ENVIRONMENTAL LEAD EXPOSURE IN FINLAND

A study on selected population groups

by

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Academic dissertation

To be publicly discussed, by permission of the Medical Faculty of the University of Helsinki, in Auditorium XII on May 29, 1975, at 12 o'clock noon.

Helsinki 1975

ISBN 951-99053-6-7

Helsingin yliopiston monistuspalvelu

1975

ABBREVIATIONS

Pb-B	Blood lead concentration
Pb-U	Urinary lead concentration
Pb-H	Lead content in hair
Pb-A	Concentration of air-suspended particulate lead
ALAD	Erythrocyte δ-aminolevulinic acid dehydratase
ALA-U	Urinary δ-aminolevulinic acid concentration
CP-U	Urinary coproporphyrin concentration
PBG	Porphobilinogen
Hb	Hemoglobin concentration
PCV	Packed blood cell volume
RBC	Red blood cells
EDTA	Ethylenediamine tetra-acetate

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in the areas of epidemiology and toxicology. Thus, lead poisoning affecting children in the U.S.A. has introduced what is probably the most urgent problem in regard to the health hazards of lead. An association between pica and lead poisoning in children was reported by Ruddock as early as in 1924. It has now been established that the ingestion of flaking paints, crumbling plaster, and putty with a lead content induces the clinical poisoning of children living in decaying building. Only the case-finding campaigns conducted in some American cities have revealed the tragic extensiveness of childhood poisoning. It has been stated that between 1 to 2 percent of the slum-dwelling children in New York and Chicago have unsuspented lead poisoning (Chisolm 1971, Guinee 1971). According to an estimate, the concentration of lead in the blood of some 250,000 children annually exceeds safe limits (Moore 1970).

By now, it has become common knowledge that environmental lead pollution has been increasing during the entire period of industrialization, and that this is a result of neglect in the supervision of industrial discharges, and the outcome of decomposition of industrial products (NAS 1972, WHO 1973 ; Waldron and Stöfen 1974). Most of the increase has been attributed to the combustion products of lead alkyls, used as anti-knock additives in gasoline (NAS 1972, WHO 1973, Waldron and Stöfen 1974). The lead content of the atmosphere in several metropolitan areas has increased to a level that is high enough to affect the absorption of lead by the inhabitants and especially those who are exposed to exhaust gas (Hofreuter et al. 1961, Ludwig et al. 1965, Thomas et al. 1967, Horiuchi 1970, Lehnert et al. 1970). It has similarly been shown that primary and secondary lead smelteries may subject the surrounding population to lead exposure which markedly exceeds that affecting the population in general, resulting in increased lead absorption (Oyanguren and Perez 1966, Djurič et al. 1971, 1972, Nordman et al. 1973, Kerin Z 1974, Martin et al. 1974).

1. INTRODUCTION

1.1. Today's lead problem

From the historical standpoint, it is probable that Nicander has the best claim to the discovery of a causal connection between lead and the symptoms of lead poisoning in the second century B.C. Although this honor has often been credited to Hippocrates (370 B.C.) (Aub 1926, Hunter 1969) this has been disputed by students of the medical history of lead (Waldron 1973). In the first century A.D., Pliny noted that lead poisoning frequently occurred among shipbuilders; in the sixteenth century, Paracelsus termed lead poisoning "the miners' disease", and in 1839 Tanquerel des Planches published an excellent study on 1200 cases of the disease (Hunter 1969). During the second half of the nineteenth century, and the first decades of the twentieth, the incidence of occupational lead poisoning was extremely high, and a fatal outcome of such poisoning was no rarity (WHO 1973, Hernberg 1975). Considerable improvements in hygienic conditions in industry have brought about a change in the character of occupational lead poisoning, despite the continuously increasing industrial use of lead; nowadays, cases are seldom severe, and the incidence has decreased significantly (Hernberg 1975).

One is traditionally apt to associate lead with the conception of manifest lead poisoning, usually of occupational origin. Although the significance of lead as an occupational poison is still accorded major importance, since the mid-sixties both the directing of research and scientific discussions concerned with the health implications of lead have been increasingly dominated by aspects of public health. This has been the consequence of extensive studies relating to environmental pollution, along with the progress made berg and Nikkanen 1970, Stuik 1974, Seppäläinen et al. 1975). To date, the significance of these subclinical effects to man's health is unknown. Nevertheless, the governments of several countries, including West Germany and Sweden, have already decided substantially to lower the maximum content of lead in gasoline with a view to reducing the environmental exposure (Campell 1973).

Consequently, the current situation is more complicated than ever; although the significance of the subclinical effects of lead to man's health is still obscure, the presence of such responses must, from the standpoint of public health, be considered as undesirable for as long as they have not been proven un-deleterious. For protection of the most susceptible individuals of the community, those groups of the general population which may be subjected to undue environmental exposure should be monitored, and the total exposure of these risk groups determined by the employment of screening measures that are as sensitive as possible.

2. LITERATURE REVIEW

2.1. Natural sources of lead exposure

Lead, a ubiquitously-distributed metal, has always been present at natural levels, that is at levels unaffected by man's activities. The average lead content in the earth's crust is about 16 mg/kg, with a variation from 6 to 20 mg/kg depending on the type of substance. Soils also have a content of about 16 mg/kg (de Treville 1964). The ubiquity of lead further entails its presence in the atmosphere, the sources being: silicate dust from natural soils, volcanic halogen aerosols, volcanic silicate smoke, forest fire smoke, aerosolic sea salts and meteoric smoke (Pattersson 1965). According to Pattersson's estimates, the contribution from these natural sources results in an average concentration in the air of

The detection of a number of subclinical lead-induced effects has also made a significant contribution to making attitudes more oriented towards the domains of public health. The development of more sensitive techniques has enabled the detection of subclinical neuropathy, even when the Pb-B has never exceeded the commonly applied safety limits in industry (Seppäläinen et al. 1975). The partial inhibition of ALAD activity has been demonstrated at blood--lead levels that are characteristic of the general population (Hernberg and Nikkanen 1970, Secchi et al. 1971, Lauwerys et al. 1973, Nordman et al. 1973). The significance of the partial inhibition of erythrocyte ALAD activity is unknown. Several authorities have regarded it as unimportant to health (Kehoe 1971, Zielhuis 1974); nevertheless, it has been demonstrated that the inhibition of erythrocyte ALAD activity correlates with a corresponding inhibition of the ALAD activity in other animal and human tissues, such as liver, brain, kidney and bone marrow (Gibson and Goldberg 1970, Millar et al. 1970, Secchi et al. 1974). Recent reports have indicated that the accumulation of protoporphyrin IX in erythrocytes begins at Pb-B levels as low as 25 to 30 µg/100 ml in women, and have further evidenced that women have a higher susceptibility to lead than have men in regard to protoporphyrin IX (Stuik and Zielhuis 1974, Stuik 1974, Roels et al. 1975).

Briefly, it may be said that the changed attitude towards lead problems arises from the circumstance that several groups of the general population are known to be exposed to environmental lead levels that raise the amount absorbed. However, no agreement has been reached as regards either the concentration of lead in blood which can be considered as acceptable for the general population (EPA 1972, Zielhuis 1974, Waldron 1974), or the concentration of lead in the ambient air at which the lead absorption begins to rise (EPA 1972, Tepper and Levin 1972). New and more sensitive methods have disclosed responses to low lead concentrations formerly regarded as consistent with a non-effect apprehension (Hernin 1923; since then, the use of alkyl lead additives has undergone an explosive increase, as is evident from the calculations of Murozumi and his colleagues, who estimated a combustion of alkyl lead compounds in the Northern hemisphere in 1933 of about 10.000 tons, against some 300.000 tons in 1966 (Murozumi et al. 1969). The lead alkyls are responsible for an approximative 98% of the total lead emissions in the U.S.A. (NAS 1972). The pollution resulting from lead alkyls is even reflected in a rise in the lead content of the icecaps of Greenland (Murozumi et al.1969). The air is cleaned by gravity, aggregation and precipitation, with rain acting as the main cleaner and thus contributing to the lead content of waters and soil. Accumulation takes place in plants, particularly in the leafy portions. This implies that leafy vegetables thereby provide lead with an opportunity to enter herbivorous animals and man (NAS 1972, Hernberg 1975). Most investigators claim that lead in the soil is taken up by plants only in an extremely small proportion, and that the chief source for uptake by plants is rainfall (NAS 1972). It follows from this that exceptional concentrations of lead in the air, in water and in food may be found in certain areas which are subjected to high traffic-density or industrial emission. Some conditions may enhance the exposure of food and water, such as the use of lead piping and lead-lined tanks, which may contaminate tap-water to even a dangerous extent (Bacon et al. 1967, Beattie et al. 1972 b); furthermore, the firing of earthenware qlaze at temperatures that are too low may allow of the release of lead into acidic foods and beverages, and constitute an important hazard to the public health (Harris and Elsea 1967, Klein et al. 1970, Ylikahri and Toivonen 1973). The production of illicit whiskey, with leaded soldering or discarded automobile radiators utilized as condensers, has caused a great deal of concern, especially in the U.S.A. (Hughes 1966, Palmisano et al. 1969, NAS 1972). Flaking paints, perishing plaster, and the putty found in decaying buildings, make up a pediatric problem of vast dimensions in the U.S.A., where in several states the legislation pertaining

0.0005 - 0.0006 μg/m^3, and in surface waters of around 0.0005 mg/kg. These estimated figures gain support from investigators of marine and arctic atmospheres (Egorov et al. 1970, Murozumi et al. 1969, Chow et al. 1969) and from studies of the lead content of ice sheets in the Northern polar regions (Murozumi et al. 1969) and deep waters of the Mediterranean and the Pacific (Tatsumoto and Patterson 1963, Chow and Patterson 1966). However, in a man-made environment the contribution from natural sources is so minimal that it lacks importance.

2.2. Man-made sources of lead exposure

In this context, no full account needs to be given of the sources of exposure; these have been reviewed in a number of exhaustive monographs in recent years (Ziegfeld 1964, NAS 1972, WHO 1973, Waldron and Stöfen 1974, Hernberg 1975), and only the most pertinent of these will be touched upon here. Man's total exposure is constituted by a background exposure derived from air, food and water, which is dependent upon geographic, socioeconomic and other factors, and a probable additional exposure arising from occupation, or from the ingestion of substances with a lead content. Ambient air, soil and water are polluted as a consequence of industrial activity, through both manufacturing processes and the decomposition of industrial products. Fly-ash from the burning of coal in power stations, steel works and factories contains up to approximately 5 per cent of particles a few microns in diameter. These have a lead content of about 100 mg/kg (Pattersson 1965). It is well known that the emission from lead-processing industrial undertakings such as secondary lead smelting plants, storage battery plants, and even tetraethyl-lead manufacturing plants, pollutes the surrounding air, watercourses and soil(WHO 1973). Of all industrial products, the alkyl lead compounds are regarded as being the most important in regard to environmental pollution. Tetraethyl lead was introduced as an antiknock agent very high, and may exceed 20 μg/m^3 (Ludwig et al. 1965, Horiuchi 1970). Lead concentrations even higher than this have been measured in the surroundings of primary and secondary lead smelters (Fugas et al. 1972, Martin et al. 1974). Unfortunately, the results reported by different authors are not easily comparable, since great differences exist between the kinds of sampling equipment , the procedures of sampling, and the analytical methods used. The first step towards international standardization of air sampling techniques has been taken by the Commission of the European Communities (CEC 1972).

Although the lead concentrations that prevail at many work places are often substantially higher than those in outdoor air,the problem involved is not comparable to that arising from outdoor air, pollution, as it concerns only healthy adults who are exposed for 40 hours weekly; exposure for the general population, however, is *continuous* and also concerns pregnant women, children, old people and disabled persons. Nevertheless, occupational exposure represents an additional load for many people.

2.3.2. Lead in drinking water

As a rule, the daily intake from water is very much lower than that from food (NAS 1972). The acceptable limit for lead content in drinking water has been fixed, by both WHO (Geneva 1963) and the US Public Health Services, at 50 μg/l. Although most of the values reported have been below this limit (McCabe et al. 1970, WHO 1973), extremely high values have also been established; these have even resulted in manifest lead poisoning (Gajdos and Gajdos-Török 1972, Beattie et al. 1972 a, Bacon et al. 1967, Heusgem and De Graeve 1972).

The hazards to health that arise from drinking domestic water contaminated by lead have resulted in serious debate, especially in to the use of lead-pigment indoor paints has been defective down to the nineteen-seventies (NAS 1972). The use of indoor paints with a lead content exceeding 2% was prohibited in Finland in 1929. Finally, the extensive use of lead in industry subjects a large proportion of industrial workers to occupational exposure. The degree of exposure is largely dependent upon the nature of the process, the elimination techniques applied, and the general hygienic conditions of the workplace. It has recently been estimated that approximately 500 to 1,000 workers in Finland are continuously exposed to the risk of occupational lead poisoning; moreover, by law, an additional 20,000 workers should receive regular health examinations by reason of exposure to lead (Tola and Hernberg 1975).

In the assessment of man's total lead exposure, each of the sources of exposure must be taken into account, and it has to be borne in mind that exposure to one of the sources may decrease the level of tolerance to another source.

2.3. Environmental exposure levels

2.3.1. Lead in ambient air

On repeated occasions, it has been demonstrated that the concentration of lead in ambient air correlates with traffic density (NAS 1972, WHO 1973). For the most part, rural monthly and annual concentrations are well below 0.5 $\mu g/m^3$ (Jost et al. 1972, CEC 1972, Tepper and Levin 1972). The yearly and monthly means in residential areas of small and medium-sized cities in the U.S.A., and also in Europe, are usually around 1 $\mu g/m^3$; in large cities, the figures are from 1 to 2 $\mu g/m^3$, and rarely exceed 3 $\mu g/m^3$, as for instance in Los Angeles (Ludwig et al. 1965, Horiuchi 1970, Tepper and Levin 1972, Fugas et al. 1972, CEC 1972, NAS 1972, Chovin et al. 1972). Short time values in busy metropolitan areas are often values calculated for Japanese adults have amounted to about 230 to 320 μg (Horiuchi 1970). A common and conspicuous feature of these reports is the wide range indicated. Wide variations occur in the methods of sampling and in the analytical methods, with consequent reduction in the reliability of any intercomparison between results.

For natural reasons, plants are exposed to airborne lead pollution. Although it would seem that airborne lead could make only a slight contribution to the edible portions of most plants that grow in the immediate proximity of highways, the content of the leafy portions of plants is strongly correlated to the concentrations of lead in air (NAS 1972). From the aspect of human exposure, leafy vegetables growing in polluted areas are of particular importance, but it has been shown that roughly 50% of the lead is removable from the leafy portions by washing (NAS 1972). High values for lead content have been found in plants growing in areas of exceptional lead contamination resulting from lead mining and refining (Goodman and Roberts 1971, Djurič et al. 1971, Kerin 1971).

No enrichment of lead occurs in the food chains of practical importance to man, and no clear pattern can be derived from available studies in regard to which kinds of food have the highest lead content. Fresh meat, fruit, vegetables, and canned or bottled foods have displayed rather high levels of lead content, although these have only rarely exceeded 1.0 mg/kg (Lehnert et al. 1969, Horiuchi 1970, Tolan and Elton 1972). Milk deserves special attention, by virtue of its making up a large proportion of infants' diet. Several investigators have reported considerably higher levels of lead in canned milk products than those in human breast or cow milk (Lamm et al. 1973, Mitchell and Aldous 1974). Lead in breast milk may be of importance if the mother is subjected to occupational lead exposure; the elevated blood-lead level will as a consequence increase both the prenatal exposure and the lead excretion via milk (Task Group on Metal Accumulation 1973). Breast milk seems

Great Britain, where lead piping is common in many residential districts. Furthermore, it has been shown that the acidity and the salinity of water influence the degree of plumbosolvency. Thus, evidence exists that soft water with a low pH, i.e. below 7.8, displays a higher lead content in over-night tap-water than does hard water of less acidity (Anonymous 1967, Wilson 1966,1967, Reed and Tolley 1967, Crawford and Morris 1967, Heusgem et De Graeve 1972, Goldberg 1974, Hem et Durum 1973). Few data indicate any kind of chemical transformation of lead in water which would correspond to the methylation of mercury, for instance. Nevertheless, a recent study implies that micro-orgamisms in lake sediments are capable of transforming certain lead compounds into a volatile tetramethyl lead (Wong et al. 1975).

2.3.3. Lead in food

Food is usually the most important contributor to the total lead exposure of the general population. The results obtained from studies of the lead content in food have shown broad variations, even as far as the same foodstuffs are concerned (Kehoe 1961 a, Schroeder and Balassa 1961, Lehnert et al. 1969, Horiuchi 1970). For the total intake of food Kehoe (1961 a) arrived at an estimate of about 300 µg/day, and has gained support from calculations made by Harley (1970). In contrast to these studies, Tepper and Levin (1972) calculated a mean of about 100 µg/day only, for American adult women. A recent report from the U.S.A., moreover, has suggested an intermediate value of 159 to 233 µg (Kolbye et al. 1974). Lehnert and his colleagues (1969) have calculated a mean uptake of 518 µg Pb/day for West-Germany (DBR) , and Vigliani and Zurlo (1968) arrived at an estimate of 400-500 µg for Milan. Thompson (1971) has reported a range of 70-750 µg, and an average of 274 µg in five persons from the United Kingdom; this is not far from the average of 220 µg derived in Great Britain, by the application of quite a different method (Tolan and Elton 1972). The

8 percent. This figure is supported by more recent studies made by means of stable isotope tracers (Rabinowitz et al. 1974), although allowance must be made for the wide range of absorption rates reported by some investigators (Hursh and Suomela 1968, Harrison et al. 1969). The absorption is, furthermore, known to be dependent upon several dietary factors; it is, for example, increased by a high protein content (Milev et al. 1970), a low content of calcium and iron (Shields and Mitchell 1941, Six and Goyer 1970, 1972), and a low content of phosphorus (Goyer and Mahaffey 1972).

