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Key scientific findings for lead

I. Hazardous properties, exposures and effects

1. Lead is a heavy metal that is toxic at very low exposure levels and has acute and chronic effects on human health. It is a multi-organ system toxicant that can cause neurological, cardiovascular, renal, gastrointestinal, haematological and reproductive effects. The type and severity of effects depend on the level, duration and timing of exposure. Lead is accumulated in bone and may serve as a source of exposure later in life. Organo-lead compounds, such as tri-alkyl-lead and tetra-alkyl-lead compounds, are more toxic than inorganic forms of lead.

2. In the environment, lead is toxic to plants, animals and micro-organisms. It bioaccumulates in most organisms. In surface waters, residence times of biological particles containing lead have been estimated at up to two years. Although lead is not very mobile in soil, lead may enter surface waters as a result of the erosion of lead-containing soil particles and the dumping of waste containing lead products.

II. Environmental transport: extent to which lead is transported on intercontinental, regional, national and local scales.

3. Lead is released by various natural and anthropogenic sources to the atmosphere and to aquatic and terrestrial environments and there are fluxes between these compartments. Lead released into the atmosphere is deposited on land and into aquatic environments and some lead released onto soil over time is also washed out to aquatic environments.

4. Once emitted to air, lead is subject to atmospheric transport. It is mainly emitted to the atmosphere in particle form. The atmospheric transport of lead is governed by aerosol (particle) transport mechanisms: in the atmosphere, lead may be transported on local, national, regional or intercontinental scales, depending on various factors, including particle size, the height of the emission outlet and meteorology. Because it has a relatively short residence time in the atmosphere (days or weeks), this metal is mainly transported over local, national or regional distances. For example, based on modelling results, the annual contribution of external emission sources to the total lead deposition in Europe has been estimated not to exceed 5 per cent, and in North America may be even lower. Episodically, however, the contribution of intercontinental transport may be significantly higher at certain locations in these two continents on some days of the year, although annual lead contribution from intercontinental transport is low.

5. While the model used to produce these results is state-of-the-art, it should be noted that the data underlying the model are based mainly on emission estimates from 1990. Another model calculation published in 1997 estimated that 5–10 per cent of emissions in the Euro-Asiatic region in the winter are deposited in the northern Arctic. It should be noted that model results have uncertainties and the resulting figures should therefore be interpreted with caution.

6. The regional and intercontinental atmospheric transport of lead contributes to deposition in remote regions such as the Arctic, where there are few local sources for lead releases. Some evidence of the limited intercontinental transport of lead is obtained from measurements of stable isotope signatures of the airborne dust in combination with air-mass back trajectories. These measurements indicate the origin of dust particles transported by air masses, and thereby provide evidence that aerosols carrying lead are transported intercontinentally and from industrialized regions to remote regions such as the Arctic, where there are very few local emission sources. Soil in Kauai, Hawaii, was found to contain lead from diverse distant sources, including lead from anthropogenic sources in Asia and North Amer-

ica. Another study, in Japan, shows long-range transport of air pollution (including lead) from continental Asia.

7. Europe and the Asian part of the Russian Federation contribute all but a small percentage of the airborne lead reaching the Arctic. Models show that the main atmospheric pathways lie across the north Atlantic, from Europe and from Siberia. Between 95 and 99 per cent of the lead deposition in the Arctic is anthropogenic. Furthermore, over the period 1993–1998, snow samples in the part of the Arctic north of Russia showed a concentration gradient with levels increasing from the easternmost to the westernmost monitoring sites. This was the consequence of the different times at which leaded petrol was phased out in different regions and of varying trends in industrial development. The transport of lead follows seasonal patterns. Lead levels in airborne particles are lowest in early autumn, and at that time of year lead reaching the Canadian Arctic comes mostly from natural sources in the Canadian Arctic archipelago and western Greenland. In late autumn and in winter, airborne lead comes primarily from industrial sources in Europe. The measured snow concentrations, however, are low compared with deposition in industrialized areas.

8. The largest single ice-core based dataset used to reconstruct Arctic metal deposition comes from the Greenland Summit deep drilling programme. The data show that the lead levels increased significantly following the industrial revolution in the nineteenth century. Lead deposition in the 1960s and 1990s was eight times higher than in pre-industrial times. With the phase-out of leaded petrol since 1970 and the implementation of emission controls, lead concentration in the ice-core has sharply decreased. The results of the programme indicate that anthropogenic emissions – and, in particular, releases of lead through the use of leaded petrol – during a given period constituted a more important source than natural sources of lead deposited in Greenland. The remarkable reduction, in parallel with the removal of lead in petrol in 1970–1997, has resulted in a return to pre-industrial levels of lead in the ice-core data.

9. With regard to aquatic systems, rivers are transport media for lead on a national and regional scale. The oceans are also a transport medium. The oceanic residence time of lead ranges from about 100 to 1,000 years, which may indicate a potential for ocean transport. Concentrations of scavenge type trace metals, however, typically decrease with distance from the sources and, in general, concentrations of scavenge-type metals such as lead generally tend to decrease along flow paths of deep water because of continual particle scavenging and subsequent sedimentation.

10. The contribution of lead to the marine environment from Belgium, Denmark, France, Germany, the Netherlands, Norway, Sweden and the United Kingdom via rivers is currently larger than the airborne inputs.

III. Sources of releases.

11. Important releases of lead may be grouped into the following categories: releases from natural sources, in other words, releases resulting from the natural mobilization of naturally occurring lead from the Earth’s crust and mantle, such as volcanic activity and the weathering of rocks; current anthropogenic releases from the mobilization of lead impurities in raw materials such as fossil fuels and other extracted and treated metals; current anthropogenic releases of lead used in products and processes as a result of mining and processing activities, manufacturing, use, disposal, recycling and reclamation; releases from incineration and installations for municipal waste, open burning and from residues containing lead; and the mobilization of historical lead releases previously deposited in soils, sediments and wastes. Emissions from leaded petrol, metal processing including recycling, mining activity and probably oceans can be considered as the sources of relevance for the long-range transport of lead.

A. Atmospheric releases (emissions).

12. The most recent study of total anthropogenic atmospheric emissions estimated the total emissions in the mid-1990s at 120,000 tonnes, of which 89,000 tonnes originated from the use of petrol additives. Besides fuel additives, non-ferrous metal production and coal combustion were the major

sources. The major natural sources of emissions to air are volcanoes, airborne soil particles, sea spray, biogenic material and forest fires.

13. Very different estimates on total emissions by natural processes have been reported. A study from 1989 estimates the total emission in 1983 at between 970 and 23,000 tonnes per year, whereas a new study estimates the total emissions from natural sources at between 220,000 and 4.9 million tonnes per year. The large disparity is mainly due to different estimates on the amount of lead moved around with soil particles.

14. As of June 2006, only two countries worldwide exclusively used leaded petrol, while 26 countries used both leaded and unleaded petrol. Since sub-Saharan Africa completely eliminated the import and production of leaded petrol in January 2006, the majority of countries still using leaded petrol are in the Asia-Pacific region. The global consumption of lead for manufacturing of petrol additives decreased from 31,500 tonnes in 1998 to 14,400 tonnes in 2003. In 1970, when the use of leaded petrol was peaking, about 310,000 tonnes was used for petrol additives in member countries of the Organization for Economic Cooperation and Development (OECD).

15. The total emission and distribution by sources vary considerably among countries. From 1983 to the mid-1990s, the quantified global anthropogenic emission of lead decreased from about 330,000 tonnes to 120,000 tonnes. Emissions have been decreasing in virtually all industrialized countries over the past twenty years. For example, in Europe, from 1990 to 2003, lead emissions decreased by about 92 per cent. In the United States of America, emissions decreased sharply during the 1980s and early 1990s due to the phase out of lead in petrol and reductions from industrial sources. Lead emissions continued to decline, but to a lesser extent, in the period from the mid-1990s to 2002. Overall emissions of lead decreased by about 95 per cent over the 21-year period from 1982 to 2002, falling from about 54,500 tonnes per year in 1982 to about 1,550 tonnes in 2002.

