Nordic Council of Ministers

Lead Review

January 2003

Nordic
COUNCIL OF MINISTERS

Nordic Council of Ministers

Lead Review

January 2003

Report no.	1
Issue no.	04
Date of issue	28. January 2003
Prepared	CRL, EHN

Table of Contents

1 Introduction

This document aims to present a brief overview of the heavy metal lead. The overview deals with the issues of production, consumption and emissions, the exposure, health and environmental impacts, regulations and substitutes to the use of lead.

The document is prepared as a background paper to the meeting in UNEP Governing Council in February 2003. The objective of the document is to evaluate lead as a global pollutant and provide a background for a request from the Nordic Countries to consider lead a potential candidate for global initiatives parallel to the initiatives currently being considered for mercury.

The document is based on available literature inclusive of reports, scientific articles and databases. The document does, however, not claim to be an exhaustive presentation covering all relevant issues in full detail.

This report has been prepared by COWI Consulting Engineers and Planners on behalf of the Nordic Council of Ministers.

2 Summary

Lead is a heavy metal with a high toxicity. Lead is toxic at very low exposure levels and has acute and chronic effects on health and the environment. Lead is not degradable in nature and will thus, once released to the environment, stay in circulation. New releases add to the already existing deposits of lead in the environment.

Lead is highly toxic to humans and has no known beneficial effects in the body. It can effect the nervous system, the reproductive system, and the heart and blood system. Even the lowest doses can impair the nervous system. Chronic low exposure is of concern. Lead accumulates in the bone structure in humans, and can be released under pregnancy from the bone structure to the blood.

In the environment lead is known to be toxic to plants, animals and microorganisms. Lead bioaccumulates in the skeleton and wet tissue in mammals and in aquatic algae and invertebrates.

The major issues of concern related to lead may be summarised as follows:

- Lead is causing concern in particular due to the possible impacts on children. Children are more susceptible to lead than adults and children of dietary deficiencies are even more susceptible. Lead influences the nervous system, slowing down nerve response. This influences learning abilities and behaviour. Children are exposed to lead before their birth, as children in the embryonic stage receive lead from their mothers through the blood. Children are, furthermore, exposed to lead via dust and soil contaminated by deposition from air and other sources. In polluted cities the lead levels in air is high enough to effect the intellectual development of children.

- Atmospheric deposition seems continuously to cause the content of lead in top soils to increase which is a trend that cannot be considered sustainable.

- Significant quantities of lead are continuously stockpiled in landfills and other deposits and represent a significant potential for future releases to the environment. The high content of lead in incineration residues hampers the efficient utilisation of these residues.

It is characteristic for lead, that many different products containing lead will end up in waste management systems and be a source of lead to incineration plants and/or landfills. Important sources include: Plastics, fishing tools, lead crystal glass including cathode ray tubes, ceramics, solders, lead flashing and many other products. To these sources must be added residues from metal shredding, steel reclamation and cable reclamation.

Emissions to the air as well as to water on an international scale seem to be decreasing due to a phase-out of leaded gasoline in important regions, improved flue gas cleaning and waste water treatment. However, air emissions of lead from vehicles are now increasing in many developing countries, because of an

increased motorization and urbanization, and the fact that in large parts of the world, only leaded gasoline is available.

Long range transport of lead by air is reflected in ice core samples from Greenland. Emissions from Eurasia and North America must be considered important sources for lead to the Arctic Region.

The environmental fate and the toxicity of lead call for a global initiative aimed at minimising human and environmental consequences of the ongoing lead emissions. The relevance of considering a global initiative comes, furthermore, from the fact that lead used intentionally in products is traded globally and that effective risk reduction measures thus must be seen in a global context.

Continued international efforts may include a global phase-out of lead in products as well as global agreements of improved emission control related to air as well as water emissions. Adequate substitutes exist for many applications for which lead is still being used.

3 General Description

3.1 Global Production and Trade

The total global mine production of lead has slightly decreased the last thirty years from 3.4 million tonnes in 1970 to 3.1 million tonnes in 2000 (table 3.1). During the same period the global consumption has increased from 4.5 million tonnes to about 6.5 million tonnes.

Table 3.1 Global mine production and consumption 1970, 1990 and 2000

Application	1970 (1000 tonnes)	1990 (1000 tonnes)	2000 (1000 tonnes)
Total mine production 1)	3,390	3,370	3,100
Total consumption 2)	4,502	5,627	6,494
Secondary production in percentage of total consumption 3)	25 %	40%	52%

1) Source: /USGS 2002b/

2) Source: See Table 2.4

3) Secondary production is calculated as the difference between total consumption and mine production.

The difference is due to the fact that secondary production from recycled lead account for an increasing part of the lead consumption. Rates of secondary production are higher in the more highly industrialised countries. In North America processing of lead scrap accounts for just over 70% of metal output. In Western Europe secondary production accounts for 60% of lead output, in Africa for 50%, in Latin America a little under 50% and in Asia less than 30% /Thornton et al. 2002/. Secondary lead is mainly produced from used lead batteries.

The market value of the current production of lead ore is estimated at $2.2 billion (1998 figures). It has been estimated that all mining, smelting and refining operations world-wide are worth around $15 billion per year /Thornton et al. 2002/. World-wide employment provided by lead mining, smelting and refining is around 72,000-89,000 with a further 2,400 employed in lead oxide production.

World mine production and reserves by country is shown in table 3.2. The measured lead reserves in 2001 total 64 million tonnes equalling about 21 years production at the year 2000 level. The identified lead resources of the world total, however, more than 1.5 billion tonnes /USGS 2001a/.

Lead-rich minerals frequently occur together with other metals, particularly silver, zinc, copper and sometimes gold. Thus lead is also a co-product of zinc, copper and silver production making the extraction of lead more economic than if it occurred in isolation. About two thirds of worldwide lead output is obtained from mixed lead-zinc ores /Ayres et al. 2002/.

Table 3.2 Mine production and reserves by country, 2000/2001 /USGS 2002a/

Country	Mine production 2000 1000 tonnes	Reserves 1) 2001 1000 tonnes
Australia	699	15,000
China	570	9,000
United States	468	8,700
Peru	271	2,000
Mexico	156	1,000
Canada	143	1,600
Sweden	108	500
Morocco	80	500
South Africa	75	2,000
Kazakhstan	40	2,000
Other countries	490	22,000
World (rounded)	3,100	64,000

1) Reserves are defined by the USGS as that part of the resources which could be economically extracted or produced at the time of determination. Reserves include only recoverable materials.

Lead is bought and sold by many countries on the world market, in the forms of ore, impure metal and refined metal, as well as final products. The USA, South East Asia, and Western Europe are the largest importers of lead in its various forms, though many of these countries also export refined metal (table 3.3). The main exporters of lead are the countries which mine large amounts of lead ore.