2.4.2. Distribution

Lead is distributed by the blood stream where about 95 percent of it is bound to the erythrocytes; only a small fraction remains in the plasma. Of the total content of lead in man, about 90 percent is bound to bone. Teeth have the highest concentrations, and long bones contain more lead than do flat ones (Schroeder and Tipton 1968, Barry and Mossman 1970). In part, bone lead is firmly bound, with the probable indication of old deposits, and in part more exchangeable, indicating comparatively recent deposits; the latter may contribute to the biologically active pool of the body burden (Task Group on Metal Accumulation 1973). In regard to the soft tissues, the aorta, liver and kidney exhibit the highest concentrations (Schroeder and Tipton 1968, Barry and Mossman 1970). The concept of a higher susceptibility of the fetus to lead is widespread. The transplacental transfer of lead is well documented (Kehoe et al. 1933, Horiuchi et al. 1966, Harris and Holley 1972, Haas et al. 1972). Haas and his coworkers (1972) found no more than small differences between maternal (16.9 µg/100 ml) and fetal (15.0 µg/100 ml) blood lead levels in a series of 294 sets. The transplacental passage should be taken into account when biological standards are being developed for lead. Lead also passes the blood-brain barrier, although it does not accumulate in the to hold a lead content of about 0.01 - 0.02 µg/g under "normal" circumstances (Murthy and Rhea 1971, Lamm et al. 1973).

It has been reported that the lead content of wine ranges from 0.05 to 0.4 µg/ml (Zurlo and Griffini 1972, Truhaut et al. 1964, Gounelle et al. 1967). This may be of importance in the scrutiny of the differences reported in Pb-B levels from wine-drinking countries (see section 2.5.1.).

2.4. Metabolism of lead in Man

2.4.1. Absorption

Absorption occurs through the respiratory and the gastrointestinal routes; in the lungs, absorption is dependent upon the deposition, mucociliary clearance and alveolar clearance (Task Group on Lung Dynamics 1966). Deposition is dependent upon the particle size and respiratory volume. Maximal deposition takes place at a particle size of 1 µm at a respiratory rate of 10 per minute. Forced respiration diminishes deposition (Nozaki 1966). Through mucociliary clearance, particles, especially large ones, are transported to the pharynx and swallowed (Task Group on Lung Dynamics 1966). The total absorption through lungs amounts to some 30-40 percent (Mehani 1966, Kehoe 1961b,Nozaki 1966). In reality, there are probably even greater variations of absorption in the general population, provided that the shape of particles present in ambient air is taken properly into account (Lawther et al. 1972 a,b).

For the general population,the absorption from the gastrointestinal tract is of major importance, since food constitutes the chief source of lead exposure. An absorption of about 10 percent has been rather widely accepted. To judge from the review by Karhausen(1972) , a more appropriate value of absorption would be around

2.5.1. Lead in blood

According to Pattersson's estimate of man's natural lead concentration in the blood of about 0.25 µg/100 ml (1965), the man-made environment has induced an increase ranging from 50 - 100 fold in the Pb-B levels. A great deal of data is available on the blood lead levels of the general population. By far the major proportion of these studies have reported that the Pb-B mean values for occupationally unexposed, rural and urban, populations range from 10 to 25 µg/100 ml (Hofreuter et al. 1961, Butt et al. 1964, Ludwig et al. 1965, Holmqvist 1966, Lehnert et al. 1967, Goldwater and Hoover 1967, Lehnert et al. 1970, Horiuchi 1970, Haeger-Aronsen 1971, Tepper and Levin 1972, McLaughlin et al. 1973, McLaughlin and Stopps 1973, Tsuchiya et al. 1974). Studies relating to similar population groups from Northern Italy have consistently disclosed somewhat higher mean values, ranging from 24 to 35 µg/100 ml (Zurlo et al. 1970, Secchi et al. 1971, Secchi and Alessio 1974). Haeger-Aronsen (1971) reported a mean value of only 8.5 µg/100 ml for 50 women from Southern Sweden. In contrast, relatively high mean values have been reported for both Finnish rural (24 µg/100 ml) and urban (28 µg/100 ml) population groups (Goldwater and Hoover 1967); however, this study was marked by methodological deficiencies.

As a rule, the Pb-B levels of urban populations, and of people heavily exposed to exhaust gas, have been found higher than those of rural populations (Hofreuter et al. 1961, Ludwig et al. 1965, Thomas et al. 1967, Lehnert et al. 1970, Horiuchi 1970, Secchi et al. 1971, Waldron 1975). An increased lead absorption has also been recorded in people living in the vicinity of lead smelters (Secchi et al. 1971, Nordman et al. 1973, Martin et al. 1974).

No association has been established between Pb-B levels and age (NAS 1972). The influence of cigarette smoking is not fully evaluated; some researchers have reported higher Pb-B levels for smokers than those for non-smokers (Hofreuter et al. 1961, Ludwig brain to any large extent (Schroeder and Tipton 1968, Klein et al. 1970, Barry and Mossman 1970).

2.4.3. Excretion

Lead is eliminated extremely slowly from the organism, and probably has a biological half-time approximating ten years (Hernberg 1975). The renal and the gastrointestinal excretion routes are the two most important. Gastrointestinal excretion occurs through secretion or the loss of lead from various glands, the loss by shedding of epithelial cells, and through biliary excretion (Task Group on Metal Accumulation 1973). Renal excretion occurs by glomerular filtration. Vostal (1963) has suggested the existence of tubular reabsorption.

Minute amounts of lead are also excreted in milk, sweat, hair, nails, and desquamating epithelium. From the standpoint of lead balance within the organism, these can be ignored, although the importance of lead excretion via the milk fed to the sucklings of mothers subjected to occupational exposure has already been emphasized (section 2.3.3.).

2.5. Concentrations of lead in human tissues

Schroeder and his colleagues have made extensive studies of the lead content of various human tissues (Schroeder and Balassa 1961, Tipton et al. 1963, 1965, Tipton and Cook 1963, Tipton and Shaefer 1964, Schroeder and Tipton 1968). Their results have been corroborated by other investigators (Barry and Mossman 1970, Horiuchi 1970). As only the lead in the blood and hair is pertinent within the compass of a population study of the present type, the review of the literature has been confined to these, with emphasis on the lead in blood.

2.5.2. Lead in hair

As hair is a biopsy material available atraumatically a number of researchers have subjected it to analysis for lead (Schroeder and Nason 1969). Hair is known to contain rather high concentrations of lead. The content seems to reflect total environmental exposure, when judgement is based upon the differences found between lead in the hair of urban and rural populations (Hammer et al. 1971, 1972, Klevay and Forks 1973). Some studies have shown that lead in the hair is higher in subjects who are occupationally exposed to lead (Hasegawa et al. 1971, El-Dakhakhny et El-Sadik 1972), and in lead-intoxicated children (Kopito et al. 1967, 1969).

2.6. Parameters reflecting lead absorption

Most investigators have accepted the concept that body lead deposits differ with regard to stability. Thus, distinctions are drawn between pools of easily exchangeable lead (blood, internal organs) intermediate exchangeable (muscle, skin), and slow exchangeable lead (bone)(Bolanowska et al. 1963, Pietrowski 1970, Zielhuis 1972). As no direct method exists for measurements of the total body burden of living persons we are forced to employ indirect assays for that purpose. There is no doubt that lead in the blood best describes the total exposure for a population group (Zielhuis 1974), but it fails to measure the total body burden. Nevertheless, it correlates well with the rapidly exchanging lead pool which has also been called the biologically available lead (Zielhuis 1974). Lead in urine has often been employed in epidemiologic studies; however, this measurement offers no advantage over Pb-B,as urinary lead is in fact excreted through glomerular filtration, and thus merely reflects the level of lead in the blood.

The biologically available lead appears to be even more accurately reflected by the urinary excretion of lead and heme precursors et al. 1965, Tepper and Levin 1972), while others have been unable to confirm such an association (Lehnert et al. 1967, Jones et al. 1972, McLaughlin and Stopps 1973). No doubt, most brands of cigarette contain lead to a varying degree (Cogbill and Hubbs 1957, Lehnert et al. 1967). Probably, the amount is connected with the former use of lead arsenate insecticides in tobacco-growing districts (Pattersson 1965). Since the 1950's, the lead arsenates have almost entirely been replaced by organic insecticides. According to Lehnert (1967), the amount of lead in a cigarette, available for inhalation is no more than 0.80 μg/Pb/cigarette, whereas most of the lead remains in the ash (Kehoe 1961b, Lehnert 1967). Consequently the absorption is minimal, when compared with that absorbed from daily food, or from urban air.

It is known that men have higher Pb-B levels than women (Hofreuter et al. 1961, Ludwig et al. 1965, Thomas et al. 1967, Zurlo et al. 1970, Haeger-Aronsen 1971, Tepper and Levin 1972, Secchi et Alessio 1974). Apparently, the difference is not fully attributable to the higher hematocrit values of men (Tepper and Levin 1972). To date, no international agreement exists in regard to biological standards for lead in the blood of the general population. Nevertheless, a proposal, based on available literature, has been formulated by Zielhuis (1974), with the total lead exposure taken into account. According to this biological guide, the highest acceptable individual value within a population group should be 40 μg/100 ml, 98 percent should be below 35 μg/100 ml, 90 percent below 30 μg/100 ml, and 50 percent below 20 μg/100 ml. The Pb-B values of women should be corrected for the haematocrit level. Moreover, the U.S. Environmental Protection Agency has suggested a maximal individual value of 40 μg/100 ml, applicable for adults and children; a maximum of 30 μg/100 ml has been proposed for expectant mothers and the fetus, as well as for the newborn (EPA 1972).

son program has been undertaken between different laboratories, and standardization of the Pb-H method is poor. So far, no agreement has been achieved even in regard to preparation of the hair samples for lead determination (Kopito et al. 1967, Hammer et al. 1972, Clarke and Wilson 1974). The wide range of lead content in hair reported in the literature is undoubtedly largely attributable to the poor standardization of the method.

2.7. Parameters reflecting lead effects

The lead exposure can also be estimated indirectly by the measurement of various parameters that reflect effects to the dose absorbed.

Lead inhibits the activity of certain enzymes involved in the heme synthesis. This effect on the enzymes results in a decline of heme synthesis, inducing a subsequent increase of urinary excretion of metabolites; furthermore, the level of the metabolites in blood rises in severe lead exposure. δ-ALA dehydratase and ferrochelatase are the best known of the enzymes inhibited by lead. Evidently, higher lead concentrations also inhibit ALA synthetase and coproporphyrinogen decarboxylase (Goyer and Rhyne 1973, Hernberg 1975). Of the metabolites, coproporphyrin III, and particularly ALA, have proved to be extremely useful as diagnostic tests in lead poisoning (Haeger-Aronsen 1960, 1971, Griggs 1964). The accumulation of protoporphyrin IX in erythrocytes always occurs at high levels of exposure (Haeger-Aronsen 1971, Sassa et al. 1973).

In comparison of the total exposure of various population groups by using a parameter of effect, the validity of the test should be high at Pb-B levels below 40 μg/ml, i.e., it must be as sensitive, specific and reliable as possible. A succession of studies has indicated that the ALAD assay is best adapted for this purpose.

after the administration of a chelating agent (Selander et al. 1966, Ellis 1966, Teisinger et al. 1969). Chisolm and Mellits (1974) have recently demonstrated that the arithmetic increase in Pb-B levels of children and adolescents resulted in an exponential increase of lead excreted following CaEDTA; this accordingly signified an exponential rate of increase in chelatable lead in the tissues. A similar relationship between Pb-B and chelatable urinary lead had earlier been reported for adults (Přerovská and Teisinger 1970). The CaEDTA mobilization test has little value in population studies as it is rather more cumbersome than the Pb-B assay.

Use of the lead content in hair for the assessment of excessive lead exposure is well established in literature (Kopito et al. 1967, 1969, Hasegawa et al. 1971, El-Dakhakhny et El-Sadik 1972). It has been claimed that Pb-H is correlated with the total body burden (Jaworowski et al. 1966). This opinion has been questioned by Schroeder and Tipton (1968), who noted that the lead content of bones increases with increasing age, but found no corresponding increase of Pb-H. The extent to which the Pb-H reflects the biologically available lead is not clear (Zielhuis 1974). However, Pb-H seems to reflect the total external lead exposure of a population group to a measurable extent, and may thus be of importance for future population studies (Klevay and Forks 1973, Hammer et al. 1971, 1972, Corridan 1974).

The analytical procedures of a Pb-B assay are known to be vulnerable to a number of errors with respect to precision, accuracy and reproducibility (Keppler et al. 1970, Weil 1971, Donovan 1971, Berlin et al. 1972, 1974a, Browne et al. 1974). It has also been stated that the variability between different laboratories probably arises from systematic errors (Berlin et al. 1974a). It is thus easy to question the comparison of the environmental exposure for various population groups, and the reliability of many epidemiological studies. As for the Pb-H assay, no intercomparihowever, it has been shown that the rise of these parameters does not begin until the Pb-B exceeds about 40 µg/100 ml (Selander et Cramér 1970, Haeger-Aronsen 1971, Tola et al. 1973). As can be concluded from the Pb-B values reported for groups of the general population (section 2.5.1.), the CP-U and ALA-U is of little value in population studies. In the planning of the study, it was still considered that the accumulation of protoporphyrin began in the proximity of Pb-B levels of 40 - 50 µg/100 ml. Recent evidence has indicated that the accumulation is initiated even at Pb-B levels of about 25 µg/100 ml; this applies solely to women; nevertheless, the protoporphyrin is still too cumbersome, and too unreliable at Pb-B levels below 40 µg/100 ml, to be used as a test of environmental exposure (Stuik 1974, Zielhuis 1974, Roels et al. 1975).

The reliability of the method has been assessed in an interlaboratory comparison study; this disclosed a precision and a reproducibility of the ALAD assay that surpassed those of the Pb-B test (Berlin et al. 1972, 1974 a,b). ALAD is also known to be a highly specific in-vivo-test, although ethyl alcohol exerts an inhibitive effect (Moore et al. 1971). Many cations inhibit the activity of ALAD in vitro; however, no evidence shows that other heavy metals inhibit ALAD in vivo (Hernberg and Nikkanen 1972). Up to quite recently it was unclear whether the inhibition of the ALAD activity in peripheral blood was an in vivo phenomenon or an in vitro artifact (Goldwater 1972, Zielhuis 1974); however, recent evidence indicates that the decrease is a true in vivo effect (Roels et al. 1974). The sensitivity of the ALAD assay has been demonstrated repeatedly (Bonsignore et al. 1965, DeBruin 1968, Hernberg and Nikkanen 1970, Hernberg et al. 1970, Haas et al. 1971, Haeger-Aronsen et al. 1971); furthermore, it displays the closest correlation to Pb-B, as compared to any other biochemical test (Tola et al. 1973, Sassa et al. 1973). The inhibition probably starts already at about 10 - 20 μg Pb/100 ml blood (Hernberg 1975); moreover, the sensitivity appears to be high enough to demonstrate low-grade differences of lead absorption (Secchi et al. 1971, 1972, Secchi and Alessio 1974, Coulston et al. 1973 a,b, Nordman et al. 1973). However, as has been pointed out by Stuik (1974) , most data on ALAD have been derived from exposed workers. At the beginning of this study, the experience of the ALAD assay in population studies was non-existent; it has more recently been suggested that the ALAD test would probably be a suitable tool for surveying the environmental exposure of the general population, and for discriminating between differences of exposure (Berlin et al. 1972, 1974 b). This study has provided an opportunity to elucidate the usefulness of the ALAD assay in the assessment of small alterations in total environmental lead exposure.

Other parameters of effect that bear a fairly close correlation to the Pb-B are the urinary excretion of ALA and coproporphyrin;

4. GENERAL DESCRIPTION OF THE MATERIAL

In the selection of population groups, special care was taken to minimize the inter-individual variation within the groups by the choice, as far as possible, of locally stable populations of roughly similar socio-economic status, and not exposed to lead in their work. Differences in dietary intake between varying population groups are difficult to discover, but the possibility of overlooking slight occupational exposure probably constitutes an even greater risk of error. For each subject the possibility of occupational exposure was checked through a questionnaire, followed by an interview. Knowledge of national occupational lead exposure patterns was gained from a parallel study, surveying the degree of exposure in relation to the field of work in Finland (Tola and Hernberg 1975). The questionnaire was specially designed for the study, for the compilation of information as regards occupational history (detailed description of former and present work and employment), present and past smoking habits, eating habits, origin of household water, time spent daily outside districts or in traffic, and present medication.

The population groups were selected from rural, urban and industrial districts (Fig. 1). Since sampling at the time involved the drawing of at least 20 ml of blood, it was decided not to include persons under 15 years of age. A summary of the entire series is given in Table 1. The distributions of separate groups by age and sex are indicated in Tables 4,8,22 and 34.

The main rural population group was selected from the Pertunmaa commune, situated about 180 km north of Helsinki. In addition, a diet survey was accomplished in Pertunmaa with respect to 23 households randomly selected from the original Pertunmaa sample. In order to preclude misjudgement from possible unrecognized special features of the Pertunmaa commune, the rural exposure was

3. OBJECTIVES OF THE PRESENT INVESTIGATION

The investigation had the following aims:

1. Determination of the levels of lead in the blood of occupationally-unexposed rural and urban population groups in Finland.

2. Study of the effects of varying concentrations of lead in the ambient air upon blood-lead levels.

3. Study of the effect of industrial lead-emitters on the blood-lead levels of the surrounding population.

4. Assessment of the total lead intake of a rural population group.

5. Evaluation of the usefulness of the erythrocyte Δ-ALAD assay in population studies for discrimination between various exposure levels.

