequences for health, Publ. Health London 94, 78-88.
HEARD, M. J. and Chamberlain, A. C. 1982 Effect of minerals and food on uptake of lead from the gastrointestinal tract in humans, Hum. Toxicol. 1, 411-415.
HEARD, M. J., Chamberlain, A. C. and Sherlock, J. C. 1983 Uptake of lead by humans and effect of minerals and food, Sci. Total Environ. 30, 245-253.
HECHT, H., Schramel, P., Moreth, F. and Schinner, W. 1981 Secondary contamination of meat with toxic elements, Fleischwirtsch

61, 1316-1325 (in German).
HECKER, L. H., Allen, H. E., Dinman, B. D. and Neel, J. V. 1974 Heavy metal levels in acculturated and unacculturated populations, Arch. Environ. Health 29, 181-185.
HORIGUCHI, S., Kurono, T. and Teramoto, K. 1982 Amounts of lead detected from household articles in elution test, Osaka Med. J. 28, 49-58.
HUNT, Th. J., Hepner, R. and Seaton, K. W. 1982 Childhood lead poisoning and inadequate child care, Am. J. Dis. Child. 136, 538-542.
HUNTER, J. S. 1980 The national system of scientific measurement, Science 210, 869-874.
HUNTER, J. M. 1977 The summer disease - an integrative model of the seasonality aspects of childhood lead poisoning, Soc. Sci. Med. 11, 691-703.
ICRP 1975 Report of the task group on Reference Man., ICRP publication no.23, Pergamon, Oxford.
INGALLS, T. H., Tiboni, E. A. and Werrin, M. 1961 Lead poisoning in Philadelphia 1955-1960, Arch. Environ. Health 3, 89-93.
INSKIP, M. and Atterbury, N. 1983 The legacy of lead-based paint: potential hazards to "do-it-yourself" enthusiasts and children, Proc. Int. Conf. Heavy Metals in the Environ., Heidelberg, 286-289.
JENSEN, A. A. 1983 Chemical contaminants in human milk, Residue Reviews 89, 1-128.
JOHNSON, D. E., Tillery, J. B. and Prevost, R. J. 1975 Levels of platinum, palladium and lead in populations of southern California, Environ. Health Perspect. 12, 27-33.
JOHNSON, D. E., Tillery, J. B. and Prevost, R. J. 1976 Baseline levels of platinum and palladium in human tissue, EPA report 600/1-76-019.
JOHNSON, D. E., Prevost, R. J., Tillery, J. B. Kimball, K. T. and Hosenfeld, J. M. 1978 Epidemiological study of the effects of automobile traffic on blood lead levels, EPA report 600/1-78-055.
JOHNSON, N. E. and Tenuta, K. 1979 Diets and lead blood levels of children who practise pica, Environ. Res. 18, 369-376.
JOHNSON, R. D., Manske, D. D., New, D. H. and Podrebarac, D. S. 1981 Pesticide, heavy metal and other chemical residues in infant and toddler total diet samples, II August 1975 - July 1976, Pestic. Monit. J. 15, 39-50.
JOHNSON, R. D., Manske, D. D., New, D. H. and Podrebarac, D. S. 1984 Pesticide, heavy metal and other chemical residues in infant and toddler total diet samples, III August 1976 - September 1977, J. Assoc. Off. Anal. Chem. 67, 145-154.
JOHNSON, D. L., Fortmann, R. and Thornton, I. 1982 Individual

particle characterization of heavy metal rich household dusts, Trace Subst. Environ. Health XVI, 116-123.
JONES, K. and McDonald, A. 1983 The efficiency of different methods of extracting lead from street dust, Environ. Pollut. B. 6, 133-143.
JONES, L., Humphreys, L., Mushak, P., Weinberg, R., Kupper, L. and Scarr, S. 1983 Independent peer review of studies concerning neurobehavioral effects of lead exposures in nominally asymptomatic children: official report of findings and recommendations of an interdisciplinary expert review committee, EPA report 600/8-83-028A.
JONES, R. R. and Stephens, R. 1983 The contribution of lead in petrol to human lead intake, In: Lead versus health, M. Rutter and R. R. Jones (Eds), John Wiley and Sons, New York, 141-177.
JOSEPHS, D. S. 1977 Abnormal exposure to lead and anaemia in Luton Asian children, Publ. Health London 91, 133-140.
JUGO, S. 1977 Metabolism of toxic heavy metals in growing organisms: a review, Environ. Res. 13, 36-46.
KANG, H. K., Infante, P. F. and Carra J. S. 1983 Determination of blood lead elimination patterns of primary lead smelter workers, J. Toxicol. Environ. Health 11, 199-210.
KARHAUSEN, L. 1972 Intestinal lead absorption, Proc. Int. Conf. Environ. Health Aspects of Lead, Amsterdam, 427-440.
KAUL, B., Davidow, B., Eng, L. M. and Gerwirtz, M. H. 1983 Lead, erythrocyte protoporphyrin and ferritin levels in cord blood, Arch. Environ. Health 38, 296-300.
KAWAI, M., Toriumi, H., Katagiri, Y. and Maruyama, Y. 1983 Home lead work as a potential source of lead exposure for children, Int. Arch. Occup. Environ. Health 53, 37-46.
KHAN, D. H. 1980 Lead in the Soil Environment, MARC report 21, Monitoring and Assessment Research Centre, London.
KIRKPATRICK, D. C., Conacher, H. B. S., Méranger, J. C., Dabeka, R., Collins, B., McKenzie, A. D., Lacroix, G. M. A., Savary, G. 1980 The trace elemental content of Canadian baby foods and estimation of trace element intake by infants, Can. Inst. Food Sci. Technol. J. 13, 154-161.
KNELSON, J. H., Johnson, R. J., Coulston, F., Goldberg, L. and Griffin, T. 1972 Kinetics of respiratory lead uptake in humans, Proc. Int. Symp. Environ. Health Aspects of Lead, Amsterdam, 391-401.
KNELSON, J. H. 1974 Problems of estimating respiratory lead dose in children, Environ. Health Perspect. 7, 53-57.
KOIVISTOINEN, P. (Ed.), 1980 Mineral composition of Finnish foods, Acta Agric. Scand. Suppl. 22, (171 p).

