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Health and safety—the downward trend in lead levels

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Abstract

Lead has been known and used by man for thousands of years and its toxic properties have been known for almost as long. In consequence, a wide body of legislation has built up and is designed to protect individuals in both the occupational and the general environments. At the occupational level, two types of controls are widely employed, namely, lead-in-air and lead-in-blood. Limits placed on the amount of lead-in-air are designed to ensure that individuals are not exposed to unsafe levels of lead via inhalation. Currently, the most common standard is 0.15 mg m^{-3} but there is a clear downward trend and levels as low as 0.05 mg m^{-3} are mandatory in some countries. Controls on the amount of lead-in-blood give a more direct indication of the exposure experienced by individuals. The most common level presently employed is 70 μg m^{-3} but, as knowledge of the health effects of lead improves, lower levels are being introduced and 50 μg m^{-3} is now fairly common. While women are no more sensitive to lead than men, some countries do employ lower blood-lead limits for women in the workplace in order to protect any developing foetus. This paper examines the levels currently in force in various countries and describes developments which are now taking place in the legislation that is being enacted in several parts of the world. As far as the general public is concerned, only a relatively small number of countries employ controls. Where controls do exist, however, they are set at much lower levels than for the occupational environment in order to protect the most sensitive members of the population. Several countries employ limits on lead in ambient air. Traditionally, these have been set at either 1.5 or 2.0 μg m^{-3}, but several countries are currently considering sharp downward revisions to levels of the order of 0.5 μg m^{-3}. A few countries offer guidance on acceptable blood levels for the general population, most commonly for children. Again downward revisions are taking place but where data are available, there is a very encouraging downward trend also in average blood-lead levels found amongst members of the population. These must be due to a combination of factors which have reduced exposures to lead. The net result is that, at least in the more industrialized countries, average blood-lead levels have fallen to extremely low levels and very few individuals can be found with blood lead levels above currently accepted levels of concern. © 1998 Published by Elsevier Science S.A. All rights reserved.

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1. Introduction

Lead is a very old and versatile metal with a wide range of important applications. Unfortunately, it is also a toxic metal which, if absorbed into the body in large amounts either through a single high exposure incident or via long-term chronic exposure to lower amounts, can result in adverse health effects. Consequently, legislation has been developed over many years, and continues to be developed, with the objective to limiting the quantities of lead to which the general population and/or those working with lead can be exposed.

This growing body of legislation, together with general increased interest in lead, tend to suggest that levels of exposure are increasing and that concerted actions are necessary to curb a growing problem. In practice, however, this is not so. Exposure to lead is on the decline and blood-lead levels in the general population and those exposed to lead in the workplace are reducing.

2. Exposure sources

Lead can be taken into the body either by inhalation or by ingestion via the air we breathe, the food we eat, and the water we drink. The principal routes by which most people are exposed to lead are shown in Fig. 1. Lead can

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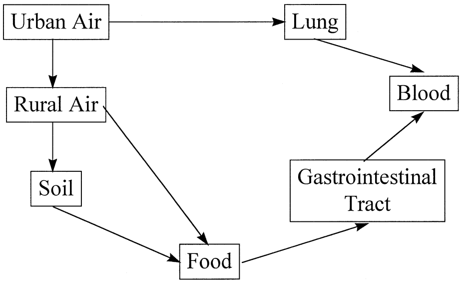

Fig. 1. Typical air lead pathways contributing to blood-leads.

be present in air in two main forms—as fume or as dust. Lead fume arises from high-temperature operations although significant fume generation does not occur below about 500°C. Fume consists of very fine particles, whereas dust particles are much larger. In the occupational environment, the obvious route of exposure is inhalation of lead dust or fume in the air. Lead absorbed into the body by the respiratory system is influenced by the particle-size distribution, the breathing rate, and the lung volume. Ingestion can also play a significant part when dust is transferred to the mouth via hands (e.g., biting fingernails), food or drink. The proportion of lead absorbed from the digestive system is about 10% in adults, whereas levels of 40–50% have been reported in children. It is for this reason that the legislation in many countries prohibits eating or drinking in the workplace.