Table 3.3 Worldwide production, consumption and trade in lead ore and metal in 1999 (derived from /Thornton et al.2002/)

Continent	Mine production [1)] (1000 tonnes)	Consumption of refined lead (1000 tonnes)	Lead ore and concentrates (1000 tonnes)		Lead metal (1000 tonnes)	
			Imports	Exports	Imports	Exports
Western Europe	242	1,699	430	195	477	394
Central and Eastern Europa	121	300	46	46	20	85
Africa	181	127	12 [2)]	94	15	57
North America	607	1,859	68	142	322	189
Central and South America	446	392	Not known	170	62	128
Asia	685	1810	314	20	552	529
Australia	650	64	0	256	0	255
TOTAL	2,942	6,251	870	923	1,448	1,337

1) Data for 2000 . The mine production figures are not totally consistent with USGS (2002a) which estimates the total mine production as 3.1 million tonnes,

2) Data for 1998.

3.2 End Uses

The global consumption of lead has during the period 1970 to 2000 increased from 4.5 million tonnes to 6.5 million tonnes /LDAI 2002/. The consumption by end uses in the OECD countries in 1970, 1990, and 2000 is shown in table 3.4.

The most significant changes in the overall use pattern in the OECD-countries are an increased consumption for batteries and a decrease in the areas of cable sheeting and petrol additives.

The overall consumption pattern for metallic lead seems to be quite similar in the Northern Europe though there are some major differences in the use of lead sheets in the building industry. Due to tradition and the style of buildings, the consumption of lead sheets for building purposes is significantly lower in Southern European countries than in Northern European countries /Tukker el al 2001/.

Table 3.4 Lead consumption by end uses in OECD countries.

Application	**1970 (%) 1)**	**1990 (%) 1)**	**2000 (%) 2)**
Batteries	39	63	75
Cable sheeting	12	5	not indicated 3)
Rolled/extruded lead (mainly sheets)	12	9	6
Ammunition	4	3	3
Alloys	7	4	4
Lead compounds	11	10	9
Petrol additives	10	2	1
Miscellaneous	5	4	2
Total OECD (1000 tonnes)	3,050	3,365	5,612 4)
Total World (1000 tonnes)	4,502	5,627	6,494 4)

1) Source: /OECD 1993/.

2) Source: /LDAI 2002/. The source does not specifically indicate that the consumption pattern concerns the OECD countries, but similar consumption pattern can be found in /ILZSG 2002/, in which it is indicated that the pattern concerns the consumption in "Western World".

3) According to the European Association of Metals cable sheets in 1997 accounted for 3% of the global consumption and 5% of the European consumption /Eurometaux 1997/.

4) Source: /ILZSG 2002/. Designated "Western World" in the source; the consumption pattern is assumed to be identical to the OECD countries.

Table 3.5 Lead compounds consumption by end uses in OECD countries 1990 (derived from /OECD 1993/)

	%
Glass pigments	
Cathode ray tubes	40
Crystal	15
Speciality glass/optical	4
Light bulbs	3
Other pigments and compounds	
Plastic additives	23
Glazes	9
Paints	4
Ceramics	2
Total consumption (1000 tonnes lead)	approx 340

Lead compounds have during the whole period accounted for about 10% of the total, but some major changes within this category have taken place. A breakdown of the production in consumption in OECD-countries in 1990 is shown in table 3.5. The major part of the lead compounds is today glass pigments for cathode ray tubes and crystal glass and stabilisers for PVC. Formerly lead pigment for glazes, paints and ceramics took up a greater share, but the consumption of pigments for these applications has decreased over the last decades (Tukker et al. 2001).

Further details about uses of lead metal and lead compounds and possible substitutes for lead can be found in Chapter 7.

It should be noted, that the data presented above concerning end uses relates to OECD countries only and may thus not be representative for other parts of the world. An important example of an end use for which the situation within OECD differs considerably from the situation outside OECD is petrol additives.

Petrol additives

The availability of unleaded gasoline varies around the world. In some regions, only leaded gasoline is available and levels of lead in the gasoline are among the highest levels found. In Africa only two of 52 nations had any unleaded gasoline available. Worldwide, and particularly in the developing world, there has been a massive increase in both “motorization” (the number of motor vehicles, especially automobiles, per capita) and urbanization. The world motor vehicle fleet increased by 25 percent between 1981 and 1988, and greater expansion is expected for the next few decades at a rate (2-3 percent per annum) much faster than that of population growth. Much of this growth is expected to take place in the developing world. /UNEP 1998/.

4 Environmental Exposure and Effects

4.1 Sources and Emissions

Lead is released to the biosphere from both natural and anthropogenic sources.

Natural sources

The major natural sources for mobilisations of lead from the earth's crust are volcanoes and weathering of rocks. The atmospheric emission from volcanoes in 1983 is estimated at 540-6,000 tonnes /Nriagu 1989/. The weathering of rocks releases lead to soils and aquatic systems. This process plays a significant role in the global lead cycle, but only rarely results in elevated concentrations in any environmental compartment.

Within the biosphere the lead is translocated by different processes. The major sources for emission to air from natural sources are volcanoes, airborne soil particles, sea spray, biogenic material and forest fires. Total emission to air from natural sources in 1983 is estimated at 970-23,000 tonnes/year /Nriagu 1989/; roughly 10% of the total anthropogenic air emission in the mid-1990s.

Anthropogenic sources

As mentioned in the previous chapter 3.1 million tonnes of lead was in 2000 extracted from the earth's crust by man and brought into circulation in the technosphere. Beside this a significant amount of lead ended up in metal extraction residues or was mobilised as impurity by extraction of other minerals like coal and lime. In 1993 in total 0.4-1.0 million tonnes was disposed of with waste from metal extraction and the use of coal (see table 4.3).

The most comprehensive assessment of the global anthropogenic lead emission dates back to 1983. The reduction in the use of lead as fuel additive and implementation of emission reduction measures has caused the emission to lower significantly. From 1983 to mid 1990's the total emission of lead to air decreased from about 330,000 tonnes (medium estimates of /Nriagu & Pacyna 1988/) to 120,000 tonnes (table 4.1).

In the mid 1990s fuel additives still accounted for 74% of the global lead emission to air (table 4.2). Besides fuel additives non-ferrous production and coal combustion were the major sources. In the EU15 in 1998 fuel additives accounted for 61% (table 4.3), but this amount will today be significantly lower making production processes (mainly non-ferrous metal production) and combustion in manufacturing industry (mainly coal combustion) the major processes.

It should be noted that some sources may be significantly underestimated due to the methodology of the inventories used for the World and EU15 estimates. In particular waste incineration may be underestimated (AMAP 2002).