KÖSTER, W. and Merkel, D. 1982 Relationships between zinc, cadmium, lead and copper contents of soils and plants when using different soil investigation methods, Landwirts Forschung Sonderheft 39, 245-254 (in German).
KOSTIAL, K. and Kello, D. 1979 Bioavailability of lead in rats fed "human" diets, Bull. Environ. Contam. Toxicol. 21, 312-314.
KOVAR, I. Z., Strehlow, C. D., Richmond, J. and Thompson, M. G. 1984 Perinatal lead and cadmium burden in a British urban population, Arch. Dis. in Childhd. 59, 36-39.
KRAJNC, E. I., Helleman, P. W., van Logten, M. J. and van Esch, G. J. 1977 Investigation of the effects of lead exposure in children living near an industrial source, Report No. 211/77 Dutch Nat. Inst. of Public Health (in Dutch).
KUHNERT, P. M., Erhard, P. and Kuhnert, B. R. 1977 Lead and delta-aminolevulinic acid dehydratase in RBC's of urban mothers and fetuses, Environ. Res. 14, 73-80.
LANDRIGAN, P. J., Gehlbach, S. H., Rosenblum, B. F., Shoults, J. M., Candelaria, R. M., Barthel, W. F., Liddle, J. A., Smrek, A. L., Staehling, N. W., Sanders, J. F. 1975 Epidemic lead absorption near an ore smelter, New Engl. J. Med. 292, 123-129.
LANDRIGAN, P. J., Baker, E. L., Himmelstein, J. S., Stein, G. F., Wedding, J. P. and Straub, W. E. 1982 Exposure to lead from the Mystic River bridge: the dilemma of deleading, New Engl. J. Med. 306, 673-676.
LARSSON, B, Slorach, S. A., Hagman, U. and Hofvander, Y. 1981 WHO collaborative breast feeding study, II Levels of lead and cadmium in Swedish human milk 1978-1979, Acta Paediatr. Scand. 70, 281-284.
LAWTHER, P. J., Commins, B. T., Ellison, J. McK. and Biles, B. 1972 Airborne lead and its uptake by inhalation, Preprint of a paper presented at a conference on Lead in the Environment, London 1972.
LAXEN, D. P. H. 1983 A curved response to lead pollution, Proc. Int. Conf. Heavy Metals in the Environ., Heidelberg, 290-293.
LEPOW, M. L., Bruckman, L., Rubino, R. A., Markowitz, S., Gillette, M. and Kapish, J. 1974 Role of airborne lead in increased body burden of lead in Hartford children, Environ. Health Perspect. 7, 99-102.
LIEBACK, J. U. and Ruden, H. 1983 Concentrations of iron, lead, cadmium, arsenic and selenium in respirable and non-respirable fractions of airborne suspended particles in Berlin, Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Hyg. Abt. 1 Orig. Reihe B. 177, 37-56 (in German).
LINDBERG, S. E. and Harris, R. C. 1981 The role of atmospheric deposition in an eastern US deciduous forest, Water, Air and Soil