Table 1. Total numbers of persons studied

	Males	Females	All
Pertunmaa			
Pb-B survey	243	256	499
diet survey	35	36	71
Haapajärvi-Pyhäjärvi	-	93	93
Helsinki			
downtown	142	37	179
suburban	37	81	118
streetsweepers	86	11	97
traffic policemen	28	-	28
Tikkurila	121	172	293
Total series	692	686	1.378

A detailed description of separate groups will be given in connection with corresponding studies.

checked by the selection of another rural group from Pyhäjärvi and Haapajärvi communes, about 400 km north of Helsinki.

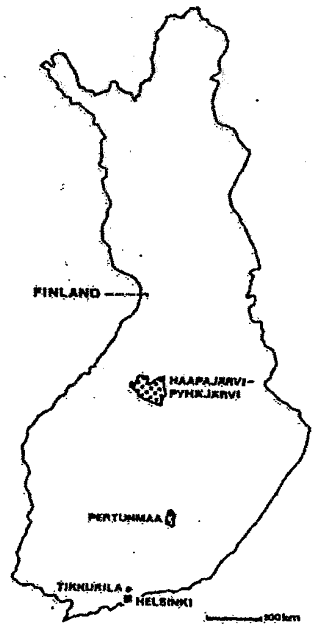

Fig. 1. Location of the districts surveyed.

Helsinki, the largest city of Finland, and the one with the highest traffic density, was selected to represent urban conditions. The urban population groups were all selected from Helsinki, and consisted of a downtown and a suburban group, with two additional target groups of street-sweepers and policemen.

Fifteen kilometers north of Helsinki is the Tikkurila district, a mixed residential and industrial area, and characterized by an exceptional congregation of lead-utilizing industries. Two secondary lead smelters, two storage battery plants, and some smaller foundries and a soldering workshop operate within the district. These circumstances prompted the incorporation of the Tikkurila population into the study. The Tikkurila study has been reported separately (Nordman et al. 1973).

on the filters as dust in sampling cycles of two weeks. The sampling devices were placed at fixed sampling stations at a height of 2.5 - 3.5 m.

The sampling continued at all sampling sites for one year. Although air sampling at some sampling sites was effected for more than one year, the results reported here relate only to the period from November 1971 through October 1972; the reliability of the analytical techniques was not regarded as satisfactory before that. Atmospheric lead sampling was carried out in Pertunmaa and Helsinki.

5.1.3. Assessment of dietary lead intake

Many investigators have estimated the amount of lead ingested daily. As pointed out in section 2.3.3. they have obtained very variable results; moreover, variations have occurred in the sampling strategy applied. The most accurate method is probably the "double portion" method, with the food consumption being measured by exact weighing (Pekkarinen 1970). This method, which is laborious and costly, has not proved popular among researchers.

With preliminary data on air lead concentrations of Pertunmaa as basis, the assumption was made that almost the entire lead exposure of the Pertunmaa population originated from dietary sources with the exception of possible occupational exposure that had to be excluded. It consequently seemed worthwhile to study the exact dietary intake of the Pertunmaa population in relation to the blood lead levels by application of the "dauble portion" method. The procedure is described in detail in section 6.2.2.

5. METHODS: GENERAL

5.1. Assessment of environmental exposure

The results of the jointly-planned dustfall lead survey in Tikkurila, and the studies on air-suspended particulate lead in Pertunmaa and Helsinki, were made available by the department of toxicology and biochemistry of the Institute of Occupational Health.

5.1.1. Sampling of dustfall lead

Dustfall lead, i.e., the proportion precipitated from the atmosphere through gravity, aggregation and rainfall, generally describes particles with a diameter exceeding 10 µm. A dustfall lead survey was carried out in Tikkurila (Laamanen and Ryhänen 1971, Nordman et al. 1973). The sampling was effected by means of collectors consisting of polyethene deposit gauges and bottles mounted on plastic-coated, wooden supporting constructions. The deposit gauge was a modified British Standard No. 1747 with an orifice diameter of 300 mm. The modification denotes an increase of the depth to 320 mm, which has proven more efficient in winter--time. The collectors were placed at a height of 2.5 - 15 m, to avoid the influence of surface dust.

5.1.2. Sampling of air-suspended particulate lead

As a rule, air-suspended lead particles have a diameter of less than 10 µm. The sampling equipment for air-suspended particulate matter comprised a holder with a membrane filter (Millipore AAWP 03700) with a pore diameter of 0.8 µm, and a pump supplying an air flow of about 10 l per minute (Neuberger V H 15). For measurement of the terminal air flow, each sampling device was fitted with a gasometer (Nordgas, Stockholm). Air lead was collected

5.4. Analytical methods

5.4.1. Lead in blood

Every Pb-B determination was performed from duplicate samples; thus the reported results of each analysis denotes the average of two parallel measurements. The duplicate samples were analyzed in different runs. The method employed throughout was that of atomic absorption spectrophotometry (Perkin-Elmer 303), described by Hessel (1968). The method error of duplicate analyses performed at different periods ranged from 1.1 to 2.0 μg/100 ml. A series of 26 duplicate samples analyzed unbeknown to the laboratory personnel showed a method error of 1.7 μg/100 ml; the method error reported by the laboratory for the same period was 1.1 μg/100 ml. The method was continuously checked by the introduction of spiked samples.

During the period from July, 1972 to June 1973, the monthly determinations of 3 spiked pig blood samples, to which 30 μg of lead ($PbCl_2$) per 100 ml of blood had been added (a total of 36 samples), resulted in a mean value of 34.0 μg/100 ml, a standard deviation of 1.7, and a range of 20.5 - 37.7 μg/100 ml. During the same period, a series of 12 human blood samples , to which had been added the same amount (30 μg Pb/100 ml) of lead, were analyzed monthly without the knowledge of the laboratory staff. These gave a mean of 46.7, a standard deviation of 3.6, and a range of 42.3 - 52.5 μg/100 ml. Unspiked duplicates were currently analyzed. The mean estimated value of the added amount of lead was 31.4 μg/100 ml. New spiked samples were prepared once a month.

The accuracy of the Pb-B method was further controlled within the compass of an Inter-Scandinavian comparison program organized by Doctors Gustav Weissglas, Åke Swensson and Lennart Sundell, Sweden. Spiked and unspiked blood samples have been distributed to the eight Scandinavian laboratories involved. The results of the inter-laboratory comparison are presented in connection with the studies concerned (Tables 6,24,25).

5.2. Choice of parameters of absorption and effect

The lead concentration in the blood was employed as a parameter indicating lead absorption, and the erythrocyte ALAD activity as a parameter of effect . The advantages and drawbacks of these, and other pertinent biological variables indicative of lead absorption or effect, have already been discussed (section 2.6. and 2.7.).

5.3. Collection of biological samples

All of the blood and dietary samples collected for the determination of lead content were stored in lead-free polyethene flasks or bottles which had been carefully washed with 10 percent nitric acid, and repeatedly rinsed with demineralized, distilled water.

Blood samples were drawn from a cubital vein into lead-free flasks. Only stainless steel syringes with polypropylene hubs were used. The skin was cleaned with a 0.2 percent benzethone chloride solution containing 2.9 percent butanol and, as solvent, 68.9 percent isopropanol. An amount of 20 ml of blood was drawn from each person for Pb-B analysis; duplicate samples were drawn from every fifth, for storage and future analysis. The Pb-B flasks were stored deep-frozen until analysis. Samples for ALAD determination were drawn into heparinized test tubes of 10 ml capacity. Otherwise, the test tubes were prepared analogously with the Pb-B flasks. For determination of the hematocrit value and the hemoglobin concentration, 2.5 ml of blood was drawn into a test tube containing 4 mg of EDTA.

5.4.5. Dustfall lead

The water-soluble fractions of the total dustfall were analyzed for lead by the atomic absorption spectrophotometry method. The ashed samples were analyzed by emission spectrography (Jarrel Ash Type 7101). The results obtained as micrograms per sample were transformed into grams per 100 m^2 per month.

5.4.6. Lead in air

The air-suspended particulate matter obtained on the membrane filters was analyzed for lead directly by X-ray fluorescence spectrometry (Philips PW 1410). A lithium-fluoride crystal (LiF 200), and a wolfram anode tube were employed. The X-ray generator was set at 60 kV and 30mA. Lead was determined from the alpha-line, 2-theta angle = 33.91. Measurement was effected three times, each one extending over a 20-second period. Background was determined at a 2-theta angle of 34.50. (Kuronen unpublished, Philips 1973, Grennfelt et al. 1971). The method was checked by parallel determination with atomic absorption spectrophotometry. The comparison is accounted for in Table 2.

5.4.7. Lead in food and beverages

All samples of food and beverages, including the water samples, were analyzed by application of the same method. The samples were evaporated, and then completely ashed at a temperature of 400-500°C. After the addition of hydrochloric acid (West and Carlton 1952), the lead portion of the fully ashed samples was extracted as the iodine complex with methyl isopropyl ketone (Talvitie and Garcia 1965). The final lead determination was effected with an atomic absorption spectrophotometer. A comparative check on the method was carried out by K.H. Schaller, M.D. at the University of Erlangen-Nürnberg, West Germany; the results of this check are listed in Table 3.

A series of duplicate samples were also analyzed twice a year in the laboratory of the American Smelting and Refining Company (ASARCO), Utah, U.S.A. These are accounted for in Tables 7 and 26. The samples of both the accuracy control programs were first analyzed at the Institute of Occupational Health, and the results were passed to the reference laboratories concerned before reports of their results had been received.

5.4.2. Erythrocyte Δ-ALAD activity

Erythrocyte Δ-ALAD activity was measured by a modified version of the method of Bonsignore and his colleagues (Bonsignore et al. 1965, Nikkanen et al. 1972). Briefly, the modification involves the use of the more stable sodium phosphate buffer and a pH of 6.8, instead of the carbonate buffer and a pH of 7.0. The activity is expressed as micromols porphobilinogen (PBG) formed during one hour of incubation at 37^{o}C per liter of packed red blood cells (RBC). The RBC volume was estimated from the hematocrit value measured previously. The method error from duplicate measurements during different period ranged from 18.4 to 36.0 µmol PBG per liter RBC. The values of the method error will be reported separately in connection with the surveys concerned. All of the ALAD assays were made within 5 hours of sampling.

5.4.3. Hematocrit value

The hematocrit value was measured with an Adams Autocrit centrifuge (CT 2900). Duplicate blood samples were spun for 4 minutes at 15,000 g.

5.4.4. Hemoglobin concentration

Blood hemoglobin was determined by the standard method, after conversion to cyanmethemoglobin.

Table 3. Accuracy check of the lead-in-food assay, provided by the laboratory of the University of Erlangen-Nürnberg. Ashing performed at the Institute of Occupational Health. Values expressed as µg/100 g.

Sample No.	Erlangen-Nürnberg value	Present value
1	26.5	23.8
2	14.7	26.3
3	14.2	22.1
4	13.0	11.6
5	10.6	17.5
6	8.5	14.8
7	19.8	21.4
8	16.2	24.3
9	18.2	11.5
10	13.7	11.5
11	11.8	16.7
12	10.5	12.5
13	14.1	21.4
14	10.3	9.7
15	8.7	14.4

Table 2. Comparison between X-ray fluorescence spectrometry and atomic absorption spectrophotometry. Values expressed as micrograms per sample.

May - July 1973			August 1973		
Sample No.	X-ray	AAS	Sample No.	X-ray	AAS
1	261	143	18	520	666
2	26	23	19	165	205
3	2	3	20	62	61
4	460	449	21	32	37
5	1170	819	22	7	6
6	1246	774	23	22	19
7	1035	552	24	37	33
8	105	93	25	24	20
9	1255	1172	26	202	198
10	581	633			
11	50	55			
12	103	132			
13	86	87			
14	47	52			
15	10	22			
16	25	34			
17	55	73			

6. ENVIRONMENTAL LEAD EXPOSURE OF A RURAL POPULATION

A study on dietary intake, exposure from ambient air, and blood lead levels.

6.1. Introduction

This investigation was conducted in the Pertunmaa commune, about 180 kilometers north of Helsinki (see Fig. 1). The total area of the commune is 474 square kilometers. In 1971 the number of inhabitants was 3,510 (1,752 men and 1,758 women)[x], i.e. 7.4 inhabitants per square kilometer. The vast majority of the population earn their livelihoods as small farmers or farm laborers. The industrial activity of the commune is restricted to a few small work shops; no lead plant operates within the district. In 1971, 562 automobiles, 497 of them gasoline driven, were registered in Pertunmaa[xx]. The population of Pertunmaa appeared to be suitable for the purpose of studying the daily lead intake and blood lead levels of the general population living in conditions of a minimum of lead pollution of the ambient air.

6.2. Material and Methods

6.2.1. Blood lead survey

In the fall of 1970, a systematic family sampling was effected. This sampling was undertaken in order to facilitate transportation to the place of examination. Of the 653 persons initially in-

x) Central Statistical Office of Finland

xx) From: Automobiles and Highways in Finland 1971, Finnish Road Association.

5.5. Statistical treatment

The normality of the distributions of separate series was tested by use of the Kolmogorov-Smirnov statistic for cumulative frequencies. In all but one series, a slight skewness was revealed, Graphically assessed, however, only the Tikkurila series disclosed a skewness that demanded a normalizing logarithmic transformation. In view of the skewness of the Tikkurila series, the Kolmogorov--Smirnov statistic was chosen for the testing of significance between the Tikkurila series and others. As for all other groups, the Welsh´s modification of the Student t-test was applied in the testing of significance of differences between the group values. This procedure takes into account the difference in the variances of the separate series by modifying the degree of freedom in the calculated t-test statistic . The robustness of the t-test was considered sufficient to compensate for the slight skewness of the distributions in all groups but for the Tikkurila group. This consideration was supported by the results obtained by re-testing the differences using the non-parametric Mann-Whitney U-test; the procedure did not alter the degree of significance arrived at by the parametric t-test. Two-tailed p-values were computed throughout.

The Pearson coefficient of correlation was applied in the measurement of the degree of relationship between characteristics of population groups or between parameters of interest. The analysis of variance was used in testing the effect of age on Pb-B levels. The standard deviation of measurement error was calculated from the formula:

$$S = \sqrt{\frac{d^2}{2\,n}}$$

where d = difference between duplicate measurements
n = number of pairs of duplicate measurements

Table 5. Cigarette-smoking habits of the Pertunmaa population

Cigarettes daily	>20	10-20	<10	cigar or pipe	non smokers
Males	10	42	43	6	142
Females	-	1	18	-	237
All	10	43	61	6	379

The collection of blood samples was carried out in the way described earlier (section 5.3.). On the same occasion the questionnaires were checked and completed. Blood samples were stored deep-frozen until analysis for lead. Hb and PCV was measured on the day of sampling.

Both winter and summer samples were analyzed in the fall of 1971. The winter blood samples were mixed with the summer samples, and each run contained similar proportions of both. The inter-mixing was done with a view to the avoidance of systematic errors when comparing the seasonally differing groups.

The method error of 399 duplicate Pb-B measurements was 1.8 μg/100 ml. The results of the accuracy check of the Pb-B method carried out during the corresponding period at seven other Scandinavian laboratories, and at the laboratory of the American Smelting and Refining Company (ASARCO), are illustrated in Table 6 and Table 7, respectively.

vited by letter to participate, 515 responded. Nine persons in all were excluded because of slight possible occupational lead exposure, and an additional 7 for technical reasons such as the clotting of blood samples. Of the 499 persons who constituted the final series, 243 were males, and 256 females. The age distribution of the entire series is indicated in Table 4. On the whole, the different age groups are of similar size, and the sexes are equally distributed. The oldest group, i.e., those over 65 years of age is, however, the smallest of both males and females.

Table 4. Distribution of the Pertunmaa population by age and sex

Age	Males	Females	All
15-24	51	49	100
25-34	35	32	67
35-44	50	40	90
45-54	34	56	90
55-64	43	56	99
65 or more	30	23	53
Total	243	256	499

Cigarette-smoking habits are shown in Table 5. Smoking did not appear to be as common a habit as anticipated; thus, only 19 females were cigarette-smokers, none of them was a heavy smoker, and 18 smoked less than 10 cigarettes a day. Only 10 of the males reported that they smoked more than 20 cigarettes a day. To disclose any possible seasonal fluctuations in Pb-B levels, approximately half (247 persons) of the group were examined between December 1970 and January 1971, and the other half (253 persons) during the period from June to August 1971. The age distribution and the cigarette-smoking habits of the winter and summer groups were identical with those of the entire series.

6.2.2. Diet survey

Several different methods are available for the assessment of food consumption, such as food accounts, interviews, questionnaire and weighing procedures, all of which have certain advantages and drawbacks. The method employed here was that of weighing, also known in the literature as the recipe method (Wilson et al. 1964), the exact or precise weighing (Pekkarinen et al. 1967) and the weighed individual-inventory method (Durnin et al. 1957). It is the most accurate method for the assessment of food consumption of individuals or families (Pekkarinen 1970). A trained investigator supervised the weighing, which was done by herself and two students. In advance, the participants received detailed information regarding the study personally from the same investigator, who emphasized the importance of not altering the usual composition of meals. For the reasons of costs and feasibility, the recording period had to be restricted to three (consecutive) days; earlier reports had indicated reason to expect considerable day-to-day variation of dietary lead intake (Thompson 1971), so that a longer period would have been preferable.

The subjects of the diet survey were randomly sampled from the orginal Pertunmaa family sample. The use of trained personnel for the weighing eliminated possible misunderstandings, and thus made random sampling possible. Thirty households were asked to participate; of these, 23 representing a total of 71 individuals responded. Of the 71 respondents (35 men and 36 women), 46 had also participated in the former blood lead survey. The age and sex distribution is indicated in Table 8. Cigarette smoking was rather uncommon: only 13 were smokers, 3 of whom were women all smoking less than 10 cigarettes a day; of the 10 male smokers only one was a heavy smoker, viz. more than 20 cigarettes a day, and 5 intermediate smokers, i.e., 10 to 20 cigarettes a day (Table 9).

Table 6. Inter-Scandinavian accuracy check of Pb-B determination in fall 1971. Values expressed as μg/100 ml.