The increased “motorization” and the still widespread use of lead additives for petrol in developing countries (see section 3.2), however, points at fuel additives as a source of lead emission to air that continuously must call for special attention in a global context. It is estimated, that 35% of automotive lead emissions are subject to long-range transport.

Table 4.1 Global emission of lead to air in mid-1990s /Pacyna & Pacyna 2001/

Economic sector	Air emission (tonnes)	%
Stationary fossil fuel combustion	11,690	10
Non-ferrous metal production	14,815	12
Iron and steel production	2,926	3
Cement production	268	0.2
Fuel additives	88,739	74
Waste disposal (incineration)	821	0.7
Total	**119,259**	**100**
Total 1983 emission to air	332,350	

Table 4.2 Sector emissions of lead to air in the EU15 in 1998 based on EMEP (derived from Tukker et al.2001)

Economic sector	Air emission (tonnes)	%
Energy generation		
- Combustion in energy and transformation industries	*20*	*1*
- Combustion in manufacturing industry	*441*	*17*
- Extraction & distribution of fossil fuels and geothermal energy	*0.0*	*0*
- Non-industrial combustion plants	20	1
Production processes	358	14
Road transport (petrol additives)	1560	61
Waste treatment (MSWIs)	124	5
Other (not included)		
- Other mobile sources and machinery	*34*	*1*
- Other sources and sinks	*0.02*	*0*
- Solvent and other product use	*1*	*0*
- Agriculture	*0.1*	*0*
Total	2,558	100

The significant decrease of air emissions noted in table 4.1 is mainly caused by improved flue gas cleaning, which has partly changed a problem of direct release to the environment to an issue of how to control lead being stockpiled in landfills and other deposits in the long time perspective.

Natural versus anthropogenic sources - long range transport

Experience from the Arctic shows that long range transport of lead by air contributes to the deposition of lead, as lead can be condensed on very fine particles able to be carried by the wind for long distances. Based on model calculations it is estimated that 5-10% of the emission in the Euroasiatic regions during the wintertime is deposited in the Northen Arctic /AMAP 1997/.

Ice core data from Greenland indicate that, along with most other heavy metals, lead levels increased significantly following the Industrial Revolution. By 1970, lead levels were twelve times what they had been less than two centuries earlier. /AMAP 2002/.

Table 4.3 Global lead releases to land in 1983 (derived from /Nriagu & Pacyna 1988/)

Source category	1000 tonnes/year	% of total to land
Agricultural and food wastes	1.5-27	1.1
Animal wastes, manure	3.2-20	0,9
Logging and other wood wastes	6.6-8.2	0.6
Urban refuse	18-62	3.1
Municipal sewage sludge	2.8-9.7	0.5
Miscellaneous organic wastes including excreta	0.02-1.6	0.1
Solid wastes, metal manufacturing	4.1-11	0.6
Coal fly ash, bottom fly ash	45-242	11
Fertilizer	0.42-2.3	0.1
Peat (agricultural and fuel use)	0.45-2.0	0.1
Wastage of commercial products	195-390	22
Atmospheric fall-out	202-263	17
Total to soil	479-1,113	
Mine tailings	130-390	19
Smelter slags and wastes	195-390	22
Total to land	804-1,820	

Releases to waste and soil

The only comprehensive assessment of global lead releases to soil and landfills dates back to 1983 (reference is made to table 4.3) .Apart from atmospheric fall-out which has decreased due to reduced use of lead as fuel additives, no major changes in the distribution among source categories is, however, assumed. The total release of lead to landfills and deposits from discarded products and production waste is about one order of magnitude higher than the total direct releases to the environment. One of the main questions is when and to what extent this lead will be mobilised and further released to the environment. Although the mobility of lead inside landfills in general is very low, and a complete wash-out of lead may require hundreds to thousands of years and in some

some cases even more, no evidence exist that landfills can be regarded as a permanent containment of lead.

It may be noted, that in some densely populated countries suffering from lack of space for landfills high efforts are invested in utilising residual products from incineration and other waste treatment processes. However, a serious constraint for effective utilisation of such residual products is the content of lead originating from discarded products ending up as waste./Brønnum & Hansen 1998/.

Lead balances for farmland in Denmark and the Netherlands show accumulation of lead in top soil. The accumulation rate has been calculated as 0.08% for Denmark and 0.06-0.2 for the Netherlands. In both cases atmospheric deposition is a dominant source. Accumulation rates for grassland may be even higher. /Brønnum & Hansen 1998; Tukker et al 2001/.

Certain regions of the Arctic contain elevated lead levels in the environment because of past and current use of lead shot by hunters. In Greenland lead shot appears to be a significant source of human dietary exposure to lead /AMAP 2002/.

Releases to water environments
The direct releases to water are relatively small compared to the releases to the air and soil. Exclusive atmospheric deposition the total releases to water in 1983 was estimated at 10,000-67,000 tonnes /Nriagu & Pacyna 1988/. Atmospheric deposition was estimated at 87,000-113,000 tonnes. The deposition has in the recent decades decreased significantly due to the decrease in the total atmospheric emission.

4.2 Environmental Effects

Lead in the environment is mainly particulate bound with relatively low mobility and bioavailability. Lead bioaccumulates in most organisms, in particular in biota feeding primarily on particles, e.g. mussels and worms. In general there is no increase in concentration of the metal in food chains (biomagnification).

Whereas many metals are converted to organic forms by microorganisms in soil, there is little evidence to suggest that the natural production of methylated lead has any general environmental significance.

The distribution of lead within animals is closely associated with calcium metabolism. In shellfish, lead concentrations are higher in the calcium-rich shell than in the soft tissue. In dolphins, lead is transferred from mothers to offspring during foetal development and breast-feeding. Lead accumulates in the bones of animals like it does in humans (see section 5.1).

The following information has largely been extracted from the IPCS monograph /WHO 1989/ unless otherwise indicated.

Birds
The most well-documented environmental effect of lead contamination is the effect of lead on waterfowls. Lead shot taken by birds into their gizzards is a source of severe lead contamination. Also lead sinkers used for angling have been demonstrated to be taken by birds. In the gizzard, the lead is slowly ground down resulting in the release of lead. It results in high organ levels of lead in blood, kidney, liver, and bone. Metallic lead is highly toxic to birds when ingested as lead shots; ingestion of a single pellet of lead shot is fatal in some bird species. The sensitivity varies between species and is dependent on diet. Since birds have been found in the wild with large numbers of lead shot in the gizzard, this poses a major hazard to those species feeding on river margins and in fields where many shots have accumulated.

Mammals
There are many reports of lead levels in wild mammals, but few reports of toxic effects of the metal in the wild or in non-laboratory species /WHO 1989/. In all species of experimental animals studied, lead has been shown to cause adverse effects in several organs and organ systems, including the blood system, central nervous system, the kidney, and the reproductive and immune systems.