Pollut. 16, 13-31.
LINDBERG, S. E. 1982 Factors influencing trace metal, sulfate and hydrogen ion concentrations in rain, Atmos. Environ. 16, 1701-1709.
LINTON, R. W., Natusch, D. F. S., Solomon, R. L. and Evans, C. A. 1980 Physicochemical characterization of lead in urban dusts, A microanalytical approach to lead tracing, Environ. Sci. Technol. 14, 159-164.
LIOY, P. J., Mallon, R. P. and Kneip, T. J. 1980 Long term trends in total suspended particulates, vanadium, manganese and lead at near street level and elevated sites in New York City, J. Air Pollut. Contr. Assoc. 30, 153-156.
LITTLE, P. and Wiffen, R. D. 1977 Emission and deposition of petrol engine exhaust Pb, Atmos. Environ. 11, 437-447.
LITTLE, P., Fleming, R. G. and Heard, M. J. 1981 Uptake of lead by vegetable foodstuffs during cooking, Sci. Total Environ. 17, 111-131.
LUCAS, J. M. 1981 Effect of analytical variability on measurements of population blood lead levels, Am. Ind. Hyg. Assoc. J. 42, 88-96.
LUDWIGSEN, R. J. 1982 Container contribution to lead in canned foods, La Riv. dell. Soc. Ital. Sci. dell Aliment. 11, 369-382.
LYON, J. L., Klauber, M. R., Graff, W. and Chiu, G. 1981 Cancer clustering around point sources of pollution: assessment by a case control methodology, Environ. Res. 25, 29-34.
MADDEN, N. A., Russo, D. C. and Cataldo, M. F. 1980 Environmental influences on mouthing in children with lead intoxication, J. of Pediatr. Psych. 5, 207-216.
MAHAFFEY, K. R. 1974 Nutritional factors and susceptibility to lead toxicity, Environ. Health Perspect. 7, 107-112.
MAHAFFEY, K. R., Annest, J. L., Barbano, H. E. and Murphy, R. S. 1979 Preliminary analysis of blood lead concentrations for children and adults: HANES II 1976 - 1978, Trace Subst. Environ. Health XIII, 37-51.
MAHAFFEY, K. R., Rosen, J. F., Chesney, R. W., Peeler, J. T., Smith, C. M. and Deluca, H. F. 1982 Association between age, blood lead concentration and serum 1,25 dihydroxy cholecalciferol levels in children, Am. J. Clin. Nutr. 35, 1327-1331.
MAHAFFEY, K. R. 1983 Biotoxicity of lead: influence of various factors, Fed. Proc. 42, 1730-1734.
MAHER, C. C., Roettgers, D. M. and Conlon, H. J. 1979 Interlaboratory comparison of blood lead determinations, Am. Ind. Hyg. Assoc. J. 40, 230-237.
MARCUS, A. 1984 Personal communication.
MCCABE, E. B. 1979 Age and sensitivity to lead toxicity, Environ. Health Perspect. 29, 29-33.

MCCUSKER, J. 1979 Longitudinal changes in blood lead levels in children and their relationship to season, age and exposure to paint or plaster, Am. J. Publ. Health 69, 348-352.
van der MEULEN, A., Hofschreuder, P., van de Vate, J. F. and Oeseburg, F. 1984 Feasibility of High Volume Sampling for determination of total suspended particulate matter and trace metals, J. Air Pollut. Contr. Assoc. 34, 144-151.
MCINTOSH, M. J., Moore, M. R., Goldberg, A., Fell, G. S., Cunningham, C. and Halls, D. J. 1982 Studies of lead and cadmium exposure in Glasgow, U.K., Ecol. Dis. 1, 177-184.
MILLAR, I. B. and Cooney, P. A. 1982 Urban lead - a study of environmental lead and its significance to school children in the vicinity of a major trunk road, Atmos. Environ. 16, 615-620.
MOORE, M. R. 1973 Plumbosolvency of waters, Nature 243, 222-223.
MOORE, M. R. 1977 Lead in drinking water in soft water areas - health hazards, Sci. Total Environ. 7, 109-115.
MOORE, M. R., Campbell, B. C., Meredith, P. A., Beattie, A. D., Goldberg, A. and Campbell, D. 1978 The association between lead concentrations in teeth and domestic water lead concentrations, Clin. Chim. Acta. 87, 77-83.
MOORE, M. R., Goldberg, A., Meredith, P. A., Lees, R., Low, R. A. and Pocock, S. J. 1979a The contribution of drinking water lead to maternal blood lead concentrations, Clin. Chim. Acta. 95, 129-133.
MOORE, M. R., Hughes, M. A. and Goldberg, D. J. 1979b Lead absorption in man from dietary sources - the effect of cooking upon lead concentrations of certain foods and beverages, Int. Arch. Occup. Environ. Health 44, 81-90.
MOORE, M. R., Meredith, P. A., Campbell, B. C. and Watson, W. S. 1979c The gastro-intestinal absorption of lead-203 chloride in man, Trace Subst. Environ. Health XIII, 368-373.
MOORE, M. R., Goldberg, A., Fyfe, W. M. and Richards W. N. 1981 Maternal lead levels after alterations to water supply, Lancet ii, 203-204.
MOORE, M. R., Goldberg, A., Pocock, S. J., Meredith, A., Stewart, I. M., MacAnespie, H., Lees, R., Low, A. 1982 Some studies of maternal and infant lead exposure in Glasgow, Scot. Med. J. 27, 113-122.
MOORE, M. R. 1983 Lead exposure and water plumbosolvency, In: Lead versus Health, M. Rutter and R. R. Jones (Eds), John Wiley and Sons New York, 79-106.
MOORE, E. L. 1984 Lead free metal can technology update and trends in food packaging, Dairy Food Sanit. 4, 47-51.
MOOTY, J., Ferrand, C. F. and Harris, P. 1975 Relationship of diet