16. The significant reduction of lead emissions was mainly due to restrictions and bans on the use of leaded petrol for vehicles, but also implementation of improved air pollution controls. As an example, in eight European countries, the reported emissions from ferrous and non-ferrous production were, on average, reduced by about 50 per cent over the period 1990–2003, while emissions from waste incineration and from public electricity and heat production, on average, dropped by 98 per cent and 81 per cent respectively. Data on lead emissions and emission trends in developing countries were not available at the time of the preparation of the present document.

17. The open burning in some developing countries of waste products containing lead could be an important source of local and regional lead emissions to the atmosphere.

B. Releases to land and aquatic systems.

18. Some lead-containing products are disposed of in various waste deposits or released to soil or the aquatic environment. The major categories are: waste and loss of ammunition from hunting, disposal of products, mine tailings and smelter slag and waste. Other products and wastes, in no particular order, that may contribute to releases during their life-cycle, include paints with lead, lead balancing weights for vehicles, lead sheathing of cables left in the ground and lead batteries (loss by breakage and recycling), and mine tailings and other wastes. The handling of wastes may lead to elevated local and regional release levels in developing countries.

19. Direct industrial and municipal releases to aquatic environments in developed countries are considered small when compared to releases to the atmosphere and land. The major industrial sources are mining and non-ferrous metal production. Weathering of rocks releases natural lead to soils and aquatic systems, which plays a significant role in the global cycle. This release is enhanced by acidic emissions. The open burning in some developing countries of waste products containing lead could be an important source of local and regional lead releases to land and aquatic systems.

IV. Production and uses of lead

20. Lead is mined in more than 40 countries, the major producers being China and Australia, which represent about 30 per cent and 22 per cent of global mining production respectively. Lead-rich minerals most often occur together with other metals, and about two thirds of worldwide lead output is obtained from mixed lead-zinc ores.

21. The total global production of lead from mining has decreased slightly, from 3.6 million tonnes in 1975 to 3.1 million tonnes in 2004. Over the same period, global refined lead production and metal consumption have increased from about 4.7 million tonnes to about 7.1 million tonnes. The reason for the difference between mine production and lead consumption is due to the fact that recycled lead accounts for an increasingly large part of the supply: recycled lead accounted for 45 per cent of global supply in 2003.

22. Lead is used and traded globally as a metal in various products. The major use of lead in recent years is lead batteries, accounting for 78 per cent of reported global consumption in 2003. Other major application areas are lead compounds (8 per cent of the total), lead sheets (5 per cent), ammunition (2 per cent), alloys (2 per cent), cable sheathing (1.2 per cent), and petrol additives (less than 1 per cent). The most significant change in the overall use pattern over the period 1970–2003 is that batteries account for an increasing part of the total, whereas the share of cable sheathing and petrol additives has decreased. Lead as pigment in paints has been discontinued in developed countries but is still used in some developing countries, specifically in industrial settings.

V. Lead issues in developing countries

23. As awareness of the adverse impacts of lead has increased, many uses have been reduced significantly in industrialized countries. In addition, as public awareness has grown, waste management systems have increasingly been put in place in industrialized countries to reduce releases of lead to the environment. That said, however, some of the uses of lead which have been phased out in industrialized countries have continued in developing countries. In addition, use of lead has continued or increased in some less developed regions or countries, for example, in plastics or in paints. Regulations and restrictions are less comprehensive or less well enforced in some developing regions. This has resulted in some of the health and environmental risks, local and regional that accompany the use, management (including collection, storage, recycling and treatment) and disposal of products containing lead. These hazardous disposal practices include open burning and indiscriminate dumping in sensitive ecosystems such as rivers and wetlands.

24. Another issue faced by developing countries is the export of new and used products containing lead, including electronic equipment and batteries, to those countries which lack the capacity to manage and dispose of the lead in these products in an environmentally sound manner at the end of their life. Another problem is posed by products containing lead that may cause exposure through normal use, such as certain toys.

VI. Levels and time trends in air and deposition

25. Most identified monitoring data for atmospheric lead concentrations and deposition come from Europe and the United States of America, although results from Antarctica, Canada, Japan and New Zealand are also available. Available data generally show a decreasing trend in air concentrations and deposition since about 1990, or earlier, depending on the country and region. For example, in 1990 the concentrations of lead in air were measured at stations located in the central part of Europe and along the coast of the North Sea. Measured background concentrations lay mainly within the 10–30 ng/m^3 range. In 2003 the concentrations mainly ranged between 5 and 15 ng/m^3. Concentrations in precipitation in central Europe in 1990 were around 2–5 µg /l. In 2003, these concentrations typically ranged from 1 to 3 µg/l.

26. Lead concentration measurements in air in the Canadian Arctic in the period 1980–2000 show a decline in lead concentrations of about 30–50 per cent, whereas data from the Eurasian side (Norway) do not reveal any noticeable trends during the same period.

27. Some modelling has been performed, mostly in Europe, to estimate deposition rates. When reported emissions are used in the models, they generally underestimate deposition (compared to measured data). The underestimation is believed to be due to the failure to include natural emissions and re-emissions of historical releases in models and to uncertainties in reported emissions.

28. In order to estimate long-term trends for different parts of Europe, measurement data were averaged over different countries. The long-term changes of air concentrations and concentrations in precipitation vary considerably across Europe. In central and north-western Europe, concentrations decreased by about 50–65 per cent between 1990 and 2003 based on these data. In northern Europe, concentrations in precipitation decreased by 30–65 per cent. Trend data for ambient lead concentrations in the United States of America for the period 1982–2001 show that, while urban and suburban sites had the greatest decrease in ambient lead concentrations during that period, rural sites also experienced significant reductions. Overall, lead air concentrations across the country have decreased by more than 94 per cent since 1983, based on available data. Furthermore, this trend has continued, although at a reduced rate throughout the 1990s, with lead concentrations decreasing by 57 per cent between 1993 and 2002. Available data indicate that atmospheric deposition is still causing the content of lead in topsoils in Europe to increase in some locations. As there were no data from some developing countries, trends of lead levels in air could not be determined.

29. The decline in use of leaded petrol is reflected in the 85 per cent decline in lead deposition rates in the Arctic from the 1970s to the early 1990s.

30. The main factors affecting the range and deposition of lead emissions include: characteristics of emission sources (higher outlets and higher emission temperatures result in higher emission plumes and, therefore, longer transport ranges); physical and chemical forms of lead in the atmosphere: large particles deposit within short ranges, small particles may be transported further; and meteorology (precipitation and wind speed), terrain, atmospheric stability and other factors.

VII. Human exposure pathways and effects

31. Neurodevelopmental effects in children, even at low levels of exposure, represent the most critical effect. Other adverse effects include neurological, cardiovascular, renal, gastrointestinal, haematological and reproductive effects.