Microorganisms
Studies have shown that lead can hamper mineralization of nitrogen in soil in acidified areas /Alloway 1995/. However, lead compounds are in general not very toxic to microorganisms and lead compounds have contrary to mercury and chromium compounds not been used as biocides. In general, inorganic lead compounds are of lower toxicity to microorganisms than are trialkyl- and tetraalkyllead compounds. There is evidence that tolerant strains exist and that tolerance may develop in others.

Aquatic organisms
The toxicity of inorganic lead salts is strongly dependent on environmental conditions such as water hardness, pH, and salinity, a fact which has not been adequately considered in most toxicity studies. Lead is unlikely to affect aquatic plants at levels that might be found in the general environment.

In communities of aquatic invertebrates, some populations are more sensitive than others and community structure may be adversely affected by lead contamination. Early development stages are more vulnerable than adult stages. However, populations of invertebrates from polluted areas can show more tolerance to lead than those from non-polluted areas. Typical symptoms of lead toxicity include spinal deformity and blackening of the tail region.

Data on toxicity etc. of lead in aquatic environments is presented in table 3.4. The typical lead levels in aquatic environments are low (seawater: below 1µg/l ; freshwater: below 5µg/L /OECD 1994/) compared to the lead levels causing effects. However, it cannot be ruled out that lead may affect fish and other organisms in areas where the lead burden is highest.

Table 4.4 Toxicity of lead in aquatic environments and bio-concentration factors (Derived from /Brønnum & Hansen 1998/)

Species, effect	Concentration [1)] µg/L (mg/kg TS)
Toxocity in freshwater	
Plankton algae (EC_{50}- growth rate, etc.)	140 - 11,000
Crustaceans (chronic)	10 - 200
Crustaceans (acute)	100 - 224,000
Fish (chronic)	0.4 - 220
Fish (acute)	1,000 - 540,000
Toxicity in the marine environment	
Plankton algae (EC_{50}-growth rate, etc.)	20 - 950
Crustaceans (chronic[)])	20 - 40
Crustaceans (acute)	50 - 27.000
Fisk (acute)	300 - >10.000
Bioaccumulation	
Algae (bio-concentrationsfactor)	2,000 - 4,000
Invertebrates (bio-concentrationsfactor)	400 - 12,400

Terrestrial organisms
The tendency of inorganic lead to form highly insoluble salts and complexes with various anions together with its tight binding to soils, drastically reduces its availability to terrestrial plants via the roots. Lead is taken up by terrestrial plants through the roots and to a lesser extent through the shoots. However, the mobility and bioavalability of lead depends e.g. of the pH-level. In acidified environments lead will be present as water soluble salts that are bioavailable /Danish EPA 1983/.

Translocation of the lead ion in plants is limited and most bound lead stays at root or leaf surfaces. As a result, in most experimental studies on lead toxicity, high lead concentrations in the range of 100 to 1,000 mg/kg soil are needed to cause visible toxic effects on photosynthesis, growth, or other parameters. Thus, lead is only likely to affect plants at sites with very high environmental concentrations.

Ingestion of lead-contaminated bacteria and fungi by nematodes leads to impaired reproduction. The information available is too meagre to quantify the risks to invertebrates during the decomposition of lead-contaminated litter.

5 Human Exposure and Health Effects

5.1 Human Exposure

In the general non-smoking adult population, the major exposure pathway is from food and water. Airborne lead may contribute significantly to occupational exposure and exposure of smokers. Inhalation is the dominant pathway for lead exposure of workers in industries producing, refining, using or disposing of lead and lead compounds (WHO 1995). In countries where leaded gasoline is still used, proximity to heavily trafficked roads may also influence airborne lead exposure. In countries where leaded drinking water pipes are used, drinking water may be a significant exposure pathway.

Food surveys have shown that lead contamination of foodstuffs in general has declined over the years reflecting a decrease in the use of lead soldered tin cans for storage of food /Tukker 2001/.

For infants and young children, lead in dust and soil often constitutes a major exposure pathway and this exposure has been one of the main concerns as to the exposure of the general population. The intake of lead will be influenced by the age and behavioural characteristics of the child and the bioavailability of lead in the source material. Baseline estimates of potential exposure of children to dusts, including intake due to normal hand-to-mouth activity, are 0.2 g dust/day for children 1–6 years old when both indoor and outdoor ingestion of soil and dust is considered, but for some children it may be up to 5 g/day /RTI 1999/. Depending on the lead content of dust/soil intake of lead with dust/soil can clearly exceed the PTWI (provisional tolerable weekly intake) value established by WHO (see below).

In adult humans, approximately 10% of the dietary lead is absorbed. However, in infants and young children as much as 50% of dietary lead is absorbed, although absorption rates for lead from dusts/soils and paint chips can be lower depending upon the bioavailability. Depending upon the type of lead compounds, particle size, and solubility in body fluids, up to 50% of inhaled lead compounds may be absorbed. /WHO 1995/

Organic lead is more bioavailable and toxic than inorganic lead. The primary source of organic lead has been leaded petrol, now phased out from the market in most OECD countries, but still in use in other parts of the World.

Absorbed lead is rapidly taken up into blood and soft tissue, followed by a slower redistribution to bone. Bone accumulates lead during much of the human life span and may serve as an endogenous source of lead that may be released slowly over many years after the exposure stops. /WHO 1995/

WHO has established a PTWI for lead of 25 µg/kg of body weight (equivalent to 3.5 µg/kg of body weight per day). This level refers to lead from all sources and was set to protect all humans, including infants and children. It was based on a model indicating daily intakes of lead between 3-4 µg/kg body weight by infants and children and is not associated with an increase in PbB concentrations /WHO 1995/. Assuming a 50% allocation to drinking-water for a 5-kg bottle-fed infant consuming 0.75 litres of drinking-water per day, the health-based guideline value for drinking water is 0.01 mg Pb/L (rounded figure). As infants are considered to be the most sensitive subgroup of the population, this guideline value will also be protective for other age groups /WHO 1993/.

5.2 Health Effects

The following information has largely been extracted from the IPCS monograph /WHO 1995/ unless otherwise indicated.

In humans, lead can result in a wide range of biological effects depending upon the level and duration of exposure. Effects may range from inhibition of enzymes to the production of marked morphological changes and death. Such changes occur over a broad range of doses. For neurological, metabolic and behavioural reasons, children are more vulnerable to the effects of lead than adults.

Of particular concern for the general population is the effect of lead on the central nervous system. Epidemiological studies suggest that low level exposure of the foetus and developing child may lead to reprotoxic effects, i.e. damage to the learning capacity and the neuropsychological development /Goyer 1986/. Studies of children indicate a correlation between higher lead contents in the blood and a lower IQ. Slowing of nerve conduction velocity has been found at low lead blood levels. Impairment of psychological and neurobehavioural functions has also been found after long-term lead exposure of workers.