to lead poisoning in children, Pediatrics 55, 636-639.
MORSE, D. L., Landrigan, P. J., Rosenblum, B. F., Hubert, J. S. and Housworth, J. 1979 El Paso revisited - epidemiologic follow-up of an environmental lead problem, J. Am. Med. Assoc. 242, 739-741.
NATIONAL Research Council 1980 Lead in the human environment, Nat. Acad. Sc. Washington DC.
NEEDLEMAN, H. L., Gunnoe, C., Leviton, A., Reed, R., Peresie, H., Maher, C., Barrett, P. 1979 Deficits in psychologic and classroom performance of children with elevated dentine lead levels, New Engl. J. Med. 300, 689-695.
NEEDLEMAN, H. L. 1983 Lead at low dose and the behavior of children, Neurotoxicology 4, 121-133.
NERI, L. C., Johansen, H. L., Schmitt, N., Pagan, R. T. and Hewitt, D. 1978 Blood lead levels in children in two British Columbia communities, Trace Subst. Environ. Health XII, 403-410.
NRIAGU, J. O. 1978a Lead in the atmosphere, In: The biogeochemistry of lead in the environment. A. Ecological Cycles, J. O. Nriagu (Ed.), Elsevier, Amsterdam, 137-184.
NRIAGU, J. O. 1978b Lead in soils, sediments and major rock types, In: The biogeochemistry of lead in the environment. A. Ecological Cycles, J. O. Nriagu (Ed.), Elsevier, Amsterdam, 15-72.
O'FLAHERTY, E. J., Hammond, P. B. and Lerner, S. I. 1982 Dependence of apparent blood lead half-life on the length of previous lead exposure in humans, Fund. and Appl. Toxicol. 2, 49-54.
O'HARA, D. M. 1982 Social factors in the recurrence of increased lead absorption in children, In: Lead absorption in children, J. J. Chisholm and D. M. O'Hara (Eds), Urban and Schwarzenberg, Baltimore/Münich, 89-101.
OKUBO, T., Tsuchiya, K., Nagasaki, M., Nakajima, T., Kamijyo, H. and Mizoguchi, I. 1978 A further study of the biological effects of lead on urban and suburban Tokyo school children, Int. Arch. Occup. Environ. Health 41, 17-23.
OKUBO, T., Omae, K., Sakurai, H., Sugita, M. and Tsuchiya, K. 1983 The relationship of airborne lead to blood lead in school children, J. Univ. Occup. Environ. Health 5 suppl., 137-144.
OXLEY, G. R. 1982 Blood lead concentrations: apparent reduction over approximately one decade, Int. Arch. Occup. Environ. Health 49, 341-343.
PACIGA, J. J., Roberts, T. M. and Jervis, R. E. 1975 Particle size distributions of lead, bromine and chlorine in urban-industrial aerosols, Environ. Sci. Technol. 9, 1141-1143.
PAGE, A. L. and Ganje, T. J. 1970 Accumulations of lead in soils for regions of high and low motor vehicle traffic density, Environ. Sci.

Technol. 4, 140-142.
PAGE, A. L. and Ganje, T. J. and Joshi, M. S. 1971 Lead quantities in plants, soil and air near some major highways in Southern California, Hilgardia 41, 1-31.
PALMER, S. and Ekvall, S. 1978 Pediatric nutrition in developmental disorders, Charles C. Thomas, Springfield Ill.
PERRELLI, G., Capellaro, E., Pira, E., Maina, G. and Vergnano, P. 1984 Further cases of lead poisoning from wine, Am. J. Ind. Med. 5, 377-381.
PIOMELLI, S., Corash, L., Corash, M. B., Seaman, C., Mushak, P., Glover, B. Padgett, R. 1980 Blood lead concentrations in a remote Himalayan population, Science 210, 1135-1137.
PIOMELLI, S., Seaman, C., Zullow, D., Curran, A. and Davidow, B. 1982 Threshold for lead damage to heme synthesis in urban children, Proc. Nat. Acad. Sci. 79, 3335-3339.
POCOCK, S. J., Shaper, A. G., Walker, M., Wale, C. J., Clayton, B., Delves, T., Lacey, R. F., Packham, R. F., Powell, P. 1983 Effects of tap water lead, water hardness, alcohol and cigarettes on blood lead concentrations, J. Epidemiol. Comm. Health 37, 1-7.
POOLE, C., Smythe, L. E. and Alpers, M. 1980 Blood lead levels in Papua New Guinea children living in a remote area, Sci. Total Environ. 15, 17-24.
POPOVAC, D., Graziano, J., Seaman, C., Kaul, B., Colakovic, B., Popovac, R., Osmani, I., Haxxiu, M., Begraca, M., Bozovic,Z., Mikic, M. 1982 Elevated blood lead in a population near a lead smelter in Kosovo, Yugoslavia, Arch. Environ. Health 37, 19-23.
PRPIC-MAJIC, D., Meczner, J., Telisman, S. and Kensanc, A. 1983 Biomedical follow-up of an environmental lead problem after engineering pollution controls of the emission source, Proc. VIth World Congr. Air Quality, Paris 2, 99-106.
PRPIC-MAJIC, D., Meczner, J., Telisman, S. and Kensanc, A. 1984 Biological monitoring of lead effects in a smelter community before and after emission control, Sci. Total Environ. 32, 277-288.
QUAH, R. F., Stark, A. D., Meigs, J. W. and Delouise, E. R. 1982 Children's blood lead levels in New Haven: a population-based demographic profile, Environ. Health Perspect. 44, 159-164.
QUARTERMAN, J. and Morrison, E. 1978 The effect of age on the absorption and excretion of lead, Environ. Res. 17, 78-83.
RABINOWITZ, M. B., Wetherill, G. W. and Kopple, J. D. 1973 Lead metabolism in the normal human: stable isotope studies, Science 182, 725-727.
RABINOWITZ, M. B., Wetherill, G. W. and Kopple, J. D. 1974 Studies of human lead metabolism by use of stable isotope tracers, Environ.