Ingestion or inhalation of lead can also take place outside the work environment. Regardless of its origins, a proportion of the lead taken into the body is absorbed and retained. Monitoring the amount of lead in the body thus provides a useful—and necessary—complement to lead-in-air monitoring as a means of protecting workers from potentially adverse health effects. Table 1 illustrates the typical lead intake rates. Within the body, the non-excreted fraction of absorbed lead is concentrated predominately in the blood, soft tissue, bones and teeth. In adults, about 95% is in the bones as compared with about 70% in children. The biological half-lifetime of lead in the blood is 20–40 days, sometimes longer. Lead in the bones can have a half-lifetime measured in years.

Generally, most non-absorbed lead passes through the digestive system and is excreted. By comparison, however, some 40–50% of the absorbed fraction is retained in the body. This is the part that gives rise to concern. Once it has been absorbed into the body, lead is transported by the blood and either excreted or stored in various organs—predominantly in bone. Although the most accurate measure of body burden is the level of lead in bone, it is difficult to measure and, as yet, is insufficiently reliable to serve as a regular monitoring tool.

The amount of lead excreted in urine provides a simpler, although indirect, monitoring method and is employed in some countries, but generally only in conjunction with other measures since it can be influenced by other factors and, therefore, is not sufficiently predictable to use as a primary control. A number of other indirect measures of lead exposure are available, mainly changes in levels of enzymes and metabolites (these are intermediate compounds by which a cell is built up from nutritive material) that are involved in the synthesis and production of red blood cells.

The measure that provides the most accurate and predictable measure of lead exposure is lead-in-blood. It is convenient and easy to use and has thus been adopted

Table 1
Estimates of lead absorbed by adults and children (1–5 years old)

Mean air lead level ($\mu g/m^3$)	Source			Total lead (%)	Air/total (%)
	Air	Food	Water		
Adults					
0.3	2.4	10	2	14.4	17
0.5	4.0	10	2	16	25
1.0	8.0	10	2	20	40
2.0	16.0	10	2	28	57
3.0	24.0	10	2	36	67
Children					
0.3	0.6	25	5	30.6	2.0
0.5	1.0	25	5	31	3.2
1.0	2.0	25	5	32	6.3
2.0	4.0	25	5	34	11.8
3.0	6.0	25	5	36	16.7
Assumptions					
	Air: respiratory volume	Food: intake	Water: concentration 20 $\mu g\ l^{-1}$		
Adults	20 m^3/day	100 μg/day absorption 10%	1 l/day absorption 10%		
Children	5 m^3/day	50 μg/day absorption 50%	0.5 l/day absorption 50%		
Respiratory absorption	40%				

almost universally as the primary biological parameter for monitoring the health of lead-exposed workers. Various medical tests, such as those listed in Table 2, are in use to measure and monitor blood lead in conjunction with other techniques. Lead-in-blood is usually determined by taking blood samples from a suitable vein. Capillary blood samples are sometimes used, although they are more prone to contamination. The frequency of monitoring is often related to the amount of lead-in-blood, so that workers with high levels are monitored more frequently than those with low levels. Several countries specify a maximum blood-lead level, above which an individual must be removed from work that exposes him/her to lead until their blood-lead has returned to an acceptable level. In some cases, return is allowed once the blood-lead has fallen below the suspension level, in other cases a lower level is required for return (e.g., in the USA, legislation specifies the suspension level is 50 μg/dl and the return level is 40 μg/dl, but, industry has implemented a voluntary programme, in which each year for 5 years, the suspension level is reduced by 2 μg/dl and the return level by 1 μg/dl. This means that by 2002, the suspension level will be 40 μg/dl and the return level 35 μg/dl.

As analytical techniques have been refined and as knowledge of the levels at which adverse effects can occur has improved, maximum permissible blood-lead levels have tended to be reduced. Thus, whereas limits of 100 μg/dl or even more were common in the 1960s and 1970s, these have now been reduced by varying amounts in different countries to the situation today where 50, 60, 70 and 80 μg/dl are all in use in some places (see Table 3). While 70 μg/dl is still the limit most commonly applied, there is a distinct trend towards the lower values and 50 and 60 μg/dl have become increasingly specified. A continuation of this trend seems inevitable and it is likely that even lower levels will be introduced.