Lead has been shown to have effects on haemoglobin synthesis and anaemia has been observed in children at lead blood levels above 40µg/dl. Lead exposure is associated with a small increase in blood pressure. There is no evidence to suggest that any association of lead blood levels with blood pressure is of major health importance.

Lead is known to cause kidney damage. Some of the effects are reversible, whereas chronic exposure to high lead levels may result in continued decreased kidney function and possible renal failure. Renal effects have been seen among the general population when more sensitive indicators of function were measured.

The reproductive effects of lead in the male are limited to sperm morphology and count. In the female, some adverse pregnancy outcomes have been attributed to lead. Lead does not appear to have deleterious effects on skin, muscle or the immune system.

The evidence for carcinogenicity of lead and several inorganic lead compounds in humans is inadequate. Classification of IARC is class 2B *'The agent (mixture) is possibly carcinogenic to humans. The exposure circumstance entails exposures that are possibly carcinogenic to humans'*/IARC 1987/.

6 International Regulation

6.1 International Conventions and Treaties

A number of international agreements have been established already in order to manage and control releases of lead to the environment and limit human and environmental exposure to lead. The relevant agreements are presented in table 6.1. It is noted that under the Rotterdam Convention a procedure for Prior Informed Consent to control import of unwanted chemicals that has been banned or severely restricted in the exporting country has been established. So far, tetraethyl lead and tetramethyl lead have been included in the procedure.

Table 6.1 Overview of international agreements containing provisions relating to lead.

International agreement or instrument	Geographic coverage	Relevance to lead	Types of measures addressing lead
LRTAP Convention and its 1998 Aarhus Protocol on Heavy Metals	Central and Eastern Europe, Canada and the United States of America	Addresses lead and lead compounds in releases, products, wastes, etc.	Goal definition, binding commitments on release reductions and recommendations, monitoring, BAT-technologies
OSPAR Convention	North-east Atlantic including the North Sea (including internal waters and territorial sea of Parties)	Addresses lead and lead compounds in releases, products, wastes, etc.	Goal definition, binding commitments on release reductions, recommendations, monitoring, information
Helsinki Convention	Baltic Sea (including entrance of the Baltic Sea and catchment areas to these waters)	Addresses lead and lead compounds in releases, products, wastes, etc.	Goal definition, binding commitments on release reductions, recommendations, monitoring, information
Basel Convention	Global	Any waste having as constituents or contaminants, excluding metal waste in massive form, lead or its compounds is considered a hazardous waste and covered by specific provisions	Binding commitments regarding international transport of hazardous waste, procedure for information and approvals on import/export of hazardous waste

6.2 Legislation

The legislation concerning products in different countries is presented in table 6.2.

Table 6.2 Legislation addressing lead or lead compounds in products /OSPAR 2000; OECD 1994; Thornton et al 2001;Brønnum & Hansen 1998/

Country/countries	**Legislation**
European Union*	Ban on the use of lead carbonates and lead sulphate in paint. Ban on lead foil wine wrappers. Ban on lead in cosmetics. Limit values for the concentration of lead in gasoline. Total phase-out of lead in gasoline is planned to take place by 2005. Restrictions on the content of lead in packaging materials. Limits on the release of lead from toys and ceramic articles intended to be in contact with foodstuffs. A general ban on the use of lead in new electrical and electronic equipment is taking effect as of 1 July 2006 /EU 2000a/. A ban on lead in vehicles with certain exemptions is going to take effect as of 1.July 2003. /EU 2000b/.
Denmark*	General ban on most uses of lead compounds not covered by EU- legislation. Also ban on many uses of metallic lead including lead flashing, fishing weights, lead solder in cans, lead shot and lead pipes and lead solders for drinking-water installations, etc. A special tax exists on new lead-acid batteries aimed at financing collection and recycling.
Belgium*, Canada, Finland*, Netherlands*, Norway, Sweden* and UK*	Ban on lead shot for wetland hunting. Sweden and Norway has notified regulation banning all lead ammunition for hunting. Canada has extended the ban to cover most game birds throughout the country.
Canada, Finland*, Germany*, Hungary, Norway, Sweden*, Switzerland	Tax, deposit or other arrangements linked to lead-acid batteries aimed at support collection and recycling.
UK*	Ban on lead fishing weights.
USA	Ban on lead solder in cans for food packaging and lead foil capsules on wine bottles. Limits on the release of lead from ceramic articles. Ban on lead solder for household plumbing. Ban on lead in house paint.
Mexico	Ban on lead for pottery.
Canada	Lead fishing weights less than 50 grams is banned in national wildlife areas and national parks.
Australia, Austria*, Canada, Finland*, Germany*, Iceland, Netherlands*, New Zealand, Norway, Sweden*, Switzerland, UK*, US, Mexico	Restrictions on lead in paint
Australia, Canada, Iceland, Japan, New Zealand, Norway, Switzerland, US and Mexico	Restrictions on lead in gasoline
Austria*, Belgium*, Germany*	Ban on lead in pesticides
Canada, France*, Netherlands*	Restrictions on lead solder in cans for food packaging
Australia	Limits on the release of lead from ceramic articles. Restictions on the content of lead in toys, pencils, crayons etc. In Queensland limit on the content of lead in materials used as fuel.
Austria*	Ban on lead in chain saw oils
France*	Ban on lead salts in imitation pearls in jewellery
New Zealand	Limit on the content of lead in toys and materials for writing, drawing, marking or painting
Switzerland	Ban on use of lead in clothing dyes.
Norway	Restrictions on lead in packaging

* Regarding individual Member States and applicant countries of the European Union, these countries are only mentioned specifically if more restricted legislation than EU-legislation is in force.

Table 6.3 Legislation addressing control of lead emission to air, water and soil environments / OSPAR 2000; OECD 1994;Brønnum & Hansen 1998/

Country/countries	Legislation
European Union*	Limits on emission to air from industrial processes and waste incineration. Limits on emission to water from certain industrial processes. Limits are based on best available techniques. Limit on content of lead sludge to be used in agricultural land and for soil exposed to sludge.
Switzerland	Limits on emission to water and air. Limits for lead content in sewage sludge for agricultural purposes.
Australia, Canada, Japan, USA	Limits on emission to water and air.
Canada, Denmark, Germany, Japan, the Netherlands, UK, USA.	Remediation criteria for soil concentration at contaminated sites
Norway	Limits on emission to air from industrial processes and waste incineration. Limits on emission to water from certain industrial processes.

* Regarding individual Member States and applicant countries of the European Union, these countries are only mentioned specifically if more restricted legislation than EU-legislation is in force.

6.3 Other Regulations

Many countries have legal standards for maximum concentration of lead in drinking water and quality standards for ambient air, fresh water and salt water etc. and have established lead threshold limits for occupational air exposure. EC-regulation setting maximum levels of cadmium in foodstuffs has been established.