32. Exposure to lead occurs mainly through inhalation of dust and air and ingestion of foodstuffs, water and dust. Attention is drawn to the following:

- Inhalation is an important route of exposure for people in the vicinity of point sources, including open burning of wastes containing lead products, in countries that still use lead in petrol, and in some occupational settings including secondary lead recovery
- Ingestion of lead in dust and soil is a major exposure pathway in children, because of their biological and behavioural characteristics
- Intake of food and beverages is usually the primary source of exposure for adults in the general population

33. There are multiple sources of exposure. Attention is drawn to the following:

- A wide range of exposure sources exist, whose characteristics vary both within and between countries

- In some countries, lead in petrol is still an important source of exposure. Other sources include lead in paint, low temperature-fired ceramics, informal sector recycling of car batteries, mine tailings and the air, soil and dust in the vicinity of point sources (e.g., smelters)

- Dust in homes with paint containing lead pigment can cause elevated blood lead levels in children

- Tap water from leaded pipes can also be an important exposure source

- Other potential sources of exposure include products containing lead, such as cosmetics, traditional medicines, toys and trinkets, contaminated spices and food colouring

34. Certain population groups are vulnerable and especially susceptible to lead. Attention is drawn to the following:

- New data highlight the special vulnerability of small children. Exposure of children can be magnified by their activities and behavioural patterns and biological characteristics

- Exposure starts in utero since lead passes through the placenta into the foetus; thus pregnant women are a population of concern

- Occupational exposure (e.g., some workers in the informal recycling sector)

- Other vulnerable population groups include socially and economically disadvantaged populations and the malnourished, whose diets are deficient in proteins and calcium

35. Lead is a well-documented neurotoxicant. Attention is drawn to the following:

- Lead exposure in children is linked to a lowering of their IQ

- Epidemiological studies consistently find adverse effects in children at blood lead levels down to 10 µg/dl. Recent studies reported lead-induced IQ decrements in children with blood lead levels below 10 µg/dl

- There is presently no known threshold for the effect of lead

- A growing number of studies suggest that exposure to lead may cause behavioural deficits and lower functional skills during childhood and later in life

36. Attention is drawn to the following observations relating to exposure levels, trends and geographic scope:

- Lead exposures occur in most, or all, countries of the world. Available data suggest that, on the global scale, the highest blood lead levels occur in Latin America, the Middle East, Asia, parts of Eastern Europe and the Commonwealth of Independent States

- Available data indicate a substantial falling trend in environmental lead exposure in many developed countries mainly due to the elimination of lead from petrol, but also to reductions in other sources of exposure (e.g., lead in paint, lead in drinking water and lead in soldered cans). Thus, in the United States of America in the 1970s, over 80 per cent of children had blood lead levels (Pb-B) exceeding 10 µg/dl, but, in a 1999–2002 study, fewer than 2 per cent exceeded this level

- Exposure levels remain elevated in many locations, however, including in some developed countries

37. Lead remains an environmental health problem. Attention is drawn to the following:

- A growing number of countries (mainly developing countries and countries with economies in transition) are recognizing and reporting the problem of environmental lead exposure in some population groups

- In many parts of the world, for many decades, there was very little public awareness of and policies relating to the potential for lead contamination and its public health effects

- As a result of its health effects and impact on development, lead may cause significant economic losses for society

VIII. Impacts on the ecosystem

38. Environmental exposure to lead is greatest near point sources (e.g., smelters), or from lead shot and sinkers used for shooting and fishing. In locations not affected by local sources, there are generally no observed effects on terrestrial organisms and plants and, in the aquatic environment, lead concentrations are normally below known effect levels. One possible important exposure route which has not been included in the review owing to lack of data is the indiscriminate disposal of waste containing lead products in sensitive ecosystems such as the many rivers and wetlands in developing countries.

39. The environmental effects of lead are well documented. Secondary poisoning has also been extensively documented, especially for predators feeding on contaminated animals. There are many reports on the levels of lead in wild mammals, but few reports of toxic effects of the metal in wild or in non-laboratory species. In all species of experimental animals studied, however, 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.

40. In a significant percentage of European soils, the lead concentrations estimated for areas away from point sources exceed the threshold concentration for adverse effects in soil, and therefore the terrestrial ecosystems are considered to be at risk.

IX. Data gaps

41. A number of data gaps and needs have been identified. Attention is drawn to the following:

- The need to develop and improve exposure assessments and use and release inventories, especially for developing countries

- The need for modelling for the southern hemisphere and a better understanding of ocean transport, re emissions, and natural releases

- The need to examine the role of long-range transport, the contribution of anthropogenic sources versus natural sources and the influence of local, regional and global sources

- The general lack of data from developing countries where environmental and health problems related to production, trade, use and disposal of lead may be more common and have a different nature that in other regions

- The need to monitor and assess lead levels in various media (such as soil and sediment) and data associated with impacts on humans, ecosystems and animals, including impacts from cumulative exposures to different forms of lead, as well as further emission data that help overcome the uncertainties in the results of the current models

- The need to collect data regarding accidental spills from mine tailings on a global scale and the real extent of these events, especially in developing countries, where capacity building is needed

- The need for real information about the quantities of lead disposed of in the environment, especially in developing countries, where the open burning of lead- containing products is a common practice, which results in atmospheric emissions

- The need to improve the information on the level of contamination of drinking water by lead as a result of leaching from landfills, especially in developing countries

- The need to collect data on concentration levels in large migrating marine mammals
- The need to examine the global flow of lead in products

Extended summary

CHAPTER 1 – Introduction

42. In 2005, the UNEP Governing Council, in GC decision 23/9 III, requested UNEP to undertake the development of reviews of scientific information on lead and cadmium, focusing especially on long-range environmental transport, in order to inform future discussions of the Governing Council on the need for global action in relation to lead and cadmium.

43. UNEP established a Working Group to assist it in developing the reviews of scientific information. The Working Group on lead and cadmium consisted of members nominated by Governments, intergovernmental organizations and non-governmental organizations. Working Group members assisted, first through a comment round by mail, then through a meeting of the Working Group, which took place 18-22 September 2006 in Geneva, Switzerland.

44. Chapters 7, 5, 4 and 3 of this report respond directly to the Governing Council request and were addressed specifically, and in that order of priority, by the Working Group at its meeting. Chapter 6, relating to production, use and trade patterns, and Chapter 2, related to chemistry were considered by the Working Group to be necessary information to provide a more comprehensive understanding of the issue and related factors. The Working Group considered that, while chapters 8, 9 and 10, and the appendices, fell outside the mandate of the Governing Council decision, they provided useful information and could be retained. They were not, however, reviewed by the Working Group.

45. During its meeting, the Working Group was unable to complete its review of the health effects (Chapter 3), and delegated responsibility for finalising this chapter to the World Health Organisation, in concert with UNEP, based on inputs from the Working Group at the meeting.

46. The Working Group recognised that, as there was ongoing work underway in other forums on this metal, it was not possible to finalise the reviews at that time. The version finalised by the secretariat after the Working Group meeting was therefore to be considered 'interim'.

47. In 2007, the UNEP Governing Council, in GC decision 24/3 III, requested UNEP to provide available information on lead and cadmium to address the data and information gaps identified in the Interim Reviews and to compile an inventory of existing risk management measures. The draft final version of the review of scientific information on lead was presented for the information of the Governing Council in its 25th session on February 2009.

48. In 2009, the the UNEP Governing Council, in GC decision 25/5 II, requested UNEP to finalize the scientific review taking into account the latest available information in line with decisions 24/3 of 9 February 2007 and 23/9 of 25 February 2005 and to report to the Governing Council at its twenty-sixth session with a view to informing discussions on the need for global action in relation to lead and cadmium.

CHAPTER 2 – Chemistry

49. Elemental lead is silvery-white and turns blue-grey when exposed to air. It is dense, malleable, readily fusible, and has a low melting point. It is soft enough to be scratched with a fingernail. Because of these characteristics, lead has been one of the most widely used metals in the history of mankind. The first reported uses of lead date back to 4000 BC, and toxicological effects have been linked to lead

since antiquity. Lead is known to bioaccumulate in most organisms, whereas it is generally not biomagnified up the food web.

50. In the atmosphere, lead will deposit on surfaces or exist as a component of atmospheric particles. In the atmosphere, lead exists primarily as lead compounds. The residence time ranges from hours to weeks. Transport of atmospheric lead is linked to the characteristics of aerosols.

51. In the aquatic environment, lead can occur in ionic form (highly mobile and bio-available), organic complexes with dissolved humus materials (binding is rather strong and limits availability), attached to colloidal particles such as iron oxide (strongly bound and less mobile when available in this form than as free ions) or to solid particles of clay or dead remains of organisms (very limited mobility and availability). The speciation of lead differs in fresh water and seawater: in fresh water, lead primarily exists as the divalent cation (Pb^{2+}) under acidic conditions, and forms $PbCO_3$ and $Pb(OH)_2$ under alkaline conditions. Lead speciation in seawater is a function of chloride concentration and the primary species are $PbCl_3^- > PbCO_3 > PbCl_2 > PbCl^+ >$ and $Pb(OH)^+$. In surface waters, average residence times of biological particles containing lead have been estimated at two to five years.