Sample No.	Lead added	Mean of 8 laboratories	Range of 8 laboratories	Present value
1	30	41	31-48	48
2	-	11	4-17	14
3	-	11	4-18	14
4	140	136	118-155	155
5	80	93	79-101	101

Table 7. American accuracy check of Pb-B determination in 1971. Samples 1 and 6, 2 and 7, 4 and 8 are duplicates. Values expressed as μg/100 ml.

Sample No.	ASARCO[x)] value	Present value
1	21	19
2	29	22
3	22	21
4	17	16
5	4	16
6	8	19
7	23	22
8	16	16

x) American Smelting and Refining Company, Utah, U.S.A.

All of the household members were kept under individual survey. Thus, all items of food to which a single respondent helped himself were weighed separately before eating. The plate waste and the discarded food were also weighed, and the total amount consumed calculated by this means. All snacks between meals were weighed. The total number of meals eaten outside homes was only 16, snacks included. Their share of the total lead intake could not be measured, only estimated.

From each meal, one fifth of all food substances was collected for analysis, but only one sample of water and other beverages was taken from each household. The solid food substances ingested by every respondent were daily pooled, thoroughly homogenized, transferred to lead-free bottles, and finally deep-frozen. When homogenizing, the precise amount of added demineralized water was weighed.

The food consumption survey was effected during the period from May 25th to June 23rd, 1972. Blood was sampled for lead analysis from each participant in connection with the survey. The hemoglobin concentration and the hematocrit value were determined on the day of sampling; the Pb-B samples were inter-mixed with the Helsinki and Haapajärvi-Pyhäjärvi samples with a view to comparability between urban and rural Pb-B levels.

6.2.3. Lead in ambient air

Air-suspended particulate lead in Pertunmaa was monitored from October 1971 to November 1972. The samples were collected at one fixed sampling site . Filters were placed at a height of about 2 meters. The equipment has been described in section 5.1.2. The samples of May 1972 had to be discarded following technical failure in connection with the collection.

Table 8. Distribution of diet survey respondents by age and sex

Age group	Males	Females	All
15-24	8	6	14
25-34	4	3	7
35-44	5	4	9
45-54	7	9	16
55-64	7	9	16
65 or more	4	5	9
All	35	36	71

Table 9. Cigarette-smoking habits of diet survey respondents

Cigarettes daily	>20	10-20	<10	non-smokers
Males	1	5	4	25
Females	-	-	3	33
All	1	5	7	58

6.3.2. Daily lead intake

The total daily lead intake through food and beverages of the 71 respondents of the dietary survey is illustrated in Table 11. A mean intake of 204 µg Pb/day was found. The standard deviation of the mean value for the three days was 67, and the range 89-360 µg Pb/day. The mean intake of men was higher than that of women, 231 µg and 178 µg, respectively. The difference is statistically significant

Table 11. Daily dietary lead intake of 71 persons on three consecutive days of sampling. Values expressed as micrograms of lead.

		Day of sampling			Mean of three days
		I	II	III	
Males	$\bar{x}$	226	230	237	231
(N=35)	SD	66	78	83	59
	range	89 - 335	137 - 496	96 - 430	119 - 360
Females	$\bar{x}$	173	182	179	178
(N=36)	SD	64	77	82	64
	range	73 - 352	81 - 387	46 - 404	89 - 305
All	$\bar{x}$	199	206	208	204
(N=71)	SD	70	80	87	67
	range	73 - 352	81 - 496	46 - 430	89 - 360

($t = 3.64$, $p<0.001$). The contribution from beverages (Table 12) is small as compared to the lead ingestion through solid food (Table 13), constituting about 15 percent of the total daily amount ingested. The mean intake through beverages of men was 46 µg Pb/day and that of women significantly lower ($t = 5.61$, $p<0.001$), i.e., 25 µg Pb/day. The intra-individual day-to-day variation was great.

6.3. Results

6.3.1. Lead in ambient air

As had been expected, the lead content of the ambient air in Pertunmaa was low throughout (Table 10). The highest monthly mean value was recorded in February 1972, and was 0.056 μg/m^3 of air. The early mean value for the whole period from October 1971 to September 1972 was only 0.025 μg/m^3. Thus airborne lead could be considered negligible as a contributor to the total lead exposure of the population of Pertunmaa; even a daily inspiratory volume of 20 m^3, and an assumed 100 percent resorption following a maximal retention of 50 percent would result in a daily resorbed amount of lead of no more than 0.25 μg.

Table 10. Monthly and yearly mean concentrations of air-suspended particulate lead in Pertunmaa. Values expressed as μg/m^3.

		Monthly mean
1971		
	November	0.02
	December	0.02
1972		
	January	0.06
	February	0.06
	March	0.03
	April	0.01
	May	- x)
	June	0.02
	July	0.01
	August	0.02
	September	0.02
	October	-
Yearly mean		0.025

x) Stroke denotes omission of sample

Table 14. Lead content of drinking water and milk from twenty-three households. Values expressed as µg/kg.

	Water	Milk
$\bar{x}$	23	32
SD	6	6
min.	15	22
max.	41	42

Table 15. Lead content of some beverages. Lead determined from pooled samples of twenty-three households. Values expressed as µg/kg.

	µg Pb/kg
Coffee	9
Tea	8
Beer; brand A	8
B	10
C	11
Home-brewed beer	24
Home-brewed mead	23
Lemonade	15

No correlation could be established between the daily lead intake and Pb-B levels of the 66 persons for whom blood samples were available. The coefficients of correlations were $r = 0.08$ for men, $r = 0.05$ for women and, for the entire series, $r = 0.05$. The mean Pb-B of 33 males participating in the diet survey was 12.3 µg/100 ml; the corresponding value for the 33 females was 7.9 µg/100 ml (Table 28).

Table 12. Daily mean lead intake through beverages. Values expressed as micrograms of lead.

	Males (N=35)	Females (N=36)	All (N=71)
$\bar{x}$	46	25	35
SD	20	9	19
min.	19	4	4
max.	116	47	116

Table 13. Daily mean lead intake through solid food. Values expressed as micrograms per day.

	Males (N=35)	Females (N=36)	All (N=71)
$\bar{x}$	185	153	169
SD	60	61	62
min.	79	71	71
max.	310	261	310

Each family under survey had a private well. Only 4 families bought their milk from stores, whereas 19 families had their own cows. The lead content of milk, water, three of the most frequently used brands of beer, tea, coffee and home-brewed beer and mead is accounted for in Tables 14-15. The lead content of coffee and tea was surprisingly low as compared to the drinking water.

15 and 64 years of age were considered ($F = 2.07$, $p > 0.1$).

Table 17 . Pb-B levels of Pertunmaa female population. Values expressed as µg/100 ml.

	Females			
Age	N	$\bar{X}$	SD	range
15 - 24	49	10.2	3.3	5 - 18
25 - 34	32	9.5	4.1	5 - 28
35 - 44	40	9.1	2.8	4 - 17
45 - 54	56	10.0	3.1	5 - 18
55 - 64	56	9.6	4.2	3 - 30
65 or more	23	8.3	2.9	4 - 15
All	256	9.6	3.5	3 - 30

The seasonal influence on Pb-B levels is presented in Table 18. The females revealed a distinct difference between summer and winter Pb-B levels, the summer level being higher than the winter level. The Pb-B level of the males was only slightly higher in summer as compared to the winter level.

Table 18. Seasonal influence on Pb-B levels of Pertunmaa population. Values expressed as µg/100 ml

	Males		Females	
	Winter	Summer	Winter	Summer
$\bar{X}$	11.8	12.4	8.9	10.4
SD	4.5	4.4	3.0	3.8
N	113	130	133	123
t	-1.05		-3.49	
p	>0.1		<0.001	

6.3.3. Blood lead survey

The Pertunmaa males displayed a mean Pb-B of 12.1 μg/100 ml (S.D. 4.5, range 2 - 35 μg/100 ml). The lowest mean Pb-B value was found in the oldest group (over 65 years), and the highest in the youngest group (15 - 24 years). The difference between these two groups was statistically significant ($t = 2.55$, $p<0.05$) (Table 16).

Table 16. Pb-B levels of Pertunmaa male population. Values expressed as μg/100 ml.

	Males			
Age	N	$\bar{X}$	SD	range
15 - 24	51	13.5	4.4	6 - 25
25 - 34	35	12.3	4.5	5 - 21
35 - 44	50	12.3	4.2	5 - 24
45 - 54	34	10.8	3.0	2 - 17
55 - 64	43	12.3	4.7	5 - 25
65 or more	30	10.5	5.5	4 - 35
All	243	12.1	4.5	2 - 35

As compared to the males, the famales disclosed a lower mean Pb-B value of 9.6 μg/100 ml (S.D. 3.5, range 3-30 μg/100 ml).The lowest mean Pb-B of the females was similarly found in the oldest group, and the highest in the youngest group (Table 17).

However, no association between age and Pb-B was detectable for the females ($F = 1.25$ $p > 0.1$). On the other hand, the males displayed a decreasing mean Pb-B value with increasing age. This correlation was statistically significant ($F = 2.47$, $p<0.05$). The association was highly dependent on the oldest age group; consequently, the correlation disappeared when only men between validity of conclusions based upon the Pb-B levels obtained depends to a large extent on the validity of the Pb-B measurement. As was pointed out in an earlier content, the Pb-B assay is susceptible to many errors (Keppler et al. 1970, Berlin et al. 1972, 1974a). In this study, the precision of the Pb-B assay appeared to be on a high level, with a method error of 1.8 µg/100 ml. Appraised from the Inter-Scandinavian and the ASARCO comparison program, the accuracy was also satisfactory. The low values found in Pertunmaa are too high rather than too low as compared to the reference laboratories; the validity of the Pb-B assay is further examined in the general discussion.

One important consideration is that the Pb-B level of the 46 persons who delivered blood samples, both for the blood lead survey, and for the diet survey, exhibited a slight but statistically significant decrease over the period of one year (Table 20). There is little reason to believe that the true Pb-B level of this group decreased in about one year; it is more likely that the difference only describes a systematical difference of the Pb-B techniques. In other words, despite the strict control of the Pb-B method, a small systematic error could not be avoided between the measurements of the two periods of analyzing. The preparation of standards, still carried out every third month in 1971 but effected every month at the time of the diet study, probably explains the difference. The measure of monthly preparation of new standards was taken after the discovery that the Pb-B values of the spiked pig blood samples (used as standards) decreased with increasing storage time. Such considerations should be borne in mind when evaluating data in the literature reporting the presence or absence of time trends with respect to Pb-B levels in population studies (Horiuchi 1970, Tepper and Levin 1972, McLaughlin et al. 1973). However, it should be emphasized that the systematic error did not confuse the results of the seasonal comparison of Pb-B levels because of the inter-mixing of samples.

The difference between male and female mean Pb-B values was distinct ($t = 6.91$, $p<0.001$). The Pertunmaa material contained 108 pairs of husbands and wives. A comparison between Pb-B levels of husbands and wives did not greatly alter the inter-sex Pb-B difference ($t = 3.54$, $p<0.001$). When the lead content is referred to the volume of packed blood cells instead of the blood volume, the inter-sex difference is diminished, but still persists (Table 19).

Table 19. Inter-sex differences of lead referred to whole blood volume and to packed blood cell volume. Values expressed as µg/100 ml of blood and µg/100 ml of packed blood cells.

	Pb-B		Pb content referred to PCV		Pb-B		Pb content referred to PCV	
	Males	Females	Males	Females	Husbands	Wives	Husbands	Wives
$\bar{X}$	12.1	9.6	26.6	23.2	11.4	9.5	25.3	22.9
SD	4.5	3.5	9.8	8.5	4.0	4.0	9.0	9.9
N	243	256	239	255	108	108	107	107
t	6.91		4.11		3.54		1.86	
p	<0.001		<0.001		<0.001		= 0.06	

For the males, no significant difference was obtained between mean Pb-B values of smokers and nonsmokers. The smokers had a mean value of 12.8, and the nonsmokers 12.0 µg/100 ml ($t = 1.36$, $p>0.1$). As the female cigarette smokers made up less than 10 percent of the entire group, it was impossible to assess the influence of cigarette smoking on Pb-B levels within this particular group.

6.4. Discussion

6.4.1. Blood lead levels

On the whole, the mean Pb-B values were lower than those generally reported in the literature, especially as regards the women. The

Table 21. Pb-B levels of Pertunmaa males in relation to nature of activity

	N	$\bar{X}$	SD
Pensioners	20	10.3	3.5
Farmers	125	11.8	4.7
Students*	22	12.7	3.3
Lumbermen**	25	13.4	5.8
Others	51	12.7	3.8

* Including 14 students spending 5 days a week in Heinola, Joensuu or Lahti

** Including farmers doing lumbering work in wintertime

6.4.2. Dietary lead intake

The daily amount of lead consumed was lower than that quoted in some reports (section 2.3.3.); however, Tolan and Elton (1972) reported very similar values from Great Britain and Kolbye and his co-workers (1974) have also calculated a mean intake of the same order of magnitude. By comparison, the value of 100 µg Pb/day for American adult women seems very low (Tepper and Levin 1972). Nevertheless, it must be emphasized that most estimates have been reached by the use of different designs of study, and varying analytical procedures. The lack of standardization with respect to methodology is a serious drawback which obscures any comparison of results.

In this study no relationship was detectable between the Pb-B and the dietary lead intake. This was presumably due to the great day-to-day variation; a longer recording period would probably have disclosed the existence of such a relationship.

Table 20. Differences between individual Pb-B levels obtained in Pertunmaa in 1971 and 1972

	Males	Females	All
N	23	23	46
$\Delta\bar{x}$	-1.04	-2.57	-1.86
ΔSD	2.12	2.66	2.58
t	-2.36	-4.62	-4.73
p	<0.05	<0.001	<0.001

The higher Pb-B level for men than that for women corroborates the findings of most researchers (Hofreuter et al. 1961, Ludwig et al. 1965, Tepper and Levin 1972), with few exceptions (Goldwater and Hoover 1967). The higher Pb-B level of males existed even after correction for hematocrit level, but diminished. The distinct difference between the dietary lead intake of men and that of women (section 6.4.2.) may account for part of the difference. Nevertheless, it is probable that the rather marked difference between the means of males and females of this series arose partly from inter-sex differences with reference to activities. The men of this study were over 75 percent manual laborers, most of whom were farmers. It can be seen from Table 21 that Pb-B levels vary, depending on the kind of activity. The least active group, i.e., that of pensioners, has the lowest mean Pb-B value, and the lumbermen exposed to chain-saw exhaust display the highest mean. In contrast, the women were almost exclusively housewives or students. There is thus reason to believe that the association between age and Pb-B levels, found in the male group only, was an effect of variations with respect to environmental exposure rather than to age; furthermore, that the absence of a clear seasonal variation for the males was due to the effect of slight additional exposure, since small farmers are frequently engaged in lumbering during fall and winter. These aspects may account for at least part of the reported decrease in the tissue levels of old people (Schroeder and Tipton 1968).

paratively low, and clearly below the 300 μg Pb/day which has been considered as the representative mean intake. Since the atmospheric lead exposure is very low in Pertunmaa, the lead levels, at least for women reflect the lead absorption from dietary sources. These Pb-B levels are among the lowest ever reported.

The results indicate that the inter-mixture of samples is necessary, even when they are all analyzed in the same laboratory. Otherwise no guarantee exists that systematic errors are avoided.

Since the lead exposure derived from ambient air was negligible, particularly for the women, it may be postulated that the Pb-B levels found represent the lowest levels to be expected in groups of the general population in industrialized countries.

With the acceptance of an overall gastrointestinal absorption of 8 percent (Waldron and Stöfen 1974), the daily average absorption for the population surveyed would be 16 μg Pb/day, with a minimum of 6 μg, and a maximum of 29 μg. The corresponding daily mean for men would be 18 μg, and that for women 14 μg daily. Generalization with regard to dietary habits of the Finnish population is risky, since recent evidence has indicated the existence of some dietary variations between Finnish urban and rural populations (Koskinen 1974). Although co-operative chains distribute most of the food consumed in Finland, the possibility of variations within the country with respect to mean lead intake cannot be excluded.

6.4.3. Lead in ambient air

The low concentration of lead found in the ambient air of Pertunmaa is in accord with the recent study on heavy metal deposition in Scandinavia (Rühling and Tyler 1973), which has reported a modest lead content of mosses from Finland, as compared to southern parts of Sweden and Norway. The concentrations in Pertunmaa are of a similar order of magnitude as values reported earlier from remote rural, non-industrialized areas, (CEC 1972) or even somewhat lower.

6.5. Conclusions

From an international point of view the Pb-B levels of the Pertunmaa population are low. The dietary lead intake is also commendable decisions made with a view to the reduction of lead pollution are largely based upon results obtained in American population studies. However, the U.S.A. differs from Europe, and from Scandinavia in particular, in many relevant respects, such as the previous use of lead pigments, traffic density, and the degree of industrialization. By reason of the lack of data from Scandinavia, it was decided to study the Pb-B levels in Helsinki and the relationship between them, and to compare urban and rural conditions.

In 1972, Helsinki had about 510,000 residents, i.e., 2,900 inhabitants per square kilometer[x)]. At the time, the total number of automobiles registered in Helsinki, according to the holder's domicile, was 110,000, of which 100,000 were gasoline-driven[xx)]. However, the inhabitants of adjacent communes bordering on Helsinki are to a large extent commuters working in the city. When these communes are taken into account, the totals rise to 730,000 people, and 140,000 gasoline-driven automibiles, respectively. Finland has no statute pertaining to the maximum content of lead in gasoline. According to the national refinery, the addition of lead to gasoline has never exceeded 0.7 g/l (personal communication, Neste Oy).