Lead is on the list of priority substances under the EC Water Framework directive and will reviewed by November 2002 for identification as a possible " priority hazardous substance" /OSPAR 2002/.

In order to reduce the lead burden to the marine environment the OSPAR Commission recommends that lead should be substituted where appropriate. Phase-out is considered possible in products as PVC, paints, electronic equipment, glass, lead shots, ceramics, fishing weights /OSPAR 2002/.

In February 1996, Environment Ministers of OECD Member countries adopted a Declaration on Risk Reduction for Lead in order to advance national and co-operative efforts to reduce risks from lead exposure. The OECD Council adopted a Resolution (C(96)42/Final) in March 1996 linking this declaration to the OECD.

In several countries voluntary agreements between industrial associations and environmental authorities have been used as alternative to formal legislation. As an example of such an agreement the European PVC industry has adopted the following reduction targets for replacing lead stabilisers on the basis of

2000 consumption levels: 15% in 2005, 50% in 2010 and 100% in 2015 /OSPAR 2002/.

Finally, it is relevant to mention the Global Lead Initiative launched at the Johannesburg Summit. This initiative is aimed at to accelerate leaded gasoline phase-out and to identify and eliminate other exposure sources with the overall objective of protecting especially children from lead poisoning /GLI 2002/.

7 Substitution

The present status regarding development and marketing of substitutes for lead is indicated in table 7.1.

The table indicates whether substitutes are available today and whether substitutes are just potential or actual alternatives marketed. It should be noted that the table is only listing one or few of the most promising substitutes, and that many more substitutes may be available or being developed. The table furthermore indicates the cost level of the substitute solution as compared to the lead solution. For applications where no alternative exist or research is ongoing, it is not possible to state precisely, when alternatives are available and ready for being marketed, as this depends heavily on the demand for substitutes.

Table 7.1 Options for substitution of lead with initial indication of level of expenses relative to Pb-technology (based on /Hansen et al. 2002; Heron 2003/)

Application	**Alternatives**	**Level of expenses relative to lead technology *1**	**Extension of alternatives**
Batteries	Lithium-ion-polymer batteries or other types.	"+" - Compared to the lead-acid battery will the lithium-ion-polymer battery cost 6 times more but last 2-3 times longer /Danionics 1998/.	On research/product development level. Price difference so far prevents further development. The lead-acid battery is generally unchallenged on the market for all major fields of application (starter batteries, traction, and emergency power).
Cable sheathing	PE/XLPE – Polyethylene/cross linked polyethylene plastic to low-voltage ground cables up to 24 kV. No alternatives to lead sheaths for marine cables and high-voltage ground cables despite significant research efforts /NKT 1997/. Aluminium is rejected as an alternative to lead due to higher internal resistance (caused by electrical turbulence) /NKT 97/.	"=" – Production costs, lifetime and quality of PE/XLPE-cables deemed equal to traditional lead cables for low-voltage ground applications /Gudum et al 2001/	PE/XLPE is substituting lead in Denmark for low-voltage ground applications. In France lead has been partly substituted for medium-voltage cables not requiring absolute long-term reliability /CECAD-plomb 1996/.
Flashing (around chimneys, windows etc.)	Alternatives may be organised as /Maag et al 2001b/: • Pure zinc, which is soft and may be treated almost as lead • Aluminium (as net or pleated) combined with rubber/polymer • Rigid profiles of aluminium, stainless steel or other metals	"+" - Cost increase estimated at 10% of total costs installed /Gudum et al 2001/.	Aluminium solutions and some rigid profiles are already available on the market. Training in pure zinc solutions has been initiated at Danish training centres for plumbers.

Application	Alternatives	Level of expenses relative to lead technology *1	Extension of alternatives
Roofing plates	Many alternative roofing materials are available. In the case of historical buildings substitution is difficult. Lead plated steel has been proposed as an alternative.	?	No alternative for historyical buildings has actually been marketed.
Sheets for corrosion protection in chemical industry	Acid resistant stainless steel	"+/++"	Alternative is available on the market.
Leaded window frames	None		
Solders for electronics	Lead free solders, surface-mount technology/ electrical glue.	"+" - Cost increase of tin based lead-free solders typically in the range of +20 – 50% /Brorson & Nylén 1997/.	Lead free products are anticipated to be marketed within the next year /Heron 2003/. Electrical glue can replace solders for some applications, but not all. Lead-free solders are needed /Christensen et al 2000/.
Solders for food cans	Lead free solders, welding, gluing	"-/+" – Lead has been substituted voluntarily.	No lead soldered food containers have been produced or used in the U.S. since December 1990 /USEPA 1994/.
Solders for electrical bulbs	Tin-zinc solders, welding or electrical glue	?	Development is still at the research level.
Solder for auto radiators made of brass-copper	Aluminium radiators soldered by Mg-Si solder may substitute brass-copper radiators /Hedemalm 1994/	"-" – Aluminium is significantly cheaper than brass/copper.	Aluminium radiators dominate the market /Hedemalm 1994/
Solders for VVS and other applications	Alternatives vary with application. For public water supply alternative solders include tin-antimony and tin-silver	"=/+" – The cost of solder is low compared to the overall costs of construction.	Alternatives are well established as the use of lead solders for public water supply is prohibited in some countries.
Ammunition	Steel, soft iron, wolfram, bismuth and tin may be used as alternatives to lead shot. Wolfram is used as powder in a polymer matrix. No research seems to have been carried out regarding alternatives for other applications like bullets for rifles and pistols. In principle all non-toxic metals with a density close to or above lead could be appropriate.	"+/++" – Costs differs with substitute: Steel Shot: + 25% Tin shot: + 50-100% Wolfram/bismuth shot: + 200-400 % /Hartmann 2001/.	Lead shot is prohibited in Denmark. The market is dominated by steel shot. In forests supplying wood for veneer production only wolfram and bismuth shot are typically allowed, as steel shots in wood damage wood saws /Hartman 2001/. Lead is so far unchallenged for other types of ammunition.