52. In soil, lead is generally not very mobile. The downward movement of elemental lead and inorganic lead compounds from soil to groundwater by leaching is very slow under most natural conditions. Clays, silts, iron and manganese oxides, and soil organic matter can bind lead and other metals electrostatically (cation exchange) as well as chemically (specific adsorption). Soil pH, content of humic acids and amount of organic matter influence the content and mobility of lead in soils. Though lead is not very mobile in soil, lead may enter surface waters as a result of erosion of lead-containing soil particles.

CHAPTER 3 - Human exposure and health effects

53. Lead is a heavy metal that is toxic at very low exposure levels and has acute and chronic effects on human health. It is a multi-organ system toxicant that can cause neurological, cardiovascular, renal, gastrointestinal, haematological and reproductive effects. The type and severity of effects depend on the level, duration and timing of exposure. Lead is accumulated in bone and may serve as a source of exposure later in life. Organo-lead compounds, such as tri-alkyl-lead and tetra-alkyl-lead compounds, are more toxic than inorganic forms of lead.

54. Neurodevelopmental effects in children, even at low levels of exposure, represent the most critical effect. Other adverse effects include neurological, cardiovascular, renal, gastrointestinal, haematological and reproductive effects.

55. Exposure to lead occurs mainly through inhalation of dust and air and ingestion of foodstuffs, water and dust. Inhalation is an important route of exposure for people in the vicinity of point sources, including open burning of wastes containing lead products, in countries that still use lead in petrol, and in some occupational settings including secondary lead recovery. Ingestion of lead in dust and soil is a major exposure pathway in children, because of their biological and behavioural characteristics. In general, ingestion of lead through food and water is the major exposure pathway for lead in adults (WHO/UNECE, 2007).

56. There are multiple sources of exposure. A wide range of exposure sources exist, whose characteristics vary both within and between countries. In some countries, lead in petrol is still an important source of exposure. Other sources include lead in paint, low temperature-fired ceramics, informal sector recycling of car batteries, mine tailings and the air, soil and dust in the vicinity of point sources (e.g., smelters). Dust in homes with paint containing lead pigment can cause elevated blood lead levels in children. Tap water from leaded pipes can also be an important exposure source. Other potential sources of exposure include products containing lead, such as some cosmetics, certain types of miniblinds, some traditional medicines, toys and trinkets, and contaminated spices.

57. Certain population groups are vulnerable and especially susceptible to lead. New data highlight the special vulnerability of small children. Exposure of children can be magnified by their activities and behavioural patterns and biological characteristics. Exposure starts in utero since lead passes through the placenta into the foetus; thus pregnant women are a population of concern. Elevated occupational exposures may take place in various settings e.g. in the informal battery recycling sector. Other vulnerable population groups include socially and economically disadvantaged populations and the malnourished, whose diets are deficient in proteins and calcium

58. Lead is a well-documented neurotoxicant and lead exposure in children is linked to a lowering of their IQ. Epidemiological studies consistently find adverse effects in children at blood lead levels down to 10 µg/dl. Recent studies reported lead-induced IQ decrements in children with blood lead levels below 10 µg/dl. There is presently no known threshold for the effect of lead. A growing number of studies suggest that exposure to lead may cause behavioural deficits and lower functional skills during childhood and later in life.

59. Lead exposures occur in most, or all, countries of the world. Available data suggest that, on the global scale, the highest blood lead levels occur in Latin America, the Middle East, Asia, parts of Eastern Europe and the Commonwealth of Independent States**.** Available data indicate a substantial falling trend in environmental lead exposure in many developed countries mainly due to the elimination of lead from petrol, but also to reductions in other sources of exposure (e.g., lead in paint, lead in drinking water and lead in soldered cans). For example, in the United States of America in the 1970s, over 80 per cent of children had blood lead levels exceeding 10 µg/dl, but in a 1999–2002 study fewer than 2 per cent exceeded this level. However, exposure levels remain elevated in many locations, for some segments of the populations, including in some developed countries. The potential for elevated Pb exposures remains, particularly in areas near major Pb sources or with exposures to Pb-based paint or high Pb levels in drinking water (U.S. EPA, 2006).

60. Present data on the concentration of lead in air, daily intake of lead with food and Pb-B (blood lead level) suggest a decreasing trend of environmental lead exposure mainly due to the elimination of lead from gasoline. Reduced blood lead levels correlating with reduced use of leaded gasoline have been demonstrated in a number of countries. As an example, blood lead levels in children and leaded petrol sales in Australia from 1979 to 1999 are shown in Figure 1.

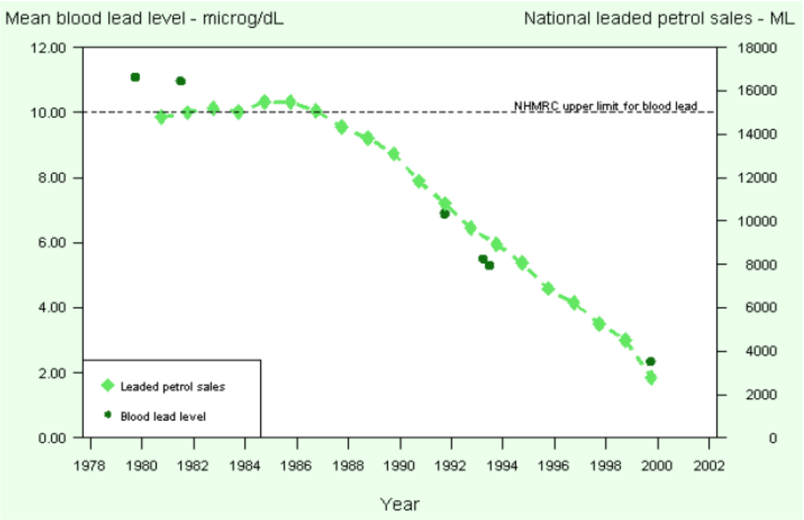


Figure 1 *Blood lead levels in children and leaded petrol sales in Australia 1979 to 1999 (Australia's submission)*

61. Lead remains an environmental health problem. A growing number of countries (mainly developing countries and countries with economies in transition) or various researchers studying environmental issues within these countries are recognizing and reporting the problem of environmental lead exposure in some population groups**.** For example, several recent studies (such as Clark C.S. *et al.*,

2006; Clark C.S., *et al*.., 2005; Adebamowo E.O., *et al*., 2006a, and Adebamowo E.O., *et al*., 2006b; and Mathee *et al*., 2007) indicate that some lead-based paints are still being used in some countries in Asia and Africa and that some children are being exposed to elevated levels of lead. In many parts of the world, for many decades, there was very little public awareness of and policies relating to the potential for lead contamination and its public health effects.

62. As a result of its health effects and impact on development, lead may cause significant economic losses for society.

CHAPTER 4 - Impacts on the environment

63. In the environment, lead tends to be mainly particle-bound and has relatively low mobility and bioavailability, though highly soluble ionic forms also exist, particularly in the marine environment. Lead bioaccumulates in most organisms, but biomagnification from one trophic level in the food web to the next is not a characteristic feature of this metal.

64. The environmental effects of lead are well documented. Secondary poisoning has also been extensively documented, especially for predators feeding on contaminated animals. There are many reports on the levels of lead in wild mammals, but few reports of toxic effects of the metal in wild or in non-laboratory species. In all species of experimental animals studied, however, 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.

65. Environmental exposure to lead is greatest near smelters or other point sources, or from lead shot and sinkers used for outdoor shooting and fishing. General atmospheric deposition from distant sources is also an input to local environments (see Chapter 5 on release sources and Chapter 7 on long-range transport). In a significant percentage of European soils, the lead concentrations estimated for areas away from point sources exceed the threshold concentration for adverse effects in soil, and therefore the terrestrial ecosystems are considered to be at risk. In the aquatic environment lead concentrations are normally below known effect levels.