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x) Central Statistical Office of Finland

xx) From: Automobiles and Highways in Finland 1973, Finnish Road Association

7. BLOOD LEAD LEVELS AND ERYTHROCYTE Δ-ALA DEHYDRATASE ACTIVITY OF SELECTED POPULATION GROUPS IN HELSINKI

7.1. Introduction

It is now known that traffic increases the lead content of air (Ludwig et al. 1965, Thomas et al. 1967, Tepper and Levin 1972, Daines et al. 1972, CEC 1972, Göthe et al. 1973). Furthermore, the isotopic composition of lead aerosols in air indicates that the decomposition products of lead alkyl are the main source of the lead in urban air (Chow and Earl 1970). In close accord with this, several studies have disclosed that exposure to exhaust gases increases the blood lead levels (Hofreuter et al. 1961, Ludwig et al. 1965, Thomas et al. 1967, Lehnert et al. 1970, Horiuchi 1970, Daines et al. 1972, Waldron 1975). However, it is still necessary to determine the concentrations of lead in the air which will increase the lead absorption to a measurable extent.

The U.S. Environmental Protection Agency, following a review of studies on the subject, has declared that lead levels of around 2 $\mu g/m^3$ of air induce a measurable increase in blood lead levels among adults (EPA 1972). The existence of an association between Pb-B levels and lead concentrations has been supported by a controlled 18-week chamber exposure study at about 3 $\mu g/m^3$, which resulted in a rise of blood lead levels (Coulston et al. 1973 b). In contrast, Tepper and Levin (1972) have not found any relationship between annual air lead concentrations, ranging from 0.14 to 4.55 $\mu g/m^3$, and blood lead levels.

Although it is impossible to draw any definite conclusions yet, measures to lower the content of lead in gasoline have been adopted by a number of Governments (Campbell 1973). However, little is known about the Pb-B levels of Scandinavian populations, and even less about the probable hazards that arise from the probable alternatives replacing lead (Berlin M. et al. 1974). The com-

7.2.2. Selection of population groups

The population groups under survey were selected from regions surrounding the air sampling sites. Two main population groups were formed in Helsinki: a downtown group derived from head post office employees, who both worked and resided within the downtown area, and a suburban group comprising employees, store clerks and clerical staff working and residing within the suburban districts concerned.

In addition, studies were made of two target groups with special exposure patterns; these comprised 97 streetsweepers, all of whom had their working place in downtown districts, and 28 of a total of 61 traffic-directing policemen operating at the time in Helsinki.

To obtain control groups for the Helsinki series, two rural population groups were selected: one was made up of the 33 men and 33 women participating in the Pertunmaa dietary survey (5 Pb-B samples were lost). The other one was formed of 93 female post employees from Haapajärvi and Pyhäjärvi communes (Fig. 1). The rural communes of Haapajärvi and Pyhäjärvi are both situated about 400 kilometers north of Helsinki, with about 8,000 inhabitants and less than 1,500 automobiles each. The numbers of inhabitants per square kilometer is 5.9 for Pyhäjärvi, and 9.9 for Haapajärvi[x)]. The corresponding data for Pertunmaa are given in section 6.1.

Distributions by age and sex of the different groups are indicated in Table 22,and the smoking habits in Table 23.

[x)] Central Statistical Office of Finland

7.2. Material and methods

7.2.1. Aerometric sampling

The sampling of air-suspended particulate lead was effected at four fixed sampling sites. The downtown sampling site (1) was situated about 300 meters from the head post office, close to the city railway station (Fig. 2.). Sampling site 2 was situated in a mixed commercial, industrial and residential area, sampling site 3 in the suburb of Pohjois-Haaga, and sampling 4 in the suburb of Otaniemi. The equipment, and the procedures for sampling and analysis are described in section 5.

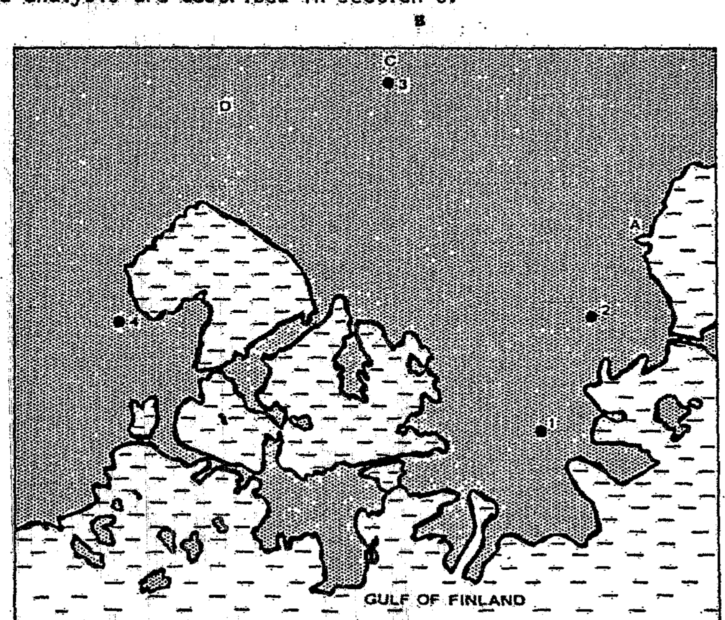

Fig. 2. Air sampling sites in Helsinki. Sampling site No. 1 = downtown, No. 2 = mixed traffic-industrial-residential, No. 3 = suburban of Pohjois-Haaga, No. 4 = suburban of Otaniemi. A = Helsinki main incinerator, B = Tikkurila lead emitters at a distance of about 10 km from sampling site No. 3, C = Haaga 3 Power station, D = lead pigment plant.

Table 23. Cigarette-smoking habits of different urban and rural population groups.

	Cigarettes daily			Pipe or cigars	Non-smokers
	> 20	10-20	< 10		
Downtown					
Males	17	42	13	6	69
Females	1	9	7	-	22
All	18	51	20	6	91
Suburban					
Males	4	9	6	2	16
Females	1	13	12	1	56
All	5	22	18	3	72
Streetsweepers					
Males	12	20	8	2	44
Females	-	1	-	-	10
All	12	21	8	2	54
Policemen					
Males	2	5	3	-	18
Haapajärvi-Pyhäjärvi					
Females	-	3	18	-	72
Pertunmaa diet survey					
Males	1	5	4	-	25
Females	-	-	3	-	33
All	1	5	7	-	58

Table 22. Distribution of different urban and rural population groups by age and sex.

Age	Downtown			Suburban			Streetsweepers			Traffic policemen	Pertunmaa diet survey			Haapajärvi-Pyhäjärvi
	Males	Females	All	Males	Females	All	Males	Females	All	Males	Males	Females	All	Females
15-24	32	7	39	18	3	21	3	-	3	6	8	5	13	12
25-34	61	13	74	9	18	27	8	1	9	17	3	3	6	18
35-44	25	6	31	6	27	33	17	1	18	2	5	4	9	26
45-54	16	7	23	3	21	24	32	6	38	3	7	8	15	23
55-64	8	5	13	-	12	12	25	3	28	-	6	8	14	12
65 or more	-	-	-	-	-	-	-	-	-	-	4	5	9	2
	142	38	180	36	80	117	85	11	96	28	33	33	66	93

Table 24. Comparative Inter-Scandinavian check of Pb-B determination. Values expressed as µg/100 ml

	Mean of 8 laboratories	Range of 8 laboratories	Present value
Spring 1972	14	10 - 18	17
	14	9 - 17	17
	51	44 - 61	61
	85	80 - 95	95
	85	81 - 93	93
	87	80 - 94	94
Spring 1973	7	5 - 13	12
	8	5 - 17	12
	26	24 - 41	31
	40	38 - 51	44
	76	74 -104	82

Table 25. Inter-Scandinavian accuracy check of Pb-B determination. Values expressed as µg/100mml

	Lead added	Calculated values		
		Mean of 8 laboratories	Range of 8 laboratories	Present value
Spring 1972	38.4	38	31 - 44	44
	77	72	67 - 78	78
	77	72	65 - 76	76
	77	74	67 - 79	77
Spring 1973	19	21	18 - 30	19
	32	34	29 - 40	32
	68	72	66 - 93	70

7.2.3. Collection of biological data

On choice of the time for collecting biological samples, attention was focused upon two determining factors. First, it was assumed that the streetsweepers' springclean of the streets was finished by the end of April, and implied a maximum exposure to street dust. Secondly, the possibility of seasonal variation had to be excluded. The streetsweepers were thus examined concomitantly with the down-town group, half of the suburban group and the Pertunmaa (dietary survey) group from the end of May through the end of June 1972, and the Haapajärvi-Pyhäjärvi group in August 1972. For practical reasons examination of the other half of the suburban group had to be postponed until June 1973. The policemen were examined as early as in November 1971, however.

Blood samples were collected , and Pb-B,ALAD, the Hb, and the PCV , were determined in the manner described earlier (section 5). Pb-B samples were deep-frozen, and stored until all the samples had been collected by June 1973.

7.2.4. Analytical methods

All of the Pb-B samples, except for those of the 29 policemen , were inter-mixed and analyzed in series made up by proportional amounts from each group, for the avoidance of systematic errors. The method error from duplicate measurements was 1.1 µg/100 ml. The results of the accuracy control program of the eight Scandinavian laboratories with reference to the time of analysis of the Helsinki series are accounted for in Tables 24-25, and the corresponding values obtained in the comparison provided by the ASARCO laboratory are given in Table 26. The ALAD assay showed a method error from duplicate measurements of 18.4 µmol PBG per liter RBC. The methods applied for the analysis of Pb-B, ALAD, particulate lead in air, Hb and PCV have been described in section 5.4.

of 0.43 $\mu g/m^3$. Seasonal fluctuations are observable in monthly means, with a tendency towards lower values during the summer months, and achievement of the highest values in the autumn and winter months.

Table 27. Monthly and yearly mean values of air-suspended particulate lead in Helsinki. Values expressed as $\mu g/m^3$. Numbers of sampling sites refer to areas as follows: 1 = downtown, 2 = mixed industrial-traffic-residential, 3 and 4 = suburban

Period of sampling	Sampling site No.			
	1	2	3	4
1971				
November	-x)	-	1.10	0.46
December	2.20	1.30	1.40	0.76
1972				
January	1.70	1.30	1.20	0.62
February	1.80	0.97	1.50	0.33
March	1.20	-	1.20	-
April	1.80	0.38	0.67	-
May	0.74	0.83	0.80	-
June	0.87	0.92	0.91	-
July	0.68	0.59	0.67	0.16
August	1.10	0.90	1.02	0.18
September	1.40	0.85	1.18	0.47
October	1.55	1.00	1.13	0.52
Annual mean	1.32	0.90	1.05	0.43

x) Stroke denotes omission of sample

Table 26. American accuracy check of Pb-B determination in 1972. Values expressed as µg/100 ml.

Sample	ASARCO[x)] value	Present value	Sample	ASARCO[x)] value	Present value
1	21	12	14	43	53
2	12	10	15	57	47
3	19	19	16	43	56
4	70	86	17	8	9
5	54	73	18	7	7
6	66	74	19	8	8
7	57	64	20	10	8
8	64	77	21	15	15
9	76	79	22	12	13
10	64	71	23	6	9
11	54	63	24	11	12
12	49	60	25	7	8
13	57	72	26	10	10

x) American Smelting and Refining Company, Utah, U.S.A.

7.3. Results

7.3.1. Lead in air

Monthly and annual mean values for lead in urban and rural air are listed in Table 27. The highest annual mean value of 1.32 $\mu g/m^3$ was measured at the Helsinki downtown sampling site; this is about 50 times the rural yearly mean value of 0.025 $\mu g/m^3$. The monthly means at this urban sampling site ranged from 0.68 to 2.20 $\mu g/m^3$, while the rural monthly mean never exceeded 0.06 $\mu g/m^3$. The sub-urban sampling site 3 displayed a higher yearly mean than did sampling site 2. The Otaniemi sampling site had a yearly average

Table 28. Blood lead levels of different urban and rural population groups. Values expressed as µg/100 ml of blood.

	Males						Females					
	Policemen	Streetsweepers	Helsinki Downtown	Helsinki Suburban	Pertunmaa (diet survey)	Pyhäjärvi	Policemen	Streetsweepers	Helsinki Downtown	Helsinki Suburban	Pertunmaa (diet survey)	Pyhäjärvi
N	28	86	142	37	33	-	-	11	37	81	33	93
$\bar{X}$	13.5	13.3	11.4	10.6	12.3	-	-	10.4	8.5	9.7	7.9	8.6
SD	2.8	4.1	3.3	2.8	3.3	-	-	3.0	2.0	2.6	1.9	2.5
min	9	7	5	6	5	-	-	5	6	6	5	4
max	20	29	23	18	19	-	-	15	14	20	12	20

Table 30. Erythrocyte ALAD activity for different urban and rural population groups. Values expressed as µmol/PBG/h/l RBC

	Males				Females			
	Streetsweepers	Downtown	Suburban	All	Streetsweepers	Downtown	Suburban	All
N	85	145	37	267	11	38	82	131
$\bar{X}$	811	1075	1020	983	746	1203	1138	1124
SD	215	193	203	234	218	175	222	239
min	335	464	552	335	449	913	770	449
max	1294	1552	1384	1552	1052	1608	2116	2116

7.3.2. Lead in blood

Table 28 lists the mean Pb-B values of the different population groups, together with the standard deviations of the means and the ranges. The most conspicuous feature of the results is that no subgroup displayed a mean Pb-B value exceeding 13.5 g/100 ml. The highest mean values were found in the groups of policemen and male streetsweepers, i.e., 13.5 and 13.3 µg/100 ml of blood, respectively. Both are higher than the means of the other urban male groups. When the male streetsweepers were tested for significance against the male downtown group, they yielded a t-value of 3.64, corresponding to a p-value of <0.001. The level of significance was similar when tested against the suburban males ($t = 4.23$, $p < 0.001$). No statistically significant differences were found between downtown and suburban or rural males. The rural males had higher Pb-B values than the suburban males ($t = 2.31$, $p < 0.05$). Throughout, the Pb-B values of the females were lower than those of the males. The highest mean was exhibited by the 11 female streetsweepers; however, this group was small, and has consequently been omitted from the statistical calculations. Surprisingly, the suburban females exhibited a mean value that somewhat exceeded those of the other female groups. This diversity was statistically significant when tested against the downtown group ($t = 2.74$, $p < 0.01$), the Pertunmaa group ($t = 4.10$, $p < 0.001$), and the Haapajärvi-Pyhäjärvi group ($t = 2.84$, $p < 0.01$). Only insignificant differences were apparent between downtown and rural females. For elucidation of whether any dependence existed between the finding of unexpectedly high lead concentrations in air at suburban sampling site No. 3, and the higher Pb-B values of the suburban females, a subdivision was made of the suburban group. Comparisons were drawn between the population living within one kilometer of sampling site No. 3 (Pohjois-Haaga), and all of the other suburbanites (Table 29). This comparison revealed that the mean Pb-B value was higher for the Pohjois-Haaga group than for the others, and applied both to males and to females. The arbitrarily-composed

Table 31. Significance testing of differences between erythrocyte ALAD activity levels of Helsinki target groups.

	Males		Females	
	t	p	t	p
Streetsweepers vs. downtown	-9.37	< 0.001	-6.37	< 0.001
Streetsweepers vs. suburban	-5.13	< 0.001	-5.59	< 0.001
Downtown vs. suburban	1.51	> 0.1	1.72	≈ 0.08

Table 32. Correlations between erythrocyte ALAD activity and Pb-B concentration after adjustment of the upper Pb-B limit at varying levels. $\bar{y}$ = mean values of ALAD activity, expressed as µmol PBG/h/l RBC. $\bar{x}$ = Pb-B mean values, expressed as µg/100 ml.

Pb-B	N	$\bar{y}$	$\bar{x}$	r	p
≤ 15	357	1050	10.3	-0.32	< 0.001
≤ 14	335	1056	10.0	-0.32	< 0.001
≤ 13	306	1064	9.6	-0.32	< 0.001
≤ 12	281	1078	9.3	-0.27	< 0.001
≤ 11	241	1097	8.9	-0.20	< 0.01
≤ 10	197	1104	8.4	-0.23	< 0.001
≥ 9	145	1135	7.8	-0.13	> 0.05

No influence of age on the Pb-B levels or the ALAD activity was detectable among any of the groups in question. This also applied to cigarette smoking with the exception of the streetsweepers' group, in which a difference of Pb-B mean values was found between cigarette smokers and nonsmokers over 45 years of age (Table 33). The difference was statistically significant at the 5-percent level ($t = 2.37$). The ALAD values showed a slightly smaller difference between smokers and nonsmokers in the older group. No such differences were found in the younger group, 44 years of age of less.

group of "other suburban" females did not differ from downtown or Haapajärvi-Pyhäjärvi females, but still had a higher mean than the Pertunmaa females. The Pb-B values among Pohjois-Haaga males and females are of the same order of magnitude as the Pb-B values of the streetsweepers.

Table 29. Lead in blood of suburbanites of Pohjois-Haaga, compared to other suburbanites

	Males		Females	
	Pohjois-Haaga	Other suburbanites	Pohjois-Haaga	Other suburbanites
N	8	28	27	53
$\bar{x}$	13.1	10.0	10.9	9.2
SD	3.2	2.3	3.4	1.9
t	2.56		2.41	
p	<0.05		<0.05	

7.3.3. Erythrocyte Δ-ALAD activity

The ALAD values are listed in Table 30. For methodological reasons, the ALAD values of the policemen were omitted; these had been analyzed before the current modification of the ALAD assay was taken into use. The streetsweepers have significantly lower ALAD values than the downtown and the suburban group, whereas only minimal differences exist between the downtown and the suburban groups. The results of significance testing between the groups are indicated in Table 31. The males also had lower ALAD values than the females ($t = 5.55$, $p < 0.001$). In this series, the relationship between ALAD and Pb-B yielded a correlation coefficient of $r = -0.37$ ($p < 0.001$, $N = 419$, range 4-29 µg Pb/100 ml). Interestingly, this negative correlation was still statistically significant when all of the Pb-B values over 10 µg/100 ml were omitted from the calculations ($r = -0.23$, $p < 0.001$, $N = 197$) (Table 32).

from traffic. Dependent upon the wind direction, these sources may have been: Helsinki main incinerator, at a distance of about 5 kilometers east of Pohjois-Haaga, the Tikkurila lead plants, situated about 10 kilometers north east of Pohjois-Haaga, a lead pigment plant at a distance of 1.5 kilometers west of Pohjois-Haaga and the Haaga 3 power station in Pohjois-Haaga. Mattson and Jaakkola (1974) have suggested that in particular the Helsinki main incinerator, but also the lead smelteries in Tikkurila (section 7) may significantly contribute to the Helsinki Pb-A, and especially to that of Pohjois-Haaga.