Application	Alternatives	Level of expenses relative to lead technology *1	Extension of alternatives
Bearings etc. of lead alloys	Babbitt metal (leaded tin bronze) for bearings may be substituted by aluminium bronze and unleaded tin bronze, assuming a lubricant can be added and the design of axles etc. allows for the higher hardness of the bearing material.	?	To the best of knowledge lead alloys are still unchallenged.
Hot dip galvanising (zinc contains 1% lead)	No knowledge of alternatives. To the best of knowledge no research for alternatives have been initiated.	?	
Weights for fishing tools and anchors	Depends on the application: • Anglers equipment: Lead can be substituted by iron, tin or zinc etc. Tin is appropriate for split shot sinkers while iron is appropriate for most weights. • Lead weights on trawls may be substituted by iron chains • Development work is ongoing with respect to leaded robes and lines – plastic coated iron bullets seems to a promising substitute for small lead bullets in robes.	"-/+/++" – Depends on application as follows: Angler split shot sinker: ~ 200 % (tin) Angler ordinary weights: ~ 50 % (zinc /iron) Weight s for trawls: ~ 0% (iron) /Ponsaing & Hansen 1995/. Robes and lines: 20 – 100% /Gudum et al 2001/.	Regarding anglers equipment and trawls substitutes are available on the market. Lead free robes are being developed. In Canadian national parks only lead-free equipment is allowed /Environment Canada 2002/.
Balance weights for vehicles	Alternatives assumed to include auto-balancing devices as well as other metal like copper tin etc. /Hedemalm 1994/.	"+"	Lead weights still dominate the market
Plating of gasoline tanks	Lead plated steel tanks can be substituted by plastic tanks	"-/="	Plastic tanks dominate the market
Yacht keels	Iron is used as alternative today, but only on boats not designed for racing. Other materials are available. The choice is partly a trade-off between speed and price. Iron keels require more maintenance than lead keels.	"-/+"	Iron and lead is sharing the market.
Lead tubes and joints for drain and water pipes etc.	For drains and water pipes alternatives include iron, copper and plastic pipes and joints. For corrosion resistant pipes/joints for industrial purposes alternatives include acid resistant stainless steel.	"-/+"	In many countries new lead pipes have not been used for domestic water supplies for over 30 years / Scoullos *et al* 2001/. However, in France lead piping still counted for 36 % of the connecting pipes in 1996 /CECAD-Plomb 1996/.
Radiation shielding	Barium and concrete are assumed to be alternatives /Hedemalm 1994/.	?	Lead dominates the market
Other: Toys, curtains, candlesticks, foils, organ pipes etc.	Alternatives vary with application and include several other materials like plastic, tin, stainless steel, aluminium etc.	?	

Application	Alternatives	Level of expenses relative to lead technology *1	Extension of alternatives
Gasoline additives	Alternatives are available and widespread	?	In many countries lead additives have been completely substituted for several years.
PVC stabiliser	Substitutes are generally calcium/zinc stabilisers, which already dominate indoor applications, and has proven useful also with respect to electrical cables/wires etc. Calcium/zinc stabilisers seem to be the primary choice also for outdoor purposes. However, research/development based on organic compounds is ongoing /Gudum et al 2001/. Organo-tin compounds have been used for more than 40 years. However, concerns about potential risks have been raised both in Sweden, Holland and Germany /Scoullos *et al* 2001/.	"+" – The cost increase related to substituting lead compounds by calcium/zinc systems is in the range of 5-10% of the total production costs for PVC-products /Gudum et al 2001/.	In Denmark lead is completely replaced for indoor purposes apart from a few products granted exemption until 2003 and electrical cable/wires allowed in imported finished products Also outdoor products like windows are now based on lead free stabilisers. Generally, lead stabilisers are expected to be completely phased out of the Danish market from 2002 /Gudum et al 2001/.
Pigments	Many alternatives are available on the market. Ultimately, the choice is a matter of costs and the colour and other characteristics preferred, like weather fastness, torsion stability and brilliance.	"-/++" - Other pigments providing other colours can easily be found at lower costs. Trying to develop the perfect substitute may be rather costly /Ponsaing & Hansen 1995/.	Other pigments are already widely used
Rust-inhibitive primers	Zinc phosphate or zinc oxide combined with iron oxide.	"+" – Assessment relates to cost of primer only. If the use of lead primers require heavy occupational safety protection the use of lead primers may be far more costly than other primers.	Lead based primers are almost completely substituted in Denmark.
Siccatives in paint	Several other siccatives are marketed. However, for special applications alternatives may be few or missing	"=/+" - Compared to price of final product, cost increase for siccative must be assumed small.	Lead based siccatives are replaced by zirconium or calcium based siccatives in the USA /Hoffman 1992/. No market data for Europe are available.
Lubricants for demanding industrial applications	No precise knowledge – research should be ongoing	?	?
Glass of cathode ray tubes	Alternatives to lead are assumed to include zirconium, strontium and barium /Hedemalm 1994/.	"+/++" - Costs of alternatives so far prevent further development.	Lead is so far unchallenged

Application	**Alternatives**	**Level of expenses relative to lead technology *1**	**Extension of alternatives**
Other applications of lead crystal glass	Alternatives depend on application /Smith 1990/: • For fluorescent tubes and light bulbs alternatives include strontium, barium, cerium etc., but alternatives are more difficult to process. • For optical glass alternatives are assumed to include barium and zinc oxides for glass with indices of refraction below 1.6 and lanthanium for glass with indices of refraction above 1.6. • For semi-crystal glass barium, potassium and zinc are alternatives. For whole crystal glass research is ongoing but no introduction of alternatives are likely, before the international quality systems for crystal glass are modified, as these systems require the use of lead /Gustavsson 1993/.	"+" – The largest Danish manufacturer of semi-crystal glass replaced lead with barium partly to reduce the costs of emission control /Fought 1993/.	Lead is so far unchallenged apart from semi-crystal glass, in which lead by some manufacturers is replaced by barium.
Glazes and enamels	Alternative systems include alkali borosilicate glasses, zinc/strontium and bismuth glasses /Cambell 1998/.	"?"	In UK around 80% of bone china, 30 % of earthenware and 40 % of hotelware is un-leaded (1998 –figures). The trend towards substitution of lead glasses continues /Campbell 1998/).

*1 Indication of the overall current user/consumer price levels for lead free alternatives as compared to lead technology. Price determining factors vary among the uses (expenses for purchase, use, maintenance etc.). Costs of waste disposal or other environmental or occupational health costs as well as local and central government costs and revenues are, however, not considered in the cost assessments given.
"–": lover price level (the alternative is cheaper)
"=": about the same price level
"+": higher price level
"++": much higher price levels

8 Literature

Alloway, B.J. 1995. ***Heavy Metals in soil.*** 2. edition. Blackie Academic & Professional, Glasgow.

AMAP 1997. ***Forurensning i Arktis - Tilstandsrapport om det arktiske miljø [Pollution in the Arctic - Report on the present state of the Arctic environment].*** Arctic Monitoring and Assessment Programme, Oslo.

AMAP. 2002. ***Arctic Pollution 2002.*** Arctic Monitoring and Assessment Programme, Oslo.

Ayres, R.U., L.W. Ayres & I. Råde. 2002. ***The life cycle of copper, its co-products and by-products***. International Institute for Environment and Development (IIED) and World Business Council for Sustainable Development (WBCSD).

Brorson, G. & M.Nylén 1997. ***Examination of environmentally adapted tin-base alloys for replacement of tin-lead solders.*** AFR-report 177. Swedish EPA, Stockholm.