Health Perspect. 7, 145-153.
RABINOWITZ, M. B., Wetherill, G. W. and Kopple, J. D. 1976 Kinetic analysis of lead metabolism in healthy humans, J. Clin. Invest. 58, 260-270.
RABINOWITZ, M. B., Wetherill, G. W. and Kopple, J. D. 1977 Magnitude of lead intake from respiration by normal man, J. Lab. Clin. Med. 90, 238-248.
RABINOWITZ, M. B., Kopple, J. D., and Wetherill, G. W. 1980 Effect of food intake and fasting on gastrointestinal lead absorption in humans, Am. J. Clin. Nutr. 33, 1784-1788.
RABINOWITZ, M. B. and Needleman, H. L. 1984 Environmental, demographic, and medical factors related to cord blood lead levels, Biol. Trace Elem. Res. 6, 57-67.
RABINOWITZ, M. B., Leviton, A. and Needleman, H. L. 1984 Variability of blood lead concentrations during infancy, Arch. Environ. Health 39, 74-79.
RAMEAU, J. T. L. B. 1972 Lead as an Environmental Pollutant, Proc. Int. Symp. Environ. Health Aspects of Lead, Amsterdam, 189-200.
RATCLIFFE, J. M. 1981 Lead in man and the environment, Ellis Horwood Ltd, Chichester.
REEVES, R., Kjellström, T., Dallow, M. and Mullins, P. 1982 Analysis of lead in blood, paint, soil and house dust for the assessment of human lead exposure in Auckland, N. Z. J. of Sci. 25, 221-227.
REITH, J. F., Engelsman, J. and van Ditmarsch, M. 1974 Lead and zinc contents of food and diets in The Netherlands, Z. Lebensm. Unters. Forsch. 156, 271-278.
RICE, C. Fischbein, A., Lilis, R., Sarkozi, L., Kon. S. and Selikoff, I. J. 1978 Lead contamination in the homes of employees of secondary lead smelters, Environ. Res. 15 375-380.
ROBERTS, T. M., Gizyn, W. and Hutchinson, T. C. 1974a Lead contamination of air, soil, vegetation and people in the vicinity of secondary lead smelters, Trace Subst. Environ. Health VIII, 155-166.
ROBERTS, T. M., Hutchinson, T. C., Paciga, J., Chattopadhyay, A., Jervis, R. E., van Loon, J., Parkinson, D. K. 1974b Lead contamination around secondary smelters: estimation of dispersal and accumulation by humans. Science 186, 1120-1123.
ROBERTS, T. M. 1975 A review of some biological effects of lead emissions from primary and secondary smelters, Proc. Int. Conf. Heavy Metals in the Environ., Toronto, 503-532.
ROCKWAY, S. W., Weber, C. W., Lei, K. Y. and Kemberling, S. R. 1984 Lead concentrations of milk, blood and hair in lactating women, Int. Arch. Occup. Environ. Health 53, 181-187.