66. The most prominent adverse impact of lead in the environment is the widespread contamination and poisoning of waterfowl that ingest shot or sinkers, as well as the contamination of their predators (secondary poisoning). The poisoning of migrating waterfowl has a transboundary aspect which is the background for addressing the use of lead shot in wetlands in the Agreement on the Conservation of African-Eurasian Migratory Waterbirds. Parties to the Agreement shall endeavour to phase out the use of lead shot for hunting in wetlands.

CHAPTER 5 - Sources and releases to the environment

67. The important releases of lead to the biosphere might be grouped into the following categories:

- Natural sources - releases due to mobilisation of naturally-occurring lead in the Earth's crust and mantle, such as volcanic activity and weathering of rocks;
- Current anthropogenic (associated with human activity) releases from the mobilisation of lead impurities in raw materials such as fossil fuels – particularly ores, coal and other extracted, treated and recycled minerals;
- Current anthropogenic releases resulting from lead used intentionally in products and processes, due to releases by manufacturing, use, disposal, recycling, reclamation or incineration of products;

68. In addition to these categories may be considered remobilisation of lead deposited in soils, sediments, landfills and waste/tailings piles from historic anthropogenic releases as well as translocation of lead naturally occurring in the biosphere.

Sources of lead emissions to the atmosphere

69. The major natural sources for mobilisations of lead from the Earth's lithosphere to the biosphere are volcanoes and weathering of rocks. In addition, insignificant amounts of lead enter the biosphere by meteoritic dust. The atmospheric emission from volcanoes in 1983 is estimated at 540-6,000 tonnes, and in a more recent study from 2001 at 1,000-10,000 tonnes. The weathering of rocks releases lead to soils and aquatic systems. This process plays a significant role in the global lead cycle, but estimates of the total amount released by weathering of rocks have not been available.

70. Within the biosphere, lead is translocated by different processes. The major natural sources of emissions to air are volcanoes, airborne soil particles, sea spray, biogenic material and forest fires.

71. Very different estimates on total releases of lead to the atmosphere by natural processes have been reported. A frequently-cited study from 1989 estimates the total emission in 1983 at 970-23,000 tonnes/year, whereas a new study estimates the total emissions from natural sources at 220,000 - 4,900,000 tonnes/year. The large disparity is mainly due to different estimates on the amount of lead moved around with soil particles. Compared to this, the most recent study of total anthropogenic atmospheric emission estimated the total emissions in the mid-1990s at 120,000 tonnes, of which 89,000 tonnes originated from the use of petrol additives.

72. The significance of anthropogenic versus natural emission for long-range transport of lead has been indicated by ice core studies from Greenland and Antarctica (see Figure 2).

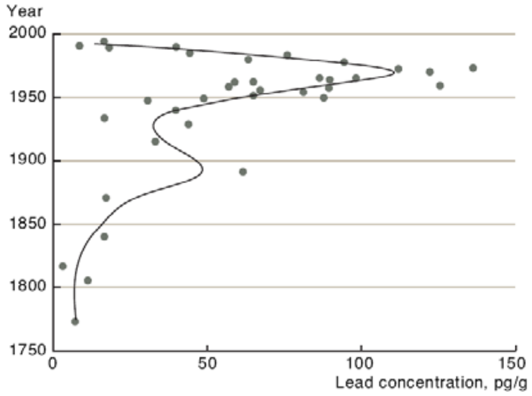


Figure 2

Lead concentration in a Greenland ice core (Boutron, 1995 as cited by AMAP, 2005). Original figure presented courtesy of AMAP, Norway

73. The data show that the lead levels in the ice cores increased significantly following the industrial revolution in the 19th century, and that the extensive use of leaded gasoline from 1950 to 1990 is reflected in the ice cores as a distinct peak followed by a substantial decrease after about 1990 as shown in Figure 2.

74. A recent study of ice and snow from the Canadian Arctic concludes that while the elimination of leaded gasoline additives in Europe, North America and Japan, and a number of other countries has helped to reduce lead emissions during the past two to three decades, aerosols in the Arctic today are still contaminated by anthropogenic lead. The average ratio of lead to scandium in the snow was far greater than that of soil-derived dust particles which indicates that about 95 to 99 percent of recent lead is anthropogenic

75. From 1983 to the mid-1990s, the quantified global anthropogenic emission of lead decreased from about 330,000 tonnes to 120,000 tonnes. In 1983, the main source was by far leaded fuel additives, and by the mid-1990s fuel additives still accounted for 74 percent of global lead emission to the atmosphere. Besides fuel additives, non-ferrous production and coal combustion were the major sources. No recent comprehensive studies of global emissions have been identified. However, the use of leaded petrol has decreased substantially since mid-1990s therefore anthropogenic emissions are expected be lower today than they were in mid-1990s.

76. The total emission and distribution by sources vary considerably among countries; the latter is illustrated in Figure 3 by data for Europe (2000) and Australia (2003). The large difference in the contribution from gasoline additives would not be seen today, as the use of leaded gasoline for vehicles is now phased out in both Europe and Australia (as well as in most other countries). Australia is the world's second largest producer of lead and zinc, and metal-ore mining and non-ferrous production account for more that 90 percent of the anthropogenic atmospheric releases in that country. In Europe, releases are more evenly distributed among the sectors with iron and steel production comprising the major industrial source category.

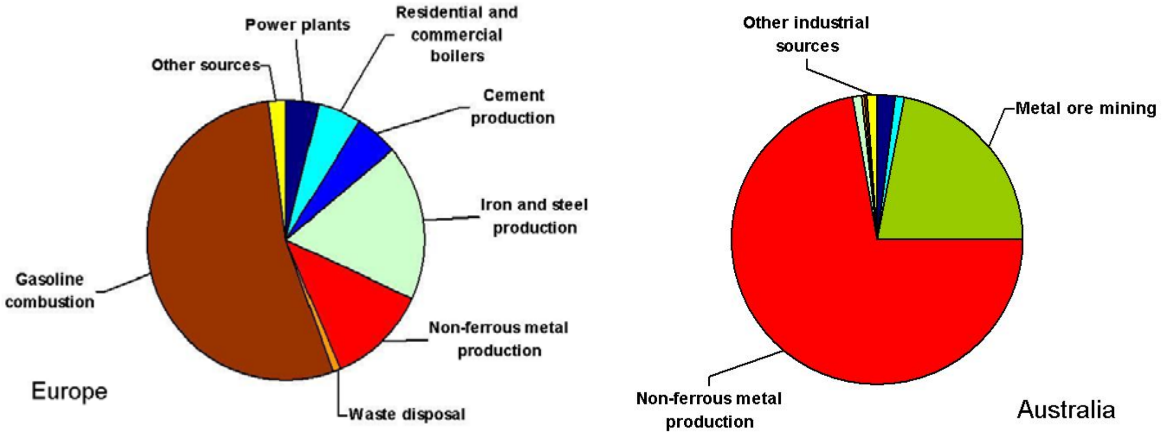


Figure 3 Distribution of atmospheric lead emissions in Europe 2000, based on expert estimates from Norwegian Institute for Air Research, NILU (ESPREME, 2006) and point source emissions in Australia 2003/4 (Australia's submission, 2005).

77. As of June 2006, only two countries worldwide used leaded gasoline solely, while 26 countries used both leaded and unleaded gasoline. Since Sub-Saharan Africa completely eliminated the import and production of leaded gasoline in January 2006, the majority of countries still using leaded gasoline are in the Asia-Pacific region. The global consumption of lead for manufacturing of gasoline additives decreased from 31,500 tonnes in 1998 to 14,400 tonnes in 2003. In 1970, when the use of leaded gasoline was peaking, about 310,000 tonnes lead was used for gasoline additives in OECD countries.