Brønnum, J. & E. Hansen. 1998. ***Bly - anvendelse, problemer, den videre indsats [Lead - uses, problems, further activities].*** Environmental Projects 377. Danish Environmental Protection Agency, Copenhagen. (In Danish).

Campbell, I. 1998. ***Lead and cadmium free glasses and frits.*** Glass Technology Vol. 39, No. 2, April 1998: 38-41.

CECAD-Plomb 1996. ***The problem of lead: Questions and answers.*** Group for the study of lead, Paris.

Christensen, F. M., T. Jørgensen & I.R. Nielsen 2000. ***Environmental and technical characteristics of conductive adhesives versus soldering.*** Working Report 16/2000, Danish EPA, Copenhagen.

Danionics. 1998. Personal information from Ole Stig Nielsen, Danionics, Odense, Denmark.

Danish EPA 1983. ***Blyforurening omkring flugtskydningsbaner*** [Lead contamination around clay pigeon shooting fields]. Danish Environmental Protection Agency

Environment Canada 2002. www.ec.gc.ca/envhome.html and www.cws-scf.ec.gc.ca/fishing/alter_e.html

EU 2000a. Proposal COD 2000/0159/. ***Proposal for a Directive of the European Parliament and of the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment.*** *COD 2000/0159.* Official Journal C 365 E , 19/12/2000 P. 0195 - 0197

EU 2000b. ***Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles.***

Eurometaux. 1997. Comments to the Danish EPA's draft to Statutory order regarding lead. Eurometaux, European Association of Metals, Intersectorial Lead Group, Bruxelles.

Fought 1993. Personal information from Jørgen Fought, Holmegård Glasværk, Holmegård, Denmark.

Heron 2003. Personal information from Henri Heron, Danish EPA, Copenhagen, January 2003

GLI 2002. ***Launching a global lead initiative: A proposal to the World Summit on Sustainable Development. Alliance to end childhood lead poisoning.***http://www.johannesburgsummit.org/html/sustainable_dev/p2_health/alliance_lead_poisoning.pdf.

Goyer, R.A. 1986. ***Toxic effects of metals***. In: Cassarett and Doull's Toxicology. The basic science of poisons. Klaassen, C.D., M.O Amdur, and J.Doull, (eds.) 3rd ed. McGraw-Hill, New York.

Gudum A. 2001. ***Økonomisk konsekvensanalyse af blybekendtgørelsen*** [Analysis of economic consequences of the lead statutory order]. COWI for the Danish EPA – draft of December 2001. Unpublished (In Danish)

Gustafsson, L. *et al.* 1993. ***Phasing out lead and mercury.*** The Swedish National Chemicals Inspectorate. Stockholm, Sweden.

Hansen, E., C. Lassen, F. Stuer-Lauridsen & J. Kjølholt. 2002. ***Heavy metals in waste.*** European Commission DG ENV. E3, Brussels. http://europa.eu.int/comm/environment/waste/heavy_metals.htm

Hartmann, P. 2001. Personal information from Poul Hartmann, National Environmental Research Institute, Kalø, Denmark.

Hedemalm, P. 1994. ***Some uses of lead and their possible substitutes.*** Kemi Report No. 3/94. The Swedish National Chemicals Inspectorate. Stockholm.

Hoffmann, L.1992. ***Muligheder for reduktion i blyanvendelsen ved substitution*** [Options for reduction of the uses of lead by substitution]. Working Report no. 40. Danish EPA, Copenhagen. (In Danish)

ILZSG. 2002. International Lead and Zinc Study Group, London. http://www.ilzsg.org/ilzsgframe.htm

LDAI. 2002. Lead Development Association International, London. http://www.ldaint.org/default.htm

NKT. 1997. Letter from NKT Cables – Power Cables Division, signed by Bo Svarrer Hansen, to the Danish EPA dated 1997-10-16 concerning use restrictions for lead.

Nriagu, J. & J. Pacyna. 1988. ***Quantitative assessment of worldwide contamination of air, water and soils by trace metals***. Nature. 333: 134-139.

Nriagu, J.O 1989. ***A global assessment of natural sources of atmospheric trace metals***. Nature. 338: 47-48.

OECD. 1993. ***Risk Reduction Monograph No.1***: ***Lead***. OECD/GD (93) 67. OECD Environment Directorate, Paris.

OSPAR 2002. ***Lead***. Hazardous Substances Series. OSPAR Commission.

Pacyna J.M. & E.G. Pacyna. 2001. ***An assessment of global and regional emissions of trace metals to the atmosphere from anthropogenic sources worldwide***. Environmental Reviews 9: 269-298.

Ponsaing, P & E. Hansen. 1995. ***Opportunities and costs of substituting Lead.*** TemaNord 1995:565. Nordic Council of Ministers, Copenhagen.

RTI. 1999. ***Toxicological profile for lead.*** Research Triangle Institute for U.S. Department of Health and Human Services. Agency for Toxic Substances and Disease Registry, Atlanta.

Scoullos, M., G. Vonkeman,I. Thornton & Z. Makuch. 2001. ***Mercury, cadmium, lead: Handbook for sustainable heavy metals policy and regulation***. Kluwer Academic Publishers, Dordrecht

Smith, K. 1990. ***Use and substitutes analysis for lead and cadmium products in municipal solid waste.*** USEPA, Office of Toxic Substances.

Thornton, I., R. Rautiu & S. Brush. 2001. ***Lead - the facts***. IC Consultants Ltd, London.

Tukker, A., H. Buijst, L. van Oers and E. van der Voet. 2001. ***Risks to health and the environment related to the use of lead in products.*** TNO Report STB-01-39.

UNEP 1998. ***Global opportunities for reducing the use of leaded gasoline***. IOMC, UNEP.

U.S.EPA. 1994. ***Lead soldered cans.*** Presentation made by U.S.EPA at the OECD Workshop on Lead Products, September 1994, in Toronto, Canada.

USGS. 2002a. ***Mineral commodity summaries.*** U.S. Geological Survey. http://minerals.usgs.gov/minerals/pubs/commodity/lead/380302.pdf

USGS. 2002b. ***Lead statistics***. In: ***Historical statistics for mineral commodities in the United States***, U.S. Geological Survey Open-File Report 01-006. U.S. Geological Survey, Reston.

WHO. 1989. ***Lead - environmental aspects.*** Environmental Health Criteria 85**.** World Health Organisation, International Programme on Chemical Safety (IPCS), Geneva.

WHO. 1993. ***Guidelines for Drinking Water Quality, Vol. 1***. WHO, Geneva.

WHO. 1995. ***Inorganic lead.*** Environmental Health Criteria 165. World Health Organisation, International Programme on Chemical Safety (IPCS), Geneva