It should be noted that many countries impose different limits for men and women. This is because lead is particularly toxic to the developing unborn child, especially during the first three months of pregnancy when many women are unaware that they are pregnant. Thus, to avoid potential problems, a number of countries have set a lower limit on blood-lead for women (sometimes only for women of childbearing capacity). Limits of 20, 30, and 40 μg/dl are currently in force in different countries, see Table 3. This is an issue, which raises much debate, particularly in countries where a strong lobby exists for equal treatment of men and women. Pressures exist in some of these countries for blood-lead limits for all workers to be reduced to the level which is imposed for women.

Table 2
Typical blood-lead tests

Free erythrocyte protoporphyrin (FEP)
Zinc protoporphyrin (ZPP)
Delta-aminolaevulinic acid dehydratase (ALAD)
Urinary coproporphyrin (CP)
Urinary aminolaevulinic acid (ALAU)

Table 3
Blood-lead limits for occupational exposure

Maximum lead level (μg/dl)	Country
Men	
80	South Africa
70	Canada
	EEC
	France
	Germany
	Greece
	Ireland
	Italy
	Luxembourg
	Spain
	Thailand
	UK
60	Israel
	Japan
	Morocco
	Netherlands
	Peru
50	Australia
	Belgium
	Denmark
	Finland
	Norway
	Sweden
	USA
Women	
40	South Africa
	UK
30	Germany
	Israel
	Norway
	Sweden
20	Australia

3. Health effects of lead

The standards that are set for the protection of the general population and lead workers are based on the known health effects of the metal. As knowledge improves, it is necessary from time-to-time to reappraise the limits which are applied and adjust them as necessary. Inevitably, this tends to result in a progressive tightening of standards as the sensitivity of measurement techniques increases and as more subtle effects can thus be detected. Thus, blood-lead limits for lead workers of the order of 100 μg/dl—a level above which clinically-significant health effects such as anaemia, colic and muscle weakness can sometimes occur—have been universally superseded and have come down steadily to the current levels of 50–70 μg/dl.

Recently, a number of national and international bodies have been making fresh assessments of the health risks attributable to lead and of the levels at which effects are observable [1]. Depending on the interpretations placed on the significance of these various effects, it is probable that some countries will seek to reduce permissible exposure limits. A brief summary of some of the effects as reported by the International Programme on Chemical Safety (an agency of the World Health Organization) are shown in Table 4 [2]. Some of these effects are in fact 'non-effects' but are included because they have been the subject of much debate and have sometimes been used as justification of the need for tighter standards. The principal health risks includes the following.

Anaemia. A decrease in number of red blood cells appears to occur at blood lead levels above 50 μg/dl.

Central nervous system. Deterioration of the nervous system and/or coma may occur from acute exposure above 80 μg/dl. CNS symptoms may be seen after prolonged exposure at blood leads not exceeding 70 μg/dl. Lesser effects are detectable to as low as 40 μg/dl.

Peripheral nervous system. Reductions in nerve-conduction velocity (that may be reversible) may be found at blood leads as low as 30 μg/dl.

Renal effects. The risk of damage to the kidney system by lead is increased at blood-lead levels above 60 μg/dl.

Blood pressure. Statistically, a doubling of blood-lead levels results in a 1 mm Hg increase in systolic blood pressure. There are doubts, however, about whether lead actually causes the effect. There is no concern about hypertension or risk of cardiovascular disease.

Reproduction. For women, there is a possible increase in pre-term delivery and reduced growth and maturation in the unborn child at blood leads between 15 and 30 μg/dl. For men, sperm structure (morphology) and function may be affected above 40 μg/dl, but the significance of the changes is unknown.

Carcinogenicity. There is inadequate evidence to suggest that lead or lead compounds are carcinogenic.

Immune system. There is no evidence that lead has an effect on the immune system.