The Pertunmaa male group displayed Pb-B values exceeding those of the other male groups of the general population. This can scarcely be attributed to dietary variations, since the mean of the Pertunmaa female Pb-B values was, on the contrary, the lowest of all groups. However, the Pertunmaa male group differs from the other male groups in one respect: they are almost exclusively workmen, small freeholders and lumbermen frequently using mechanical equipment such as chain saws. This structural difference between the groups was unavoidable. The other groups of the general population has satisfactory similar structures; they were locally stable, wage-earning groups of approximately equivalent socioeconomic status, spending the entire day in the vicinity of the air sampling sites, and mostly working at ground floor or first floor level. There is little reason to believe that cumbersome random or systematic sampling would have offered any advantage over the "chunk" sampling employed. Although dietary differences might exist between urban and rural groups, the possibility of systematical differences within Helsinki is unlikely. The possibility that the analytical techniques might entail systematic errors was coped with by the intermixture of all samples, and the introduction of similar proportions from each group in the analytical runs.

It is probable that women are more suitable than men when it is a matter of assessing differences between the environmental exposure of varying population groups. Although special care was taken to

Table 33. Effect of cigarette-smoking on Pb-B and erythrocyte ALAD activity in Helsinki streetsweepers (Pb-B values expressed as µg/100 ml, ALAD as PBG/h/l RBC)

		≤45 years of age		>45 years of age	
		smokers	nonsmokers	smokers	nonsmokers
Pb-B	N	13	15	29	28
	$\bar{x}$	12.9	12.5	14.9	12.2
	SD	2.8	4.3	5.2	2.9
	t	0.30		2.37	
	p	>0.1		<0.05	
ALAD	N	13	15	29	28
	$\bar{x}$	814	846	751	852
	SD	177	254	216	204
	t	-0.39		-1.82	
	p	>0.1		=0.08	

7.4. Discussion

The most striking result obtained is the low level of Pb-B found in all the groups. As a whole, the mean values for the urban and the rural population groups are about the lowest reported Pb-B values for general populations. It is, however, difficult to achieve a satisfactory degree of comparability to other studies in the absence of inter-mixing. The analytical validity of the low values will be appraised in the "General Discussion".

The absence of differences between rural and urban Pb-B levels also arouses interest. No differences whatever were apparent between the downtown and the two rural population groups. The Pohjois-Haaga group exhibited unexpectedly high Pb-B values. The Pb-A mean values of Pohjois-Haaga were also surpriginsly high, approximating to the downtown levels. In all probability these are attributable to at least four lead-emitting sources apart

The ALAD assay proved useful in discrimination between separate groups whose Pb-B levels differed to a small but measurable extent. The negative correlation between Pb-B and ALAD appeared, furthermore, to prevail at extremely low Pb-B levels. The ALAD test is discussed in more detail in section 10.3.

7.5. Conclusions

The Pb-B levels of all the groups studied were low. No differences were observable between Pb-B levels of downtown and rural residents despite the fact that the Pb-A concentrations in Helsinki were 50 times as great. The Pohjois-Haaga Pb-B levels were slightly higher than the downtown levels, although similarity was found in the Pb-A concentrations. The difference may have originated in: 1) chance, 2) higher exposure to dustborne lead for the Pohjois-Haaga population, or 3) different emitting sources producing particles with different characteristics (chemical composition, shape, solubility) which may affect the rate of absorption (Lawther et al. 1972 a,b). Nonetheless, Helsinki traffic alone does not increase the Pb-B levels of the general population to an extent that is significant in practice. The exposure to exhaust gas and dust of the traffic policemen and the streetsweepers is followed by a measurable increase in Pb-B levels.

exclude additional exposure of occupational origin, men seem to be subjected to a higher risk of undergoing additional exposure, probably through work or leisure-time activities. The Pb-B values of the Pohjois-Haaga females seem to indicate a measurable effect of Pb-A amounting to about 1 $\mu g/m^3$, whereas the downtown group did not exhibit any effect of this kind. Nonetheless, it must be emphasized that the use of a few fixed sampling devices is an inadequate method for assessment of the exposure of an entire population group. Furthermore, in population studies it is difficult to cope with interindividual variations of dietary lead intake that mask the influence of low lead concentrations in ambient air.

The finding that the streetsweepers had rather higher Pb-B values is consistent with earlier reports (Lehnert et al. 1970, Lorant and Svoboda 1973).

Cigarette smoking was not found to exert any effect upon Pb-B within the groups of the general population. Only in the streetsweepers' group over 45 years of age did the smokers show higher Pb-B values than nonsmokers. No such difference was discernible in the younger age group. The literature is controversial on this point. Some investigators have reported higher Pb-B levels for smokers than for nonsmokers (Hofreuter et al. 1961, Ludwig et al. 1965, Tepper and Levin 1972), while others have been unable to detect such an effect (Lehnert et al. 1967, Daines et al. 1972, McLaughlin and Stopps 1973). It seems probable that in itself the inhalation of tobacco smoke does not have a measurable effect on Pb-B levels. The differences reported are probably attributable to the ingestion of particles from contaminated fingers. The occurrence of the difference in the older groups alone presumably arose from hygienic differences between the age groups, a longer period of lead accumulation, and decreased mucociliary activity of the smokers.

8.2. Material and Methods

8.2.1. The Tikkurila area

Tikkurila is a mixed residential and industrial area, fifteen kilometers north of Helsinki. Two secondary lead smelteries, two storage-battery plants, one battery factory with a small foundry, along with a group of soldering workshops, operate within this area (Fig. 3). The arable land close to lead smelter A (Fig. 3) belongs to the Government Agricultural Research Center, whose investigators found in 1970 that the snow, and the needles of conifer trees, had an exceptionally high lead content which markedly increased as the smeltery was approached (Lakanen and Erviö 1971). A later report disclosed heavy lead pollution of the soil surrounding the smeltery (Erviö and Lakanen 1973).

Smeltery A was founded in 1935. From 1950, when the filters went out of order, until 1970, the smoke discharged from the furnaces was not purified. The amount emitted in 1970 was estimated by the plant management to be 22 tons, expressed as metallic lead, on the basis of the amounts regained after the installation of purification equipment in 1971. This amount is equal to 25 percent of the calculated total emission from Helsinki traffic (Mattsson and Jaakkola 1974).

8.2.2. Target population

Random sampling of the population over fifteen years of age, and living not further than four kilometers from either one of the smelteries, was carried out in the spring of 1970. The 621 persons so selected were invited by letter to participate in the study; of these, 334 responded, and were examined between June and November 1970. All those with even the slightest present or previous occupational exposure to lead were excluded from the

8. BLOOD LEAD LEVELS AND ERYTHROCYTE Δ-ALA DEHYDRATASE ACTIVITY IN RESIDENTS AROUND LEAD EMITTING INDUSTRIES

8.1. Introduction

It is well documented that lead smelteries contaminate the soil, air, water, and plants around them (Alloway and Davies 1971, Kerin et al. 1972, Kerin 1974). When this study was planned, the data indicating an increase in the lead absorption by people living in such vicinities was scanty (Oyanguren et al. 1966). More recent studies have reported increased absorption in populations living near lead-emitting industries, as has become evident from rises in the Pb-B and Pb-U (Djurič et al. 1971, Secchi et al. 1971, Martin et al. 1974, University of Toronto 1974) and from the increased lead excretion following provocation with CaEDTA (Djurič et al. 1972). Extreme conditions have increased the excretion of ALA-U into the urine (Djurič et al. 1971). This is of particular importance, as ALA-U is a parameter of lead toxicity. Furthermore, the increase in this parameter does not become measurable until the Pb-B rises above 40-50 μg/100 ml (Selander and Cramér 1970, Tola et al. 1973). No data on ALAD of populations living near lead smelteries were available when the present study was started. However to judge from the negative correlation obtained between Pb-B and ALAD of occupationally unexposed subjects (Hernberg and Nikkanen 1970), it seemed likely that the ALAD assay would be sufficiently sensitive to reflect the anticipated differences in lead exposure of the population living in an area characterized by industrial lead pollution.

Table 34. Distribution of the Tikkurila series by age and sex.

Age	Males	Females	All
15 - 24	24	21	45
25 - 34	17	26	43
35 - 44	29	39	68
45 - 54	24	34	58
55 - 64	20	25	45
65 or more	7	27	34
Total	121	172	293

Table 35. Cigarette-smoking habits of Tikkurila population

	Cigarettes daily			Pipe or cigars	Non-smokers
	>20	10-20	<10		
Males	11	21	14	3	67
Females	-	16	12	-	149
All	11	37	26	3	216

8.2.3. Methods

The procedures of collecting biological samples and the analytical methods have been described in section 5. Pb-B analyses from Tikkurila survey showed a method error of duplicate determinations of 2.0 µg/100 ml. The results of the Inter-Scandinavian accuracy control of the Pb-B assay are listed in Table 6. The method control performed by the ASARCO laboratories at the same period of time is accounted for in Table 7. At that time new spiked standards were prepared every third month. The ALAD determinations displayed a method error of duplicate analyses of 36 µmol PBG per liter RBC.

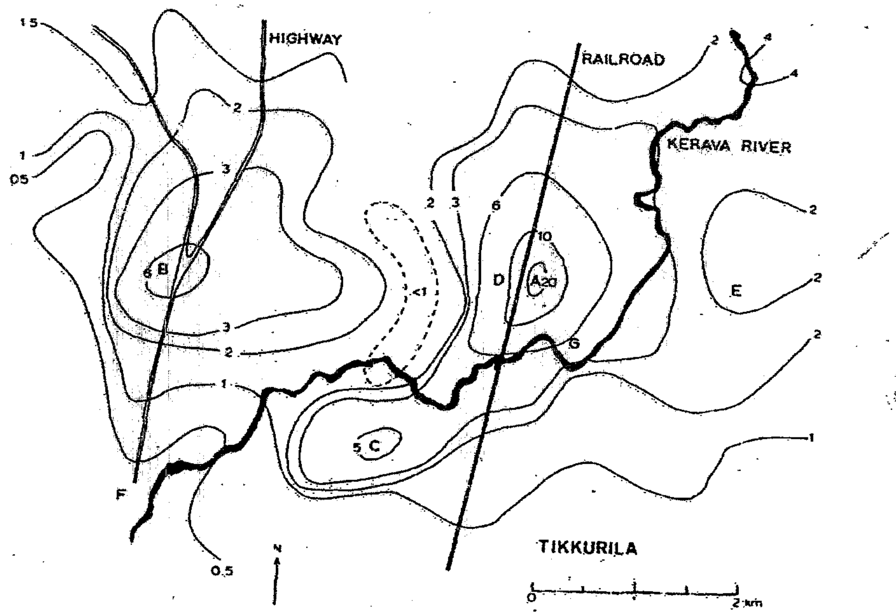

Fig. 3. The Tikkurila area. A and B = secondary lead smelteries, C = battery factory with a small foundry, D = accumulator plant, E = soldering workshops, F = accumulator plant, G = Agricultural Research Center. The isopleth numbers are equivalent to monthly dustfall lead within the marked zones, expressed in grams per 100 m^2.

study. In all, 16 persons were omitted for this reason, along with a further 25 persons for other reasons such as clotting of the blood sample, or their moving from the district. Of the remaining 293 persons, 121 were males, and 172 females. The age distribution is presented in Table 34. In all, 30 males and 23 females were working outside the district, while 91 males and 149 females were both residing and working within it. Of them, 12 males and 62 females, mostly housewives and pensioners, spent the whole day at home. The major part of the population studied (239 persons) was made up of inhabitants living around smeltery A. The cigarette-smoking habits are indicated in Table 35.

0.07, p >0.1). If only the 59 subjects living around smeltery A and spending the whole day at home are included, the correlation between Pb-B and the distance is even stronger (r = -0.62, p <0.001), as is observable from Fig. 6. The correlation of ALAD with the distance in this group was of the same magnitude as that for the entire population (r = 0.28, p <0.05).

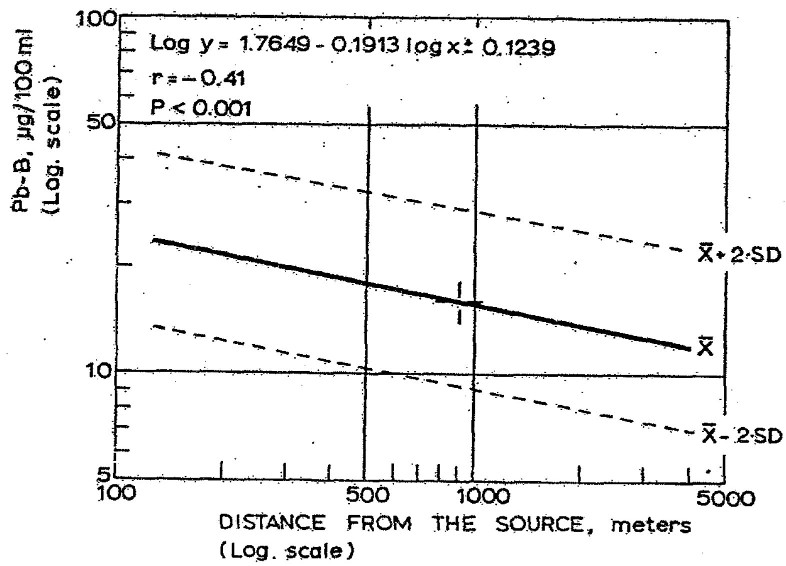

Fig. 4. Correlation between blood-lead concentration and distance of habitation from the emitting source (smeltery A).

The dustfall lead survey was effected in Tikkurila between October 6th and November 6th. The dustfall was sampled by 80 collectors, spread over an area of 40 square kilometers. Arbitrary isopleths for total leadfall were drawn, and the Pb-B and ALAD results were correlated to the so-formed zones representing varying degrees of leadfall. The leadfall isopleths are illustrated in Fig. 3.

In the handling of the data, consideration had to be given to the neighborhood of lead smelter B being sparsely inhabited, with practically no settlement within one kilometer of the chimney. Consequently, the 54 persons from this neigborhood are included merely in those calculations in which the distance to the emitting source was not an essential feature. They have also been omitted from the correlations between blood lead concentrations and total leadfall.

Logarithmic transformation has been applied for calculation of the means and standard deviations in view of the skewness of the distributions.

8.3. Results

Lead smeltery A exerted a distinct effect on the Pb-B's of the surrounding population; this is apparent from the negative correlation between those values and the distance of habitation from the emitting source ($r = -0.41$, $p < 0.001$) (Fig. 4). This effect was more pronounced in the females ($r = -0.49$, $p < 0.001$) than in the males ($r = -0.23$, $p < 0.05$). The increased average lead absorption in people living near the smeltery was accompanied by a decrease in their erythrocyte ALAD activity. However, Fig. 5 indicates that the correlation with the distance from the source was weaker than that for Pb-B ($r = 0.21$, $p < 0.01$). The correlation was, furthermore, almost entirely attributable to the females ($r = 0.28$, $p < 0.01$), since, on an average, the ALAD values of the males were similar irrespective of where they lived (r =

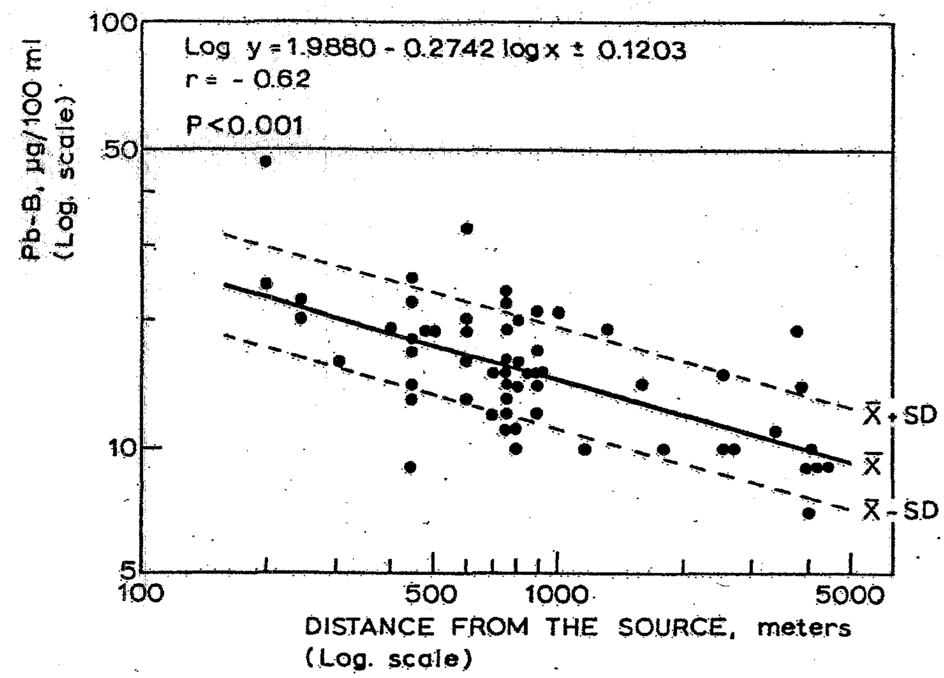

Fig. 6. Correlation between blood-lead concentration and distance of habitation from smeltery A, as concerns only the 59 subjects who spent the whole day at home.