78. The trend in emissions in the industrialised countries is illustrated in Figure 4, showing the decrease in total atmospheric emission of lead in Europe from 1990 to 2003. During that period the lead emission in Europe decreased by about 92 percent. Similar decreases have occurred in North America during this time frame. The significant reduction of lead emissions was mainly due to restrictions and bans of the usage of leaded gasoline for vehicles, but also implementation of improved air emission controls. As an example, in eight European countries the reported emission from ferrous and non-ferrous production was on average reduced by about 50 percent during the period from 1990 to 2003, whiles emission from waste incineration and public electricity and heat production on average were reduced by 98 percent and 81 percent, respectively.

79. Data on lead emission and the trend in the emission in developing countries have not been available for this review.

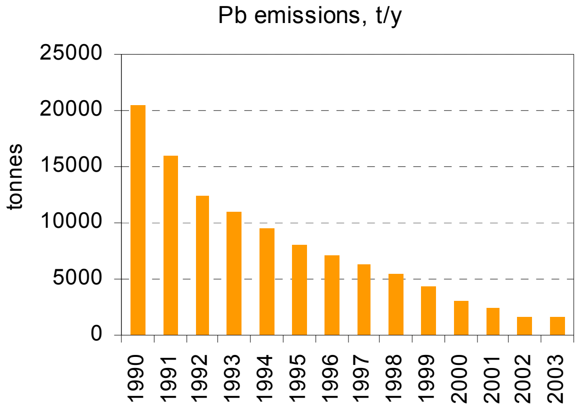


Figure 4

Trends in atmospheric emission of lead in Europe (24 countries within the EMEP area) 1990-2003(UNECE, 2006)

Anthropogenic sources of lead releases to land

80. Human activities significantly influence the global cycle of lead. In 2004, an estimated 3.15 million tonnes of lead were extracted from the Earth's crust by humans and brought into circulation in society. Besides this, a significant amount of lead ended up in metal extraction residues or was mobilised as impurities during the extraction of other minerals like coal and lime. In 1983, a total of 0.4-1.0 million tonnes of such mobilised lead was disposed of with waste from mining, base metal production and from the use of coal.

81. The only comprehensive assessment of global anthropogenic lead releases to soil and waste deposits dates back to 1983. It was estimated that in total about 600,000-1,660,000 tonnes of lead were directed to waste deposits or released to soil at that time. To this it is added an atmospheric deposition to land of about 200,000 to 260,000 tonnes of lead. The three major categories were: waste/loss of commercial products (mainly ammunition lost by hunting), mine tailings and smelter slag and waste. Apart from atmospheric deposition, which has decreased due to the reduced use of lead as a fuel additive, these releases to land may still be at about the same magnitude, but the data should be interpreted with care.

82. The major source of direct lead releases to soil is the use of ammunition. The total global consumption of lead for ammunition was about 120,000 tonnes in 2003. Ammunition is partly used for hunting and lost to the environment, and partly used in shooting ranges, where the lead is either accumulated at the range or collected for recycling. Studies indicate that in the long term lead lost with ammunition may increase the lead content of soils in some countries. Moreover, lost lead shot may poison waterfowl and other birds ingesting the shot.

83. Other products lost to the terrestrial environment in various countries, are paints with lead pigments, lead balancing weights for vehicles, lead sheathing of cables left in the ground and lead batteries (loss by breakage and recycling).

84. Large amounts of lead are directed to landfills and waste dumps with discarded products and residues from mining and base metal production.

85. Studies from Denmark and the Netherlands indicate that about 10 percent of the total flow of lead with products is ending up in landfills. As lead compounds (which in most countries are hardly recycled) account for about 10 percent of the total global lead consumption, it is highly probable that at least 10 percent of the consumption is accumulated in landfills. With a global consumption of about 7 million tonnes, the amount of lead ending up in landfills with discarded products could be 500,000-1,000,000 tonnes. The concern in some countries in this regard is the potential fate of the disposed lead over the long term.

86. If not managed in an environmentally sound fashion, the large amounts of lead ending up in tailings and other residues from mining and base metal production represent a substantial threat to local water resources and soil.

Sources of lead releases to aquatic environments

87. Direct releases to aquatic environments are considered relatively small compared to releases to the atmosphere and land. Total releases to water in 1983, excluding atmospheric deposition, were estimated at 10,000-67,000 tonnes. In addition, atmospheric deposition to aquatic environments was estimated at 87,000-113,000 tonnes; a figure that most likely is considerably lower today.

88. Weathering of rocks releases natural lead to soils and aquatic systems, which plays a significant role in the global cycle. This release is enhanced by acidic emissions. The open burning in some developing countries of waste products containing lead could be an important source of local and regional lead releases to land and aquatic systems.

89. Major industrial sources are mining and non-ferrous metal production. It is uncommon to include loss of lead in fishing sinkers and scuba diving weights in inventories of lead releases, but this release may be of significance. A study estimates the total loss of lead with fishing equipment for angling and commercial fishing in the EU at 2,000-8,000 tonnes. Of particular concern in some countries is the loss of small sinkers in inland waters, which (like the situation regarding lead shot) may be ingested by birds or dissolved in waters through corrosion.

CHAPTER 6 - Production, use and trade patterns

90. Lead is mined in more than 40 countries, the major producers being China and Australia, which represent 30 percent and 22 percent of global mining production, respectively. Lead-rich minerals most often occur together with other metals, and about two-thirds of worldwide lead output is obtained from mixed lead-zinc ores (Figure 5).

91. The total global mine production of lead has decreased slightly during the last thirty years, from 3,600,000 tonnes in 1975 to 3,100,000 tonnes in 2004. During the same period, global refined lead production and metal consumption have increased from about 4,700,000 tonnes to about 7,100,000 tonnes.

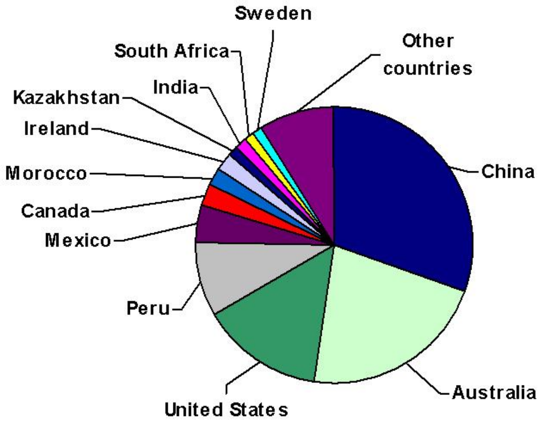


Figure 5 Global mine production by country (based on USGS, 2006)

92. The reason for the difference between mine production and lead consumption is that recycled lead increasingly accounts for a larger part of the supply. Recycled lead accounted for 45 percent of global lead supply in 2003. Most of the recycled lead comes from used lead batteries, with the remainder coming from other sources such as lead pipes, sheets, cable sheathing and wastes from fabricating/processing operations.

93. The different steps from mining to manufacturing of final products often take place in different countries and there is extensive trade in ores, concentrates, unrefined and refined metallic lead and final products between countries and continents. Main importers of raw materials (ore, concentrate and unrefined lead) are Europe and Asia; main exporters are Australia and South America.

94. Lead is used for a large number of applications. The review lists more than 50 application areas; some of the areas consist of a number of different specific sub-applications. The useful properties

of lead include: a low melting point, ease of casting, high density, low strength, ease of fabrication, acid resistance, corrosion resistance, electrochemical reaction with sulphuric acid, and the ability to attenuate sound waves, ionising radiation and mechanical vibration.

End-uses of lead

95. The major end-use of lead is lead batteries, accounting for 78 percent of reported global consumption in 2003. Other major application areas are lead compounds other than those used in batteries (8 percent of the total), lead sheets (5 percent), ammunition (2 percent), alloys (2 percent) and cable sheathing (1.2 percent). The most significant change in the overall use pattern during the period 1970 to 2003 is that batteries account for an increasing part of the total, whereas cable sheathing and petrol additives have decreased due to substitution.