ROELS, H. A., Buchet, J. P., Lauwerys, R. R., Bruaux, P., Claeys-Thoreau, F., Lafontaine, A., van Overschelde, J. 1976 Impact of air pollution by lead on the heme biosynthetic pathway in school-age children, Arch. Environ. Health 31, 310-316.
ROELS, H. A., Hubermont, G., Buchet, J. P. and Lauwerys, R. R. 1978a Placental transfer of lead, mercury, cadmium and carbon monoxide in women III, Factors influencing the accumulation of heavy metals in the placenta and the relationship between metal concentration in the placenta and in maternal and cord blood, Environ. Res. 16, 236-247.
ROELS, H. A., Buchet, J. P., Lauwerys, R. R., Bruaux, P., Clayes-Thoreau, F., Lafontaine, A., van Overschelde, J., Verduyn, G. 1978b Lead and cadmium absorption among children near a ferrous metal plant - a follow-up study of a test case, Environ. Res. 15, 290-308.
ROELS, H. A., Buchet, J. P., Lauwerys, R. R., Bruaux, P., Claeys-Thoreau, F., Lafontaine, A., Verduyn, G. 1980 Exposure to lead by the oral and the pulmonary routes of children living in the vicinity of a primary lead smelter, Environ. Res. 22, 81-94.
ROHBOCK, E. 1981 The effect of airborne heavy metals on automobile passengers in Germany, Environ. Int. 5, 133-139.
ROSEN, J. F., Chesney, R. W., Hamstra. A., DeLuca, H. F. and Mahaffey, K. R. 1980 Reduction in 1,25 dihydroxyvitamin D in children with increased lead absorption, New Engl. J. Med. 302, 1128-1131.
ROSMANITH, J., Einbrodt, H. J. and Gordon, Th. 1975a Relationships between emissions of lead and zinc and the levels of lead, zinc and cadmium in blood, urine and hair in children, Zentralbl. Parasitenkd. Infektionskr. Hyg. Abt. 1 Orig. Reihe B. 161, 125-136 (in German).
ROSMANITH, J., Schröder, A., Einbrodt, H. J. and Ehm, W. 1975b Investigation of children living in an industrial area polluted by lead and zinc, Umwelthygiene 9/75, 266-271 (in German).
ROSMANITH, J., Einbrodt, H. J. and Ehm, W. 1976 Interactions between lead, cadmium and zinc in children living in an industrial area, Staub. 36, 55-62 (in German).
ROSMANITH, J., Einbrodt, H. J. and Ehm, W. 1977a On the relationship between cadmium and lead in children with different exposures to cadmium or lead, Zentralbl. Bakteriol. Parasitenkd. Infektionskr. Hyg. Abt. 1 Orig. Reihe B. 165, 207-225 (in German).
ROSMANITH, J., Eberhard, A., Gordon, Th., Greiling, H., Einbrodt, H. J. and Ehm, W. 1977b On the relationships between blood lead, erythrocytes, hemoglobin and age in children living in a small industrial city with low levels of lead pollution, Zentralbl. Bakteriol.

Parasitenkd. Infektionskr. Hyg. Abt. I Orig. Reihe B. 164, 99-110 (in German).
ROSTRON, C. 1982a Are we at risk from lead?, Part I, Fd. Chem. Toxicol. 20, 617-621.
ROSTRON, C. 1982b Are we at risk from lead?, Part II, Fd. Chem. Toxicol. 20, 967-970.
RUTTER, M. 1980 Raised lead levels and impaired cognitive/ behavioral functioning: a review of the evidence, Dev. Med. Child. Neurol. 22, Suppl. 42, 1-26.
RYU, J. E., Ziegler, E. E., Nelson, S. E. and Fomon, S. J. 1983 Dietary intake of lead and blood lead concentration in early infancy, Am. J. Dis. Child. 137, 886-891.
SALTZMAN, B. E., Yeager, D. W. and Meiners, B. G. 1983 Reproducibility and quality control in the analysis of biological samples for lead and mercury, Am. Ind. Hyg. Assoc. J. 44, 263-267.
SARTOR, F. and Rondia, D. 1980 Blood lead levels and age: a study in two male urban populations not occupationally exposed, Arch. Environ. Health 35, 110-116.
SARTOR, F. and Rondia D. 1981 Setting legislative norms for environmental lead exposure: results of an epidemiological survey in the east of Belgium, Toxicol. Lett. 7, 251-257.
SARTOR, F., van Beneden, P. and Rondia, D. 1981 Water lead concentrations and measurements of health risks in a soft water drinking area, Proc. Int. Conf. Heavy Metals in the Environ., Amsterdam, 39-43.
SARTOR, F., Manuel, Y., Rondia, D. and Geubelle, F. 1983 Possible minimal renal dysfunctions, impairment of the heme biosynthetic pathway and blood lead levels in children in a soft water area, Proc. Int. Conf. Heavy Metals in the Environ., Heidelberg, 425.
SAYRE, J. W., Charney, E., Vostal, J. and Pless, I. B. 1974 House and hand dust as a potential source of childhood lead exposure, Am. J. Dis. Child. 127, 167-170.
SCHAFFNER, R. M. 1981 Lead in canned foods, Food Technol., December, 60-64.
SCHALLER, K. H., Schiele, R., Weltle, D., Krause, C. and Valentin, H. 1976 Blood lead levels in mothers and children in different areas, Int. Arch. Occup. Environ. Health 37, 265-276 (in German).
SCHELENZ, R. and Boppel, B. 1982 Changes in the content of arsenic, lead, cadmium and mercury during food preparation, Landwirts Forschung Sonderheft 39, 342-352 (in German).
SCHMITT, N., Philion, J. J., Larsen, A. A., Harnadek, M. and Lynch, A. J. 1979 Surface soil as a potential source of lead exposure for young children, Can. Med. Assoc. J. 121, 1474-1478.