The means and standard deviations of the Pb-B's and ALAD activities in the whole population have been tabulated in Tables 36 and 37. The mean Pb-B for men is higher than that for women ($t = 7.02$, $p < 0.001$). A statistically significant negative correlation became evident between the Pb-B and the ALAD values (Fig. 8). The correlation was of the same order of magnitude for males ($r = -0.32$, $p < 0.001$) and females ($r = -0.34$, $p < 0.001$). No relationship was found between Pb-B and age. Smokers had slightly higher Pb-B values than nonsmokers (Table 38). Only males are included in view of the small number of female smokers available.

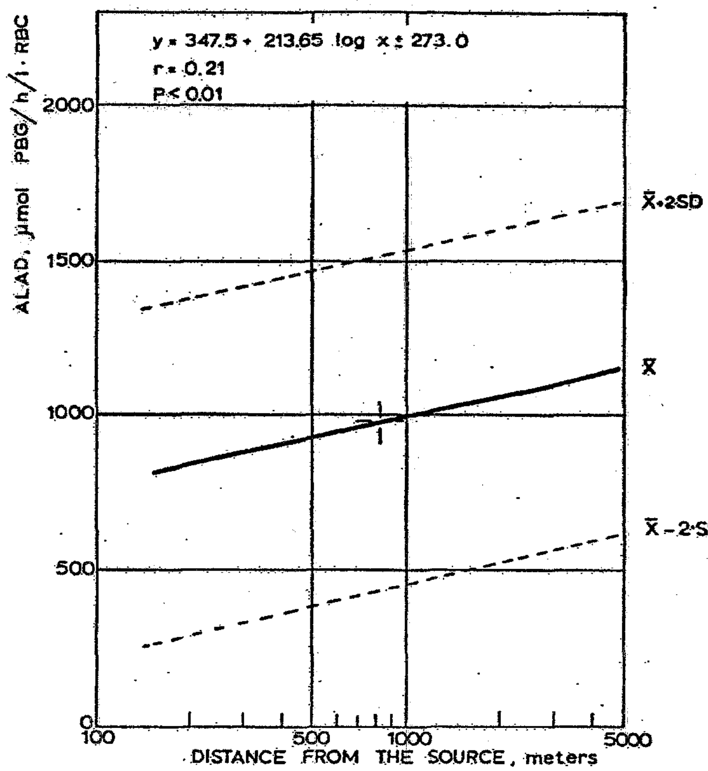

Fig. 5. Correlation between erythrocyte ALAD activity and distance of habitation from the emitting source (smeltery A).

The results of the dustfall survey are presented in Fig. 3., in which the isopleth numbers are equivalent to monthly dustfall lead in grams per 100 m^2. The dustfall lead markedly increases on the lead smelteries being approached. A statistically significant correlation is obtained when the Pb-B's of people living in the different zones, defined by the isopleths, are correlated with the monthly dustfall lead within the corresponding zones ($r = 0.32$, $p < 0.001$). The correlation is visualized in Fig. 7 .

Table 36. Blood-lead concentrations in 293 inhabitants of the Tikkurila area. Values expressed as µg/100 ml.

	N	$\bar{x}$	$\bar{x}$-SD	$\bar{x}$+SD
Males	121	18.1	13.6	24.1
Females	172	14.3	10.6	19.1
Total	293	15.7	11.5	21.5

Table 37. Erythrocyte ALAD activities in 276 inhabitants of the Tikkurila area. Values expressed as µmol PBG/h/l RBC.

	N	$\bar{x}$	SD
Males	115	948	271
Females	161	1031	284
Total	276	996	281

Table 38. Effect of cigarette-smoking on Pb-B levels of the Tikkurila population. Values expressed as µg/100 ml.

	>20 cigarettes a day	All smokers	Nonsmokers
N	11	46	70
$\bar{x}$	21.4	19.1	17.6
t	----------	2.43	----------
p	----------	<0.05	----------
t		---------- 1.75	----------
p		----------=0.08	----------

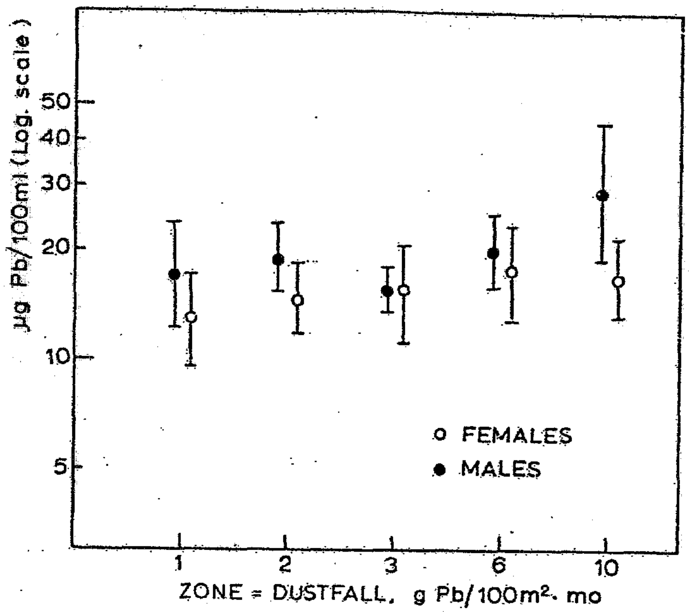

Fig. 7. Correlation between Pb-B levels and monthly dustfall lead. The numbers on the abscissa are equivalent to monthly dustfall lead in grams per 100 m^2. Note log scale on the ordinate

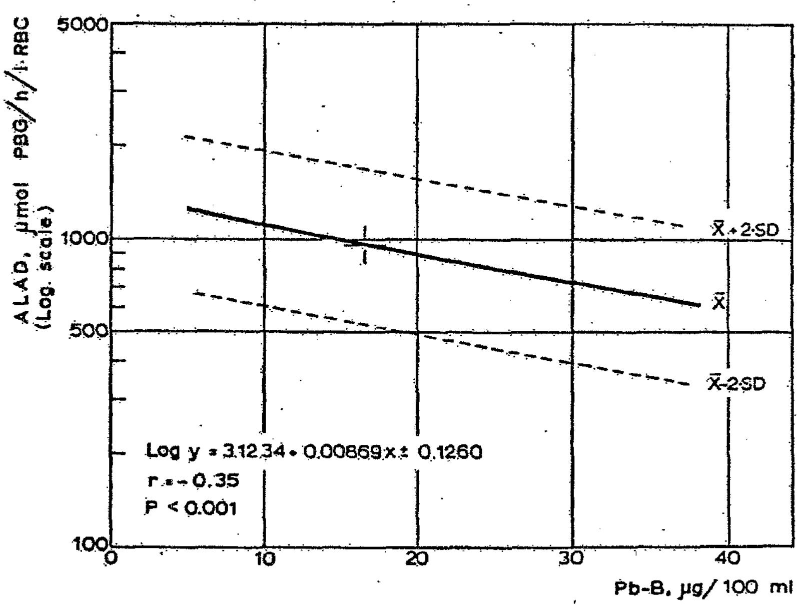

Fig. 8. Correlation between blood-lead concentration and erythrocyte ALAD activity.

that the study was accomplished after the installation of purification devices at smelter A; the Pb-A levels were thus presumably even higher in 1970.

Moreover, the Tikkurila survey disclosed higher Pb-B values for males than for females. Within this population, however, the magnitude of the difference may have been affected by certain features of the material. For instance, smokers, and heavy smokers in particular, who in this study displayed slightly higher Pb-B values than nonsmokers, were more frequent among the men. Furthermore, the mean distance to the emitting source (smeltery A) was 880 m for the females, and only 760 m for the males. Both factors would tend to increase the differences between the Pb-B levels of men and women. Moreover, if lead content is referred to the PCV instead of to whole blood, the inter-sex difference is diminished from 18 (males) and 14 (females) µg/100 ml whole blood to 39 and 34 µg/100 ml packed blood cells, respectively.

From the results obtained in this study, it is obvious that the lead pollution originating from the lead smelteries may be sufficiently heavy to increase the lead absorption of the surrounding population to a measurable extent.

8.4. Discussion

Both the dustfall lead and the Pb-B measurements confirm that under certain conditions the population living around a lead smeltery may be subjected to lead exposure that definitely exceeds "normal" rural or suburban levels, and that the exposure is increased when the emitting source is approached. The fact that a negative correlation was demonstrable between the distance of habitation and Pb-B, stresses that smeltery A was a heavy polluter indeed, since other circumstances tended to weaken such a relationship. First, smeltery A was not the only source of lead pollution. Several other lead-emitting plants are located in the district, and in addition, highway and ordinary suburban traffic contribute to the total amount of pollution. Secondly, only part of the people spent most of their time at home, or even within the district. This was probably the more important factor, and explains why the use of monthly dustfall lead zones as a reference, instead of the distance of habitation, did not greatly improve the correlation. The same explanation is apparently also valid in regard to females having stronger correlations than males between the Pb-B and the distance of habitation from smeltery A; of the 59 persons living around that smeltery, and spending the whole day at home, 49 were women. When consideration is limited only to those spending the whole day at home, a substantial improvement is observable in the correlation between Pb-B and the distance.

The increased lead exposure was not only evident as a rise in Pb-B; a partial inhibition of the ALAD activity was also demonstrable. The dose-response effect for ALAD was not so marked as that for Pb-B, however, and was demonstrable in women only. For technical reasons the Pb-A in Tikkurila could not be measured. However, a study conducted in 1973 on particulate lead in the air at Tikkurila showed a maximum monthly mean of 6.4 $\mu g/m^3$ of air in the vicinity of smeltery A. The mean concentration for six months was 1.8 $\mu g/m^3$ (Vornamo 1974). It must, however, be emphasized

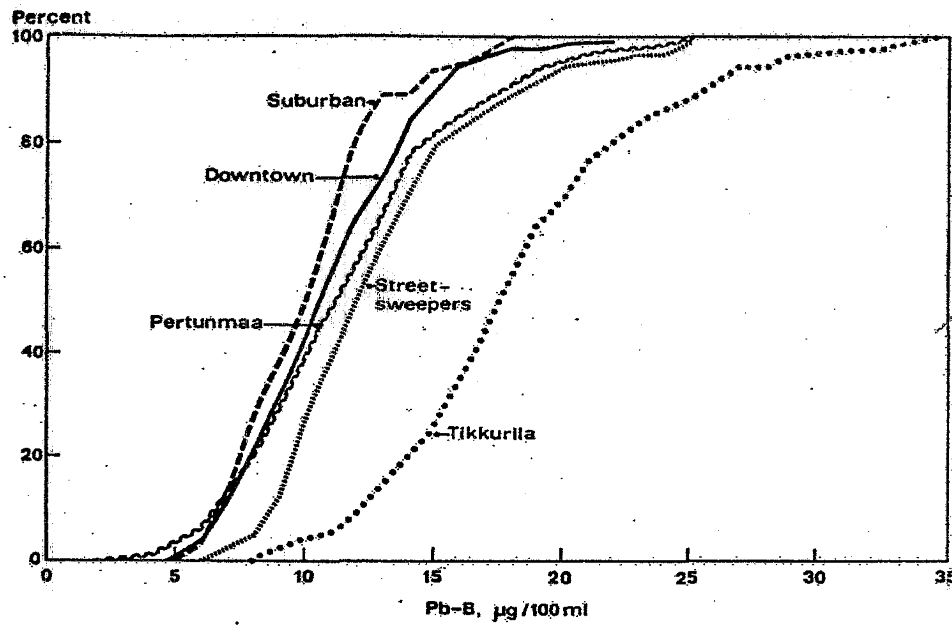

Fig. 9. Cumulative percentage distribution of male Pb-B values of separate series

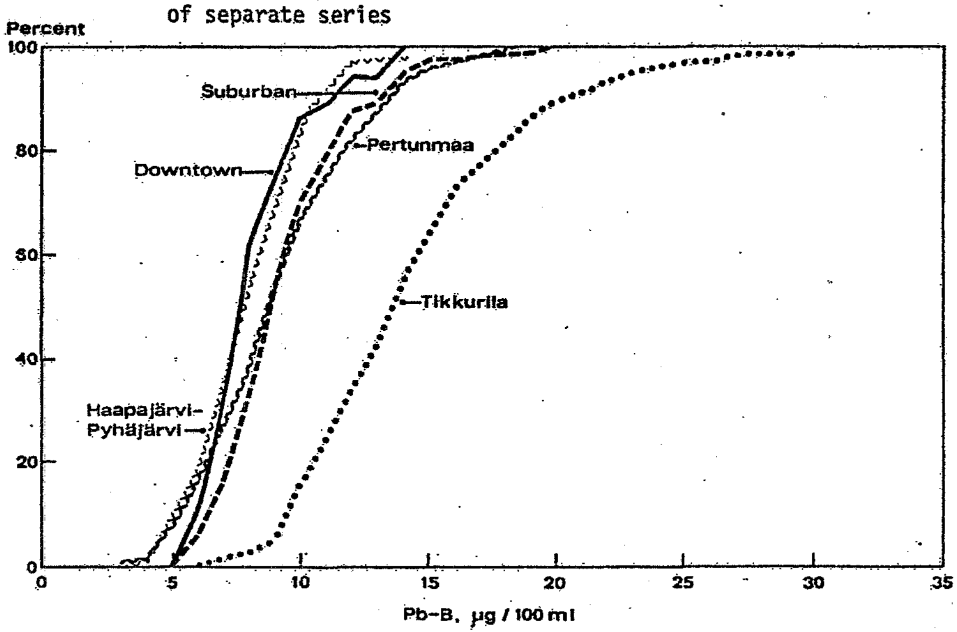

Fig. 10. Cumulative percentage distribution of female Pb-B values of separate series

9. COMPARATIVE RESULTS

The results obtained in the separate groups have been combined with a view to the achievement of greater clarity. Table 39 illustrates the annual mean Pb-A levels of different rural and urban air sampling sites. The downtown sampling site exhibited a yearly mean 50 times as great as the rural mean. The lowest annual mean in Helsinki was obtained at the suburban Otaniemi sampling site; this value exceeded the rural mean to the extent of nearly 20 times.

Table 39. Annual mean concentrations of air-suspended particulate lead at urban and rural sampling sites. Values expressed as $\mu g/m^3$. Helsinki sampling site numbers refer to areas as follows: 1 = downtown, 2 = mixed industrial-traffic-residential, 3 and 4 = suburban

Sampling site		Annual mean
Pertunmaa		0.025
Helsinki	1.	1.32
	2.	0.90
	3.	1.05
	4.	0.43

The cumulative percentage distribution of Pb-B values of men and women are presented in Figs. 9 and 10, respectively. The female streetsweepers have been omitted from the figure, in view of the smallness of the group. The distribution curve of the Tikkurila group shows the most apparent difference from all the other groups, throughout revealing Pb-B levels that exceeded, at a statistically highly significant level, all of the Pb-B levels disclosed by the other groups (Table 40). The testing of significance between the groups was done by means of the Kolmogorov-Smirnov test, because of the skewness of the Tikkurila distribution. In general, the skewness of the distribution increases with increasing Pb-B values.

not been taken into account (Nozaki 1966), and the shape and the chemical composition of particles may highly alter the figures of absorption (Lawther et al. 1972 a, b). It can be seen from Table 41 that the total daily intake of lead is distinctly below the provisional tolerable weekly intake of 3 mg per adult person proposed by the Joint FAO/WHO Expert Committee on Food Additives (FAO/WHO 1972).

Table 41. Daily lead intake and absorption at an annual mean air lead concentration of 1.3 $\mu g/m^3$. Values expressed as micrograms of lead.

	Daily intake		Daily absorption	
Source	Mean	Range	Mean	Range
Food	169	71 - 310	14	6 - 25
Beverages	35	4 - 116	3	trace* - 9
Air	20	11 - 33	7	4 - 12
Total	224	86 - 459	24	10 - 46

* Trace denotes <1 μg

The hematocrit values for all groups are given in Table 42. No inter-group differences of statistical significance existed. The mean hematocrit values for men ranged from 45.5 to 46.2 percent, and those for women from 41.5 to 42.4 percent. The hemoglobin mean values (Table 43) varied between 14.4 and 15.5 g/100 ml for men, and between 12.9 and 13.9 g/100 ml for women. The hemoglobin values of the Tikkurila males and females being significantly lower than the others was considered to be due to systematic errors of the analyses; this group was the only one analyzed by non--professional laboratory personnel. A true difference between the groups seems less intelligible.

Table 40. Significance testing for the Tikkurila Pb-B levels as compared to other population groups.

	Males		Females	
	D	p	D	p
Tikkurila vs.:				
Streetsweepers	54.3	<0.001	47.1	<0.05
Policemen	50.2	<0.001	-	-
Downtown	64.0	<0.001	71.0	<0.001
Suburban	74.3	<0.001	56.1	<0.001
Pertunmaa	57.9	<0.001	51.5	<0.001
Haapajärvi-Pyhäjärvi	-	-	70.1	<0.001

The Helsinki downtown population was subjected to the highest concentrations of lead in ambient air. An attempt has been made to estimate the total daily amount of lead absorbed by this population group, taking into account the lead inhaled from the air, and ingested with food and beverages (Table 41). In view of the great number of meals eaten outside homes, and the voluntary participation of entire households being a prerequisite, a dietary study in Helsinki, identical with the Pertunmaa survey, was considered to be impracticable. Thus the assumption was made that no important differences existed between urban and rural dietary lead intake. A gastrointestinal absorption of 8 percent, and an average amount of inhaled lead reaching the blood stream of 37 percent at a respiratory rate corresponding to a daily 15 m^3 of air, were applied. The Pb-A concentration used in the calculations was 1.3 $\mu g/m^3$. The calculated mean absorption of about 24 µg Pb/day is distinctly lower than the values obtained by Kehoe (1961a) and Schroeder and Tipton (1968). However, it should be emphasized that the value conceals large inter-individual variations with respect to absorption (Hursh and Suomela 1968); furthermore, the degree of physical activity altering the respiratory volume has

10. GENERAL DISCUSSION

10.1. Validity of the Pb-B assay

When this study was begun, the Pb-B assay was known to be vulnerable to systematic errors. As interpretation of the results would be completely dependent on the validity of the Pb-B assay, great care was taken to ensure its accuracy and precision throughout the work (section 5.4.). The precision appeared to be on a high level during all of the surveys. The method error of duplicate measurements reported by the laboratories (1.1 µg/100 ml), somewhat lower than that noted for a set of 26 duplicate samples analyzed unbeknown to the laboratory personnel (1.7 µg/100 ml), is consistent with the findings of Berlin and his colleagues (1974 a), who suggested that laboratories tended to reject outlying results when reporting. All of the Pb-B values reported here were mean values of two parallel determinations; if the discrepancy between duplicate measurements exceeded 5 µg/100 ml, the analyses were repeated. This procedure probably accounts for the differences referred to above.