96. Some differences among countries concerning "first uses" are apparent: consumption patterns to some extent reflect the countries' industry structures as regards the manufacturing of lead-containing products. Two examples are shown in Figure 6. In the Republic of Korea, with an extensive car industry, batteries accounted for 87 percent of total consumption, whereas in the United Kingdom, rolled/extruded lead accounted for 46 percent of lead consumption. The latter may also indicate regional differences in end-use patterns, as lead is extensively used in the building industry in the United Kingdom and other northern European countries (for lead roofing and roof flashing).

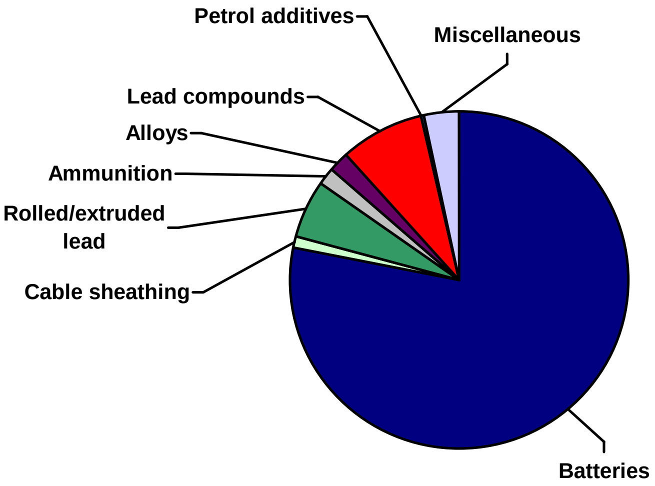
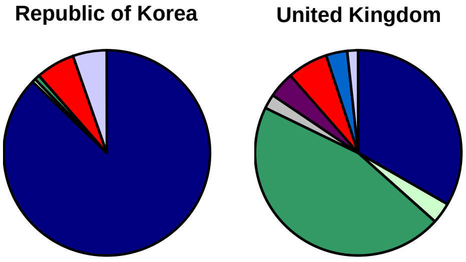


Figure 6

Intentional lead consumption by end-uses in 2003 as reported by member countries of the International Lead and Zinc Study group (ILZSG) representing about 86 percent of the total global consumption of lead. (ILZSG, 2006)



Two country examples of distribution of lead for "first uses" i.e. use of lead for manufacturing processes, by application area. (ILZSG, 2005)

Lead compounds

97. During the period from 1970 to 2003, lead compounds, apart from petrol additives and lead compounds in batteries, have accounted for about 10 percent of total lead consumption. Glass for cathode ray tubes and plastic additives represented the single largest uses of lead compounds in 2001 (Figure 7). Some major changes within this category, however, have taken place. A breakdown of consumption in "Western World" countries is shown in the following figure. Formerly, lead pigment for paints and ceramics took up a greater share, but the consumption of pigments for these applications has decreased over the last decades, partly due to regulation in some countries.

98. The reported use of lead for petrol additives was 14,400 tonnes in 2003, corresponding to about 5 percent of the consumption of lead in petrol in 1970. Consumption of leaded petrol for vehicles is

steadily decreasing, but leaded petrol is still used in most (if not all) countries for some types of propeller-driven aircraft.

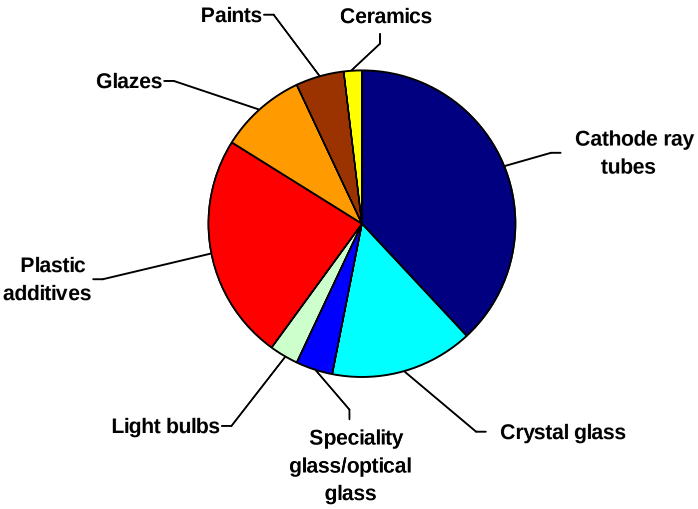


Figure 7

Consumption of lead compounds by end uses in 2001 as reported by "Western World" member countries of the International Lead and Zinc Study group (ILZSG, 2005).

Blue colours indicate the use of lead in glass.

Lead compounds in batteries and petrol additives are not included.

CHAPTER 7 - Long-range transport in the environment

99. Environmental transport pathways explored in this review include atmospheric transport, ocean transport, river transport and transport in large, transboundary lakes. These are considered the most important pathways for environmental transport of lead beyond the local scale.

100. Long-range transport in the environment here refers to transport in air or water of substances (e.g. lead) whose physical origin is situated in one country and which are transported and deposited to another country at such a distance that it may not generally be possible to distinguish the contribution of individual emission sources. Regional transport here refers to such transport within a geographical region such as for example Africa or North America, whereas intercontinental transport refer to such transport from one continent to another, for example between Asia and North America.

Atmospheric transport of lead

101. Atmospheric transport is currently considered the most important mechanism of long-range lead dispersion in the environment. Once emitted to the atmosphere, lead may be transported locally, regionally, or intercontinentally depending on various factors, including particle size, the height of the emissions outlet and meteorology. Because it has a relatively short residence time in the atmosphere (days or weeks), this metal is mainly transported over local, national or regional distances. Under certain conditions, lead can be transported by airflows over hundreds or even thousands of kilometres, and can contribute to the exposures to lead for humans and ecosystems at locations far away from the emission source.

102. Various human activities result in elevated lead concentrations in the environment. Measurements of lead concentration in ice cores, fresh water sediments and peat bogs demonstrate a significant increase in airborne lead depositions compared to the pre-industrial period (e.g. Candelone and Hong, 1995; Farmer *et al.*, 1997; Coggins *et al.*, 2006). Lead mass concentrations measured in atmospheric aerosol were much higher (up to 1000 times) than the concentration in soil-derived dust. This kind of enrichment has been observed even in such remote locations as Greenland, the Bolivian Andes, New Zealand and Antarctica.

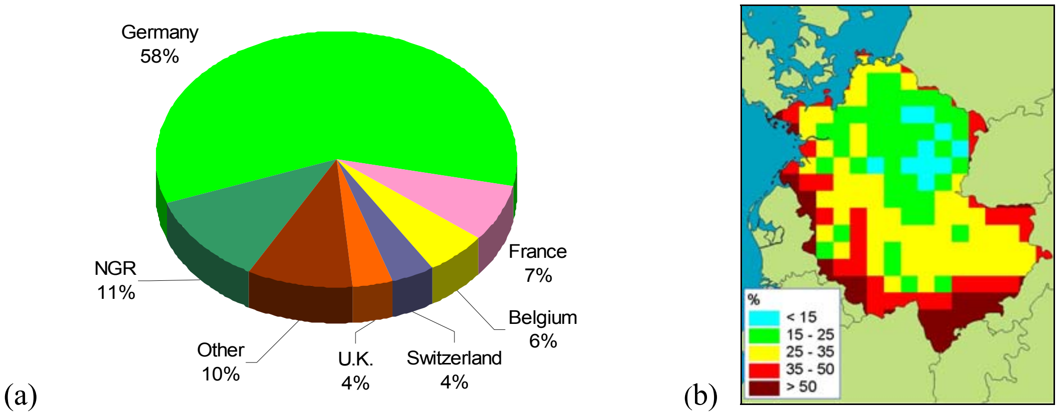


Figure 8 *Main contributors to deposition of lead in Germany (a) (NGR - natural, global sources and re-emission); Spatial distribution of contribution of external anthropogenic sources to lead depositions in Germany (b) (calculated with the MSCE-HM model, Ilyin et al., 2005).*

Regional scale atmospheric transboundary transport

103. Lead is primarily transported atmospherically over regional distances; that is, within the region or continent where the lead was originally emitted. Figure 8 (a and b), for example, illustrates the contributions of transboundary lead in Germany. Generally speaking, about 30 percent of total lead depositions in Germany are the result of atmospheric transport from anthropogenic sources in other nearby countries (such as France and Belgium), and 10 percent from natural sources and re-emission. About 58 percent of deposition is due to anthropogenic sources within Germany. In regions close to national borders, contributions from external sources can exceed 50 percent, whereas in the central part of Germany it can be less than 15 percent.