SCHROEDER, H. A. and Tipton, I. H. 1968 The human body burden of lead, Arch. Environ. Health 17, 965-978.
SCOKART, P. O., Meeus Verdinne, K. and de Borger, R. 1983 Mobility of heavy metals in polluted soils near zinc smelters, Water, Air and Soil Pollut. 20, 451-463.
SEIFERT, B., Drews, M. and Aurand, K. 1984 Indoor heavy metal exposure of the population around a secondary lead smelter, Proc. Indoor Air 1984 2, 177-182.
SHAPER, A. G., Pocock, S. J., Walker, M., Wale, C. J., Clayton, B., Delves, H. T. and Hinks, L. 1982 Effects of alcohol and smoking on blood lead in middle aged British men, Brit. Med. J. 284, 299-302.
SHARRETT, A. R., Carter, A. P., Orheim, R. M. and Feinleib, M. 1982a Daily intake of lead, cadmium, copper and zinc from drinking water: the Seattle study of trace metal exposure, Environ. Res. 28, 456-475.
SHARRETT, A. R., Orheim, R. M. Carter, A. P., Hyde, J. E. and Feinleib, M. 1982b Components of variation in lead, cadmium, copper and zinc concentration in home drinking water: the Seattle study of trace metal exposure, Environ. Res. 28, 476-498.
SHELLSHEAR, I. D., Jordan, L. D., Hogan, D. J. and Shannon, F. T. 1975 Environmental lead exposure in Christchurch children: soil lead a potential hazard, N. Z. Med. J. 81, 382-386.
SHERLOCK, J. C. 1983 Heavy metal intakes by critical groups, Proc. Int. Conf. Heavy Metals in the Environ., Heidelberg, 269-273.
SHERLOCK, J. C., Smart, G. A., Walters, B., Evans, W. H., McWeeny, D. J. and Cassidy, W. 1983 Dietary surveys on a population at Shipham, Somerset, United Kingdom, Sci. Total Environ. 29, 121-142.
SMART, G. A., Warrington, M. and Evans, W. H. 1981 The contribution of lead in water to dietary lead intakes, J. Sci. Food Agric. 32, 129-133.
SMART, G. A., Warrinton, M., Dellar, D. and Sherlock, J. C. 1983 Specific factors affecting lead uptake by food from cooking water, J. Sci. Food Agric. 34, 627-637.
SNEDECOR, G. W. and Cochran, W. G. 1967 Statistical Methods, Iowa State University Press, Ames, Iowa, 6th edition.
SNEE, R. D. 1981 Evaluation of studies of the relationship between blood lead and air lead, Int. Arch. Occup. Environ. Health 48, 219-242.
SNEE, R. D. 1982 Silver Valley lead study: further analysis of the relationship between blood lead and air lead, J. Air Pollut. Contr. Assoc. 32, 170-175.
SOLOMON, R. L. and Hartford, J. W. 1976 Lead and cadmium in dusts and soils in a small urban community, Environ. Sci. Technol. 10,

773-777.
STARK, A. D., Meigs, J. W., Quah, R. F. and De Louise, E. R. 1978 Family operational cofactors in the epidemiology of childhood lead poisoning, Arch. Environ. Health 33, 222-225.
STARK, A. D., Quah, R. F., Meigs, J. W., and De Louise, E. R. 1982a Relationship of sociodemographic factors to blood lead concentrations in New Haven children, J. Epidemiol. Comm. Health 36, 133-139.
STARK, A. D., Quah, R. F., Meigs, J. W., and De Louise, E. R. 1982b The relationship of environmental lead to blood lead levels in children, Environ. Res. 27, 372-383.
STEBBINGS, J. H. 1981 Epidemiology, public health and health surveillance around point sources of pollution, Environ. Res. 25, 1-7.
STEINNES, E. 1983 Contamination of surface soils by heavy metals from air pollution: significance of long-distance atmospheric transport, Proc. Int. Conf. Heavy Metals in the Environ., Heidelberg, 1170-1173.
STINETT, S. S., Buffler, P. A. and Eifler, C. W. 1981 A case-control method for assessing environmental risks from multiple industrial point sources, Environ. Res. 25, 62-74.
STOLLEY, H., Kersting, M. and Droese, W. 1981 Trace element and heavy metal intake with food in 2-14 year old children, Monatschr. Kinderheilkd. 129, 233-238 (in German).
STREHLOW, C. D. and Barltrop, D. 1982 Nutritional status and lead exposure in a multiracial population, Trace Subst. Environ. Health XVI, 40-47.
TASKINEN, H., Nordman, H. and Hernberg, S. 1981 Blood lead levels in Finnish pre-school children, Sci. Total Environ. 20, 117-129.
TER HAAR, G. and Aronow, R. 1974 New information on lead in dirt and dust as related to the childhood lead problem, Environ. Health Perspect. 7, 83-89.
TER HAAR, G. and Chadzynski, L. 1979 An investigation of elevated blood lead levels in Detroit children, Arch. Environ. Health 34, 145-150.
THOMAS, H. F., Elwood, P. C., Welsby, E. and St Leger, A. S. 1979 Relationship of blood lead in women and children to domestic water lead, Nature 282, 712-713.
THOMAS, H. F. 1980 Domestic water usage and blood lead levels, Publ. Health London 94, 294-295.
THOMAS, H. F., Elwood, P. C., Toothill, C. and Morton, M. 1981 Blood and water lead in a hard water area, Lancet i, 1047-1048.
TOSTESON, T. D., Spengler, J. D. and Weker, R. A. 1982 Aluminium, iron and lead content of respirable particulate samples from a