In regard to accuracy, it is observable from the Inter-Scandinavian comparison corresponding to the period of the Pertunmaa Pb-B study (Table 6) that at the time our method showed somewhat higher Pb-B values than did most of the other laboratories; our values were systematically higher than the mean values of the 8 participating laboratories, and furthermore with several samples our values were the highest of all. The agreement between results obtained by the ASARCO laboratories and those of the Institute of Occupational Health was much closer than is usually found in inter-laboratory comparisons (Keppler et al. 1970, Berlin et al. 1972, 1974 a)(Tables 7 and 26). The accuracy control of the period of the diet survey and the Helsinki and Haapajärvi-Pyhäjärvi surveys also shows that our Pb-B values were slightly higher than the mean of the Scandinavian laboratories and the ASARCO labora-

Table 42. Hematocrit value of different urban and rural population groups

	N	$\bar{x}$	SD	range
Tikkurila				
Males	113	45.7	2.8	38-53
Females	166	41.8	2.6	36-50
Helsinki				
Males	182	45.8	2.8	38-54
Females	121	41.8	2.5	33-49
Streetsweepers				
Males	85	46.1	2.8	38-52
Females	11	42.2	2.1	38-46
Traffic policemen				
Males	28	46.2	3.2	34-51
Pertunmaa				
Males	239	45.5	3.5	36-57
Females	254	41.8	3.5	27-57

Table 43. Hemoglobin concentration of different urban and rural population groups. Values expressed as g/100 ml.

	N	$\bar{x}$	SD	range
Tikkurila				
Males	113	14.4	1.0	11.3-16.6
Females	166	12.9	0.9	11.0-16.2
Helsinki				
Males	182	15.3	1.1	11.9-18.0
Females	120	13.7	1.0	11.3-15.9
Streetsweepers				
Males	85	15.4	1.0	13.0-17.5
Females	11	13.9	0.6	12.6-14.6
Traffic policemen				
Males	28	14.7	1.2	10.0-16.1
Pertunmaa				
Males	240	15.0	1.2	11.9-18.6
Females	254	13.4	1.2	6.3-17.7

within the biological guide proposed by Zielhuis (1974), and below the maximum allowable individual values suggested by both Zielhuis (1974) and the U.S. Environmental Protection Agency (1972) (See section 2.5.1.). Only one person, living at a distance of 100 m from the chimney of one of the lead smelteries, had a value that exceeded the proposed limit of 40 µg/100 ml. The narrow range obtained in this study was probably due to the scrupulous omission of all subjects with possible occupational exposure.

10.3. The ALAD assay in population studies

The sensitivity of the ALAD test has been established by many investigators (Bonsignore et al. 1965, DeBruin and Hoolboom 1967, Hernberg et al. 1970, Haas et al. 1971, Haeger-Aronsen et al. 1971, Millar et al. 1970, Tola 1973). Moreover, it has repeatedly been shown that the specificity is high (Hernberg and Nikkanen 1972), and the accuracy and precision are good (Berlin et al. 1972, 1974 b). It has been suggested that the ALAD assay, by virtue of these characteristics, would be suitable for population surveys (Hernberg et al. 1970, Berlin et al. 1972, 1974 b, Berlin and Schaller 1974). Despite the exceptionally low Pb-B levels found in the present study, the ALAD assay appeared to be sufficiently sensitive for discrimination between most groups in which the Pb-B levels differed at a statistically significant level. The ALAD test failed to reflect only the differences found between the downtown and the suburban females, and differences between the two suburban groups (section 7.3.3.). When the study was initiated, no experience had been gained of ALAD from population studies, but during its course some researchers reported on their experience in population studies where the ALAD test has been employed. Secchi and his colleagues, for instance, have successfully applied the ALAD test in studies on varying population groups subjected to different degrees of environmental lead exposure (Secchi et al. 1971, 1972, Secchi and Alessio 1974). The Pb-B levels of those population groups from Milan, or tories, although the agreement was close, especially at low Pb-B levels (Tables 24-26). It can be concluded that, if anything, the values reported by the Institute of Occupational Health were systematically a little higher than the mean values of the reference laboratories.

10.2. Blood lead levels in Finland

The mean Pb-B levels found in the target groups selected to represent the Finnish general population were throughout among the lowest ever reported (Hofreuter 1961, Ludwig et al. 1965, Holmqvist 1966, Lehnert et al. 1967, Horiuchi 1970, Tepper and Levin 1972), together with values obtained for smaller groups from Southern Sweden (Haeger-Aronsen et al. 1971) and Denmark (Nygaard et al. 1973). Goldwater and Hoover (1967) have also reported relatively low values for some population groups. The low values reported here can scarcely be attributed to systematic errors, since the values were too high rather than too low, as compared to the techniques of the reference laboratories.

The only population groups in which urban pollution became evident, as reflected by elevated Pb-B values, were the streetsweepers and the policemen, both of which experienced more exposure than other populations. However, consistently with all other categories, the streetsweepers' values were comparatively low; they were thus only about one half of those reported for streetsweepers in Frankfurt a.M. (Lehnert et al. 1970) and Vienna (Lorant and Svoboda 1973). The Pb-B values of 15 traffic policemen in Stockholm have been reported to be of similar order of magnitude (Göthe et al. 1973).

The inhabitants of Tikkurila exhibited a distinctly higher lead absorption, which was closely correlated to the distance of residence to the main source of emission.

Nevertheless, it can be concluded that all of the separate groups surveyed displayed percentile distributions of their Pb-B values

An important feature of the results was that the negative correlation between Pb-B and ALAD was statistically highly significant ($p < 0.001$), even at Pb-B levels of 10 µg/100 ml or below. This has a bearing upon the question of whether or not a threshold exists for the inhibitiory effect of Pb-B on ALAD activity. Both the conception of a threshold, and that of a non-threshold have their advocates. However, whether a threshold is obtained or not seems to be a question of the sensitivity and precision of the methods applied.

In the comparison of environmental exposure, the Pb-B technique applied currently is the most straightforward method, although it calls for advanced equipment and skilled personnel. On the other hand, the ALAD assay is less expensive, less exacting and has a higher inter-laboratory comparability than has the Pb-B method (Berlin et al. 1972, 1974a,b).The only important drawback of the ALAD method is the lack of stability, which means that the analyses should be performed within five hours of sampling (Nikkanen et al. 1972). According to the experience gained in this study, the ALAD assay appears to be a useful epidemiological tool for comparison of environmental lead exposure in various populations.

10.4. Preventive needs for Finland in the light of the present study

The results presented here do not indicate any effect of traffic alone on lead absorption by the general adult population. Although the streetsweepers displayed an increase in absorption as did the policemen, they cannot be ranked in the same category as the general population, as they are subjected to additional exposure to air- and dustborne lead. Even so, the rise in absorption was very small. The relatively higher Pb-B values of the Pohjois-Haaga group were most probably attributable to additional exposure derived from lead-emitting sources other than traffic. This opinion gains support from the study by Mattson and Jaakkola (1974), who calculated the rural neighborhoods of Milan, however, were higher than the commonly reported levels for general populations (see section 2.5.1.). Also, Lob and his co-workers were able to discriminate between a rural and an urban group of schoolboys by employment of the ALAD assay. The mean Pb-B values of the two groups were 18.9 for the rural, and 22.2 μg/100 ml for the urban group (Lob et al. 1972). In contrast, Kennedy and his colleagues (1972) did not discover any relationship between ALAD activities and Pb-B values below 25 μg/100 ml. Valloton and his colleagues (1973) could not establish a significant correlation between Pb-B levels and ALAD activities in people unexposed to lead by profession; neither did Coulston's team find any inhibition of ALAD in their 18-week chamber exposure study at 3.2 μg Pb/m^3 of air, although a distinct elevation of the Pb-B levels occurred. However, in an identically designed study at 10.9 μg Pb/m^3 of air, a distinct inhibition of the ALAD activity was noted (Coulston et al. 1973 a, b). These seeming discrepancies are probably attributable to methodological aspects. Close correlation between Pb-B and ALAD necessarily calls for extremely high precision and sensitivity in both methods. These aspects become even more important when the range of variation is very narrow, as is the case in studies of the general population. The validity aspects of the Pb-B have already been discussed, and will not be repeated here. In regard to the ALAD assay, the most important feature is standardization of the pH value, which presupposes a stable buffer. Furthermore, all of the researchers referred to above used a pH of 7.0, which according to Nikkanen and his co-workers (1972) is less sensitive than the 6.8 employed here; however, the highest correlation coefficient was found by Nikkanen and his colleagues at a pH of 6.4. With a view to the comparability between laboratories, it thus seems reasonable to recommend the standardized ALAD assay suggested by Berlin and Schaller (1974) for future population studies; the method employs a pH of 6.4, and has been specially developed to suit low--level exposure to environmental lead.

lead additives in gasoline cause impairment of the effectiveness of such equipments; thus, further aspects favoring a reduction of lead content in gasoline must be borne in mind (Prescott 1972, EPA 1973). Regardless of the solution that is chosen, the reduction of lead additives will be associated with high costs. The first obvious step towards a reduction of atmospheric lead pollution should accordingly be directed towards the more easily controllable pollution that originates in lead-processing plants, incinerators, power stations and other coal-burning manufacturing establishments.

a dispersion into the Helsinki air of about 10 kg Pb/h from traffic, and a total of about 3 kg Pb/h from the Helsinki main incinerator alone.

Since in principle all surplus lead exposure should be avoided, reduction of the lead content of gasoline is a praiseworthy measure. Nevertheless, the results reported here indicate that the problem seems much less urgent in Finland than in countries with high population and traffic density. The elimination or the reduction of lead additives will lead to lower-octane gasoline, or necessitate the maintenance of octane ratings by some substitute, or substitutes, for lead. Lower-octane gasoline requires lower compression ratios, which signify a loss in engine performance, and an increase in gasoline consumption; this is an undesirable consequence against the background of energy crises. A loss in performance would in particular affect the relatively small, highly-tuned European cars. The means to preserve the octane ratings by other additives will thus assume major importance. The easiest and least costly way would be that of increasing the content of aromatic hydrocarbons (Boddy 1972, Campbell 1973). Unfortunately, the content of aromatic hydrocarbons in European fuel is already higher, for instance, than that in the U.S.A.

The implications connected with an increased content of aromatic hydrocarbons in gasoline are probably even more obscure than the continued use of lead. Berlin, Gage and Johnson (1974) have reviewed the likely consequences of such an increase. An increase of potentially carcinogenic polynuclear aromatic hydrocarbons in ambient air would occur. Probably, an increase of toxic products, such as eye-irritating ones, would take place as a result of the photochemical reactivity of a number of hydrocarbons. Moreover, a subsequent increase in the benzene content would introduce an occupational risk for all those involved in the handling of the gasoline. Although the emission of hydrocarbons can partly be controlled by the use of catalytic exhaust-treatment devices, the men displayed a mean of 13.5 µg/100 ml, indicating a slight increase in the lead absorption.

No effect on Pb-B levels of traffic alone was detectable within the general population; thus, no statistically significant differences were found between downtown and rural or suburban Pb-B levels. The observation that the Pohjois-Haaga suburbanities disclosed higher Pb-B levels than did other suburbanities indicates that factors other than traffic should be borne in mind in assessment of the effect of traffic on lead absorption.

The mean Pb-B of 293 inhabitants of the Tikkurila area, at a statistically highly significant level, exceeded the means of all the other groups. A distinct correlation was apparent between the distance of habitation from the emitting source (a secondary lead smeltery) and the Pb-B levels . The rise in Pb-B on approaching the emitter was accompanied by a decrease in the erythrocyte ALAD activity. Similarly, there was established a correlation between Pb-B levels and the monthly dustfall lead within the area.

The age per se was not found to have any relationship to the Pb-B level. An effect of cigarette-smoking on Pb-B levels was established only in the Tikkurila male population, and the streetsweepers aged 45 years or more, indicating that probably factors other than the inhalation of cigarette smoke itself may explain the detection of higher Pb-B values in smokers than in nonsmokers. Men in each separate group had higher Pb-B levels than had women. This difference was not entirely attributable to the higher hematocrit value of men. The distinctly higher dietary-lead intake for men than that for women probably accounts for part of the difference.

The usefulness of the ALAD assay was evaluated within the compass of the Helsinki and Tikkurila surveys. The ALAD assay proved useful and reliable in the discrimination between separate groups whose Pb-B levels differed to a small but measurable extent. The

11. SUMMARY

The levels of lead in the blood of the adult general population in Finland were determined during the period June 1970 - June 1973. The population groups were selected to represent varying degrees of environmental lead exposure. The possibility of occupational exposure to lead was scrupulously excluded. The rural population groups were sampled in the commune of Pertunmaa, and the communes of Haapajärvi and Pyhäjärvi; all the urban groups were sampled in Helsinki. In addition, a survey was made of the population living in Tikkurila, a district characterized by its congregation of lead--utilizing manufacturing plants. The concentrations of air-suspended particulate lead were studied in Helsinki and Pertunmaa; the population groups were sampled from the geographic vicinity of the sampling sites. By the employment of a double portion method, and a recording period of three days, the dietary lead intake was assessed in 23 rural households in Pertunmaa. Care was taken to ensure the accuracy and precision of the analytical methods, and the Pb-B assay in particular, by continuously checking the methods at experienced laboratories.

There was found a mean dietary lead intake of the Pertunmaa population amounting to 204 μg/day (range 89 - 360 μg/day). The mean intake of men was higher (231 μg/day) than that of women (178 μg/day).

The annual mean concentration of lead in air in Helsinki ranged from 0.43 to 1.32 μg/m^3. The corresponding mean at the rural sampling site (Pertunmaa) was 0.025 μg/m^3.

From an international standpoint, the Pb-B levels were low. The highest mean Pb-B value in groups of the general population was disclosed by the rural male group (12.3 μg/100 ml), and the lowest by the female respondents of the diet survey (7.9 μg/100 ml). A group comprising 86 male streetsweepers from Helsinki displayed a Pb-B mean value of 13.3 μg/100 ml, and 28 traffic-directing police-

12. ACKNOWLEDGEMENTS

The subject of this study was suggested to me by Sven Hernberg, M.D., Associate Professor, and Scientific Director at the Institute of Occupational Health, my friend and teacher to whom my sincere thanks are due. During the course of the study, his never-failing enthusiasm and advice gave me great encouragement. I am deeply grateful for his constructive criticism while the final report was being prepared. I am also greatly indebted to Professor Martti J. Karvonen, M.D., Ph.D., former Chief of the Institute, and his successor, Jorma Rantanen, M.D., who have both taken great interest in the investigation and have placed all the facilities of the Institute at my disposal.

I am especially indebted to Professor Ilari Rantasalo, M.D., for the interest he has shown, and for the valuable help he has provided in the final stage of the study.

I wish to thank Professor Kimmo Aho, M.D., for the valuable and sound criticism I received during the preparation of the manuscript.

Gratitude is due to Miss Raili Vilhunen, M.Sc. (Eng.), and Mr Jorma Nikkanen, M.Sc., for their supervision of laboratory analyses, and to Mrs Hilkka Järventaus, who in this part of the work gave skilful technical assistance. I am also obliged to Professor Arvo Laamanen, Ph.D., Mr Aulis Ryhänen, M.Sc. (Eng.), and Mr Hannu Vornamo, M.Sc., for their cooperation in connection with the aerometric surveys.

My thanks are due to Acting Professor Maija Pekkarinen, Dr. Agr. Sc., for the invaluable help she provided in the planning of the diet survey, and to Miss Lea Turpeinen, M.Sc., for supervising the collection of food samples; this exacting collection work was done by Miss Pirjo Paattiniemi and Miss Pirjo Mäkelä, to whom my gratitude is also due.

negative correlation between Pb-B and ALAD activity was found to prevail at a statistically significant level still at Pb-B levels of 10 µg/100 ml or lower.

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In the statistical treatment of my data, I have received valuable help and advice from Mr Timo Partanen, M.Sc., Mr Erkki Järvinen, M.Sc., Mr Markku Nurminen, M.Sc., Mrs Sisko Asp, M.Sc. and Mrs Pirjo Fahlström. For all this, I wish to express my sincere thanks. During the course of the study several persons have earned my deep gratitude for their unselfish assistance; I feel especially indebted to Mrs Ritva Vesanto, Mrs Tuulikki Poukka, Raija Berghäll, M.D., Frederika Tekonen, M.D., Ove Näsman, M.D. and Miss Ritva Järnström. Similarly, I wish to thank Mrs Marja-Liisa Korkala for her drawings.

My very cordial thanks are extended to Professor Nils Riska, M.D., Head of Mjölbolsta Hospital, for his constant encouragement, and the supporting attitude he adopted to my investigation.

My warmest gratitude is, however, due to my wife, who throughout took an encouraging interest in my investigation; moreover, her endless understanding and patience greatly facilitated my work during the long course of the study.

My gratitude is also extended to Mr Fred A Fewster, who revised the language of the manuscript.

This investigation has been supported financially by the Finska Läkaresällskapet.

Helsinki, April 1975

Claës Henrik Nordman

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