The latest evidence, therefore, indicates that in several health areas where anxieties have been expressed in recent years, there is, in fact, little cause for concern. On the other hand health effects are being detected at various blood-lead levels, namely, 60 μg/dl (renal effects), 50 μg/dl (anaemia), 40 μg/dl (central nervous system and male reproduction), 30 μg/dl (peripheral nervous system), and 15 μg/dl (female reproduction). While the peripheral nervous system effects are acknowledged to be of lesser concern and female reproductive effects are clearly not relevant to a male workforce, all the other effects have to be taken very seriously. Accordingly, there is a mounting body of evidence which points to the desirability of setting occupational exposure limits in the region of 40–60 μg/dl. Thus, it must be anticipated that standards will move in this direction, quite possibly accompanied by reductions in lead-in-air standards.

Table 4
Principal health risks of lead

Anaemia
Peripheral nervous system
Blood pressure
Carcinogenicity
Renal effects
Central nervous system
Reproduction
Immune system

Some countries do, as already discussed, set a lower suspension limit for women than for men. The suggestion that effects on reproduction may occur as low as 15 μg/dl could act to drive these limits even lower. Similarly, a recent review by the American Conference of Governmental Industrial Hygienists (ACGIH) comments on the fact that a woman whose blood lead exceeds 10 μg/dl—the present guideline from the Centers for Disease Control (CDC) as a 'level of concern' for children—could be at risk of giving birth to a child whose blood lead exceeds 10 μg/dl. This again could present a strong argument for lowering still further the occupational exposure limits for women.

4. Principal control measures

The general level of lead in the earth's crust is in the range 10–70 μg/kg. Much of this arises form natural sources. Higher levels, however, occur near places where an above-average amount of lead is experienced, such as near roadways or some mining and/or smelting locations.

Current 'baseline or background' levels of lead in the atmosphere are estimated to be in the range of 50 μg m^{-3}. It is exceedingly difficult to say how much of this is due to natural sources and how much is due to anthropogenic sources. In non-urban sites located near urban areas, lead levels on average can be much higher, say around 0.5 μg m^{-3}, while in rural areas, levels in the range of 0.1 to 0.3 μg m^{-3} have been reported.

Present levels of lead in water rarely exceed a few μg/l, except possibly near areas of unusual lead activity: the natural concentration of lead in surface water, on average, has been estimated to be 0.02 μg/l.

Measures to reduce lead exposure vary from country to country according to local circumstances and variations in significant sources of exposure. Typical actions include:

- reduced use of lead-based solders in food and beverage cans
- elimination of lead pipes and lead solders in water-supply systems
- increased use of unleaded gasoline.

Two main measures are generally employed in the control of lead exposure in the workplace—the amount of lead in the air breathed by workers and the amount of lead in the blood of individual workers. Numerical standards for these two measures vary somewhat from country to country, but there is an overall slow downward trend as both the knowledge of the effects of lead and the ability to measure smaller and smaller quantities has improved.

Despite the fact that lead-in-air and lead-in-blood standards are usually used in tandem to protect workers, there is in fact no simple relationship between the two measures. Certainly, a high level of lead-in-air will result in higher blood-lead levels than a low air-lead level, but the relationship cannot be quantified accurately and the impact on the blood-lead levels of individual workers varies considerably, in part at least as a reflection of their personal working habits and variations in body chemistry. Various studies have attempted to quantify an air-lead/blood-lead relationship for groups of workers and these have produced results which vary by up to an order of magnitude, from as low as 0.02 μg/dl, lead-in-blood per μg m^{-3} lead-in-air, to up to 0.02 μg dl^{-1}/μg m^{-3}.

Despite the limitations outlined above, measurement of the amount of lead-in-air, much of which is less than 10 μg in diameter, provides a relatively simple means of monitoring a worker's potential exposure. Lead-in-air levels are usually measured using samplers which are either placed at strategic-points in the workplace (static samplers) or which are worn by individual workers with the sampling head as close as possible to the individual's breathing zone (personal samplers). Static samplers are effective at highlighting failures or efficiency losses in extraction systems, while personal samplers give a more accurate reflection of the actual exposure of individual workers.

Many countries set limits on permissible levels of lead-in-air [3]. In most cases, these are based on personal samplers, although sometimes the method is not specified. It is common practice to specify the limit as an average over a period of time, a so-called time weighted average (usually 8 or 40 h, Table 5), to reflect the exposure of a typical working day or working week. Current lead-in-air limits that are in force in a range of countries are given in Table 3.