personal monitoring study, Environ. Int. 8, 265-268.
TSUCHIYA, H., Mitani, K., Kodama, K. and Nakata, T. 1984 Placental transfer of heavy metals in normal pregnant Japanese women, Arch. Environ. Health 39, 11-17.
VAHTER, M. (Ed.) 1982 Assessment of human exposure to lead and cadmium through biological monitoring, Karolinska Inst. Stockholm.
VOSTAL, J. J., Taves, E., Sayre, J. W. and Charney, E. 1974 Lead analysis of house dust: a method for the detection of another source of lead exposure in inner city children, Environ. Health Perspect. 7, 91-97.
WAGNER, V., Wagnerova, M., Wokounova, D., Kriz, J., Madlo, Z., Mohyla, O. 1981 Correlations between blood lead concentrations and some blood protein levels in children residing in lead polluted and control areas, J. Hyg. Epidem. Microb. Immunol. 25, 97-112.
WALTER, S. D., Yankel, A. J. and Lindern, I. H. 1980 Age specific risk factors for lead absorption in children, Arch. Environ. Health 35, 53-58.
WATSON, W. N., Witherell, L. E. and Giguere, G. C. 1978 Increased lead absorption in children of workers in a lead storage battery plant, J. Occup. Med. 20, 759-761.
WATSON, W. S., Hume, R. and Moore, M. R. 1980 Oral absorption of lead and iron, Lancet ii, 236-237.
WEDDING, J. B., McFarland, A. R. and Cermak, J. E. 1977 Large particle collection characteristics of ambient aerosol samplers, Environ. Sci. Technol. 11, 387-390.
WHO 1977a Environmental Health Criteria 3: Lead, Geneva.
WHO 1977b Environmental Health Criteria 4: Oxides of nitrogen, Geneva.
WHO 1978 Environmental Health Criteria 8: Sulfur oxides and suspended particulate matter, Geneva.
WIBOWO, A. A. E., del Castilho, P. and Zielhuis, R. L. 1977 Smoking habits and blood lead levels, Tijdschr. Soc. Geneesk. 55, 287-288 (in Dutch).
WIGLE, D. T. and Charlebois, E. J. 1978 Electric kettles as a source of human lead exposure, Arch. Environ. Health 33, 72-78.
de WIJN, J. F. and van Staveren, W. A. 1980 Everyday food, Bohn, Scheltema and Holkema, Utrecht (in Dutch).
WINNEKE, G., Hrdina, K. G. and Brockhaus, A. 1982 Neuropsychological studies in children with elevated tooth lead concentrations, I Pilot study, Int. Arch. Occup. Environ. Health 5, 169-183.
WINNEKE, G., Krämer, U., Brockhaus, A., Ewers, U., Kujanek, G., Lechner, H., Janke, W. 1983 Neuropsychological studies in children

with elevated tooth lead concentrations, II Extended study, Int. Arch. Occup. Environ. Health 51, 231-252.
WOIDICH, H. and Pfannhauser, W. 1980 Trace elements in infant foods: arsenic, lead, cadmium, Z. Lebensm. Untersuch. Forsch. 170, 95-98 (in German).
YANKEL, A. J., Lindern, I. H. and Walter, S. D. 1977 The Silver Valley lead study: the relationship between childhood blood lead levels and environmental exposure, J. Air Pollut. Contr. Assoc. 27, 763-767.
YULE, W., Landsdown, R., Millar, I. B. and Urbanowicz, M. A. 1981 The relationship between blood lead concentrations, intelligence and attainment in a school population: a pilot study, Dev. Med. Child. Neurol. 23, 567-576.
ZAREMBSKI, P. M., Griffiths, P. D., Walker, J. and Goodall, K. B. 1983 Lead in neonates and mothers, Clin. Chim. Acta. 134, 35-49.
ZIEGLER, E. E., Edwards, B. B., Jensen, R. L., Mahaffey, K. R. and Fomon, S. J. 1978 Absorption and retention of lead by infants, Pediatr. Res. 12, 29-34.
ZIELHUIS, R. L. 1974 Biological quality guide for inorganic lead, Int. Ach. Arbeitsmed. 32, 103-127.
ZIELHUIS, R. L. 1975 Dose response relationships for inorganic lead, Int. Arch. Occup. Health 35, 1-18, 19-35.
ZIELHUIS, R. L. and Wibowo, A. A. E. 1978 The health significance of the concentration of lead in blood, Ned. Tijdschr. Geneesk. 122, 793-798 (in Dutch).
ZIELHUIS, R. L., del Castilho, P., Herber, R. F. M., Wibowo, A. A. E. and Salle, H. J. A. 1979 Concentrations of lead and other metals in blood of two and three year old children living near a secondary smelter, Int. Arch. Occup. Environ. Health 42, 231-239.
ZIELHUIS, R. L. 1981 Exposure limits to metals for the general population, Proc. Int. Conf. Heavy Metals in the Environ., Amsterdam, 429-439.
ZIELHUIS, R. L. 1984 Removal of lead from petrol?, Ned. Tijdschr. Geneesk. 128, 1662-1666 (in Dutch).
ZWENNIS, W. C. M. 1984 Interlaboratory comparison of the quality of the analysis of lead and cadmium in blood, Medical Biological Laboratory/TNO Rijswijk. Report No. 1984-9 (in Dutch).

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