It is apparent that the majority of countries currently employ limits of either 100 or 150 μg m^{-3}. Only a few years ago, however, 100 μg m^{-3} was an unusually low value and 50 μg m^{-3} (presently in force in Norway and the USA) was unknown. In other words, there is a distinct downward trend in occupational exposure limits and it must be anticipated that more countries will lower their limits to 100 or 50 μg m^{-3} over the next few years [4].

Returning to the matter of blood-lead levels, a recent study of male lead workers under medical surveillance in the UK during 1994/95 gives an interesting insight into the number of workers whose blood-lead exceeds certain key levels, analysed by type of work. Out of 17,500 workers only 205 (1.2% of the total) exceeded the suspension limit of 70 μg/dl and were required to be removed from exposure to lead. Of these, 106 (2.4%) were employed in the battery industry. The next largest sectors were demolition (22, 3.2%) and smelting and refining of lead (17, 0.4%). The number of workers whose blood-lead levels exceeded 60 μg/dl was also reported in the survey. In this case 686 (3.9%) of workers were involved, of whom 371 (8.4%) were employed in the battery industry, 94 (2.2%) in lead smelting and refining and 53 (7.8%) in demolition. These (data) show clearly that the majority of lead workers can be held at relatively low blood-lead levels, but that special care needs to be taken in some sectors in order to avoid higher levels of exposure.

Table 5
Limits for occupational exposure

Maximum lead level (mg/m^3)	Country
0.2	Morocco
	Argentina
	Australia
	Peru
	France
	Italy
	Thailand
	South Africa
	Spain
0.15	Belgium
	Canada
	EEC
	India
	Ireland
	Mexico
	UK
0.1	Australia
	Denmark
	Finland
	Germany
	Israel
	Japan
	Netherlands
	Sweden
	Switzerland
0.05	Norway
	USA

5. Data on general blood leads

As far as the general population is concerned there have been many studies of blood-level levels in various countries. Unfortunately, few studies have been carried out that enable comparisons to be made in a particular country at different periods of time. Such work is necessary if reliable trends in blood-leads are to be followed closely. It is clear, however, that there is an overall decline in blood-lead levels among the general population. This is due to a variety of actions which have been taken in some countries to reduce exposure.

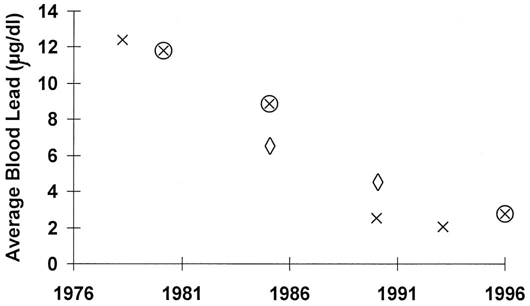

Fig. 2. General population blood-lead trends. × = USA; ⊗ = UK; ◇ = Germany.

Unlike the occupational environment, there are few guidelines on what constitutes an acceptable level of exposure for the general population. Nevertheless, it is clear that children represent the sector of the population most susceptible to adverse effects of lead. A consensus is emerging that the maximum acceptable blood-lead for children lies in the region of 10 μg/dl. The majority of blood-lead surveys in recent years indicate that average blood-lead levels are now well below this level in some countries. In the USA and in the UK, it is possible to monitor average blood-lead trends from published papers. Data from these countries, together with those from comparable data in Germany are summarized in Fig. 2. Tables 1 and 2 combines the results and demonstrates clearly that, in these countries, average blood-lead levels have declined by a factor of at least four over the last 15 years.

6. Conclusions

Permissible lead limits for lead-exposed workers are steadily being reduced. While most blood-lead suspension limits for men are currently in the region of 50–70 μg/dl, a trend towards 40–50 μg/dl seems likely in the future. Limits for women could move towards 20 μg/dl. Lead-in-air limits are also declining in parallel with blood-lead limits and levels of 50 or 100 have been enforced.

A further challenge is to ensure that blood-lead levels in the general population are reduced to minimum achievable levels in those parts of the world where the present levels exceed medically safe limits.

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