Intercontinental atmospheric transport

104. The evidence for intercontinental atmospheric transport of lead is limited. Due to the relatively short residence time of lead in the atmosphere (days or weeks) the airborne dispersion of this lead has a pronounced local or regional character. However, data from ice core measurements in Greenland and the Antarctic indicate that lead can be transported over distances of up to thousands of kilometres. According to modelling results, the annual contribution of external emission sources to the total lead deposition in Europe does not exceed 5 percent, and in North America it is even lower (Figure 9 a,b). However, based on the model calculations, episodically, the contribution of intercontinental transport can be significantly higher at certain locations on these continents. Based on the model calculations, daily contributions from lead transported from one continent to the other are calculated to exceed 35 percent of total deposition during these episodes on some days of the year.

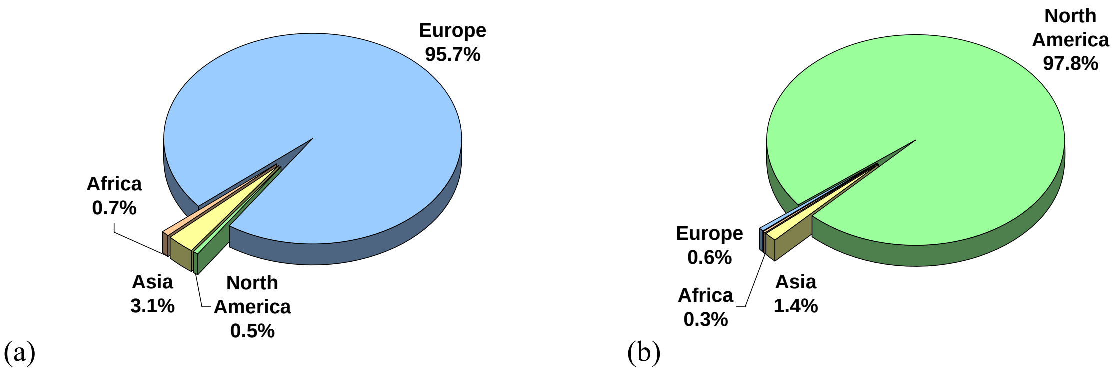


Figure 9 Relative contribution of different continents of the Northern Hemisphere to annual lead deposition in Europe (a) and North America (b)(calculated with MSCE-HM-Hem model).

105. Since lead is transported in the atmosphere in composition aerosol particles, evidence of its intercontinental transport can also be obtained from measurements of stable isotope signatures of the airborne dust in combination with air-mass back trajectories (trace back or air movements). These measurements indicate the origin of dust particles transported by air masses, and thereby provide evidence that aerosols carrying lead are transported intercontinentally, as well as from industrialised regions to remote regions with few local emission sources such as the Arctic.

Main principles of lead atmospheric transport

106. The main factors affecting behaviour, fate and deposition of lead emitted to the atmosphere during its long-range atmospheric transport include:

- Characteristics of emission sources (higher outlets and higher emission temperatures lead to higher emission plumes and longer transport ranges);
- Physical and chemical forms of lead in the atmosphere:
    - Lead is emitted to the atmosphere as a component of aerosol particles; large particles are deposited within short ranges, small particles may be transported over hundreds or thousands of kilometres;
    - Wet deposition of lead-containing particles also depends on particle hydrophoby (water repellence), meteorology, and other factors;
    - Dry deposition is most effective for large particles due to gravitational settling. Ultrafine particles are, however, also easily deposited on ground surfaces due to their high mobility;
- Atmospheric stability: stable atmospheric conditions keep pollution near the ground, resulting in short transport ranges and low dispersion; unstable conditions lead to the pollution plume rising to altitudes with stronger winds, which in turn transport pollution over longer distances;
- Wind speed: high wind speeds increase the potential for long-range transport;
- Precipitation intensity: wet deposition is enhanced by high precipitation rates (rain, snow);
- Earth’s surface characteristics: the highest dry depositions take place over rough terrain, such as areas of significant vegetation (forest, shrubs, etc.) and urban areas; the lowest dry depositions occur over smooth terrain (desert, snow cover) and water bodies.

Atmospheric transport models

107. Atmospheric transport models can add to the description and prediction of heavy metal pollution as provided by actual measurements of lead concentrations in ambient air and precipitation. Notably, transport models can help explain the origins and pathways of transboundary atmospheric lead pollution. A number of models for atmospheric transport of heavy metals cover Europe and North America. Two of the identified transport models cover lead transport in the Northern Hemisphere. No models covering other regions of the world have been identified.

108. Atmospheric transport models are normally compared with measured data. Some of the identified transport models have also been evaluated in inter-comparison studies where the modelling results obtained by each transport model are compared to other models and available measured values. The ability of different models to predict actual situations is summarised in these studies. Based on such evaluations, it appears that the accuracy and availability of emission estimate inputs are of key importance to the models' ability to predict transport outputs. Most assessed models exhibit a good prediction of actually measured values, when emission input data are based on (or supplemented with) independent expert estimates. When reported emission estimates are used alone as input to the models, the models tend to show lower results than actually measured in the field. The uncertainty of reported emission

estimates, and lack of inclusion of natural emissions and re-emission of former lead depositions in the model inputs, are possible causes for the under-predictions

Monitoring of air concentrations and atmospheric deposition

109. Most identified monitoring data for atmospheric lead concentrations and deposition is from Europe and the U.S.A.; results from Japan, Antarctica and New Zealand are, however, also described.

Aquatic transport of lead

110. Extensive data regarding lead concentrations in the water column exist for specific locations in the world's oceans, and for different years over the last two to three decades. Through the literature search performed for this review, however, no examples were identified of modelling or other attempts to quantify the general horizontal transport of lead - or any other heavy metals - with ocean currents. Only two non-modelling examples were found that quantified the exchange of heavy metals (lead and cadmium) by ocean currents between one specific ocean - the Arctic Ocean - and neighbouring oceans. These examples suggest that ocean transport may be an important pathway.

111. In addition, the nature of ocean currents indicates their potential for the transport of pollutants on a global scale. Global, deep-sea ocean currents are (with varying strength) connected to one big, dynamic system, the so-called thermohaline circulation or "global conveyer belt", which transports enormous water masses through the Atlantic Ocean, the Southern Ocean around Antarctica, and the Pacific Ocean. The existence of ocean transport modelling of other pollutants (such as persistent organic pollutants, or POPs) demonstrates that ocean modelling for heavy metals may be relevant.

112. Lead entering the ocean by atmospheric transport, by direct discharges or via river transport will normally be in the particulate state, and will be bound to other particulate material and sink to ocean sediments. General oceanic residence time (in the water column) of scavenge-type metals like lead is characterised as short - in the range of 100-1000 years - which is about equivalent to the overall mixing time of deep-sea ocean waters (around 600 years). One reference indicates the specific residence time of lead in surface water as <5 years, yet still long enough to permit transfer of contaminant lead from for example the North Atlantic into the Arctic.

113. The concentrations of metals such as lead normally decrease with distance from the sources, and concentrations generally tend to decrease along the flow path of deep water due to continual particle scavenging.

114. Rivers are important transport media for heavy metals on a national and regional scale. The significance of rivers as transport pathway for lead can be illustrated by data for the Greater North Sea. The total annual riverine and direct input of waterborne lead the in the UK, Sweden, Norway, the Netherlands, Germany, France, Denmark and Belgium in 1996 totalled about 798 tonnes of these the riverine inputs accounted for 740 tonnes or more than 90 percent (both estimates based on the lower estimates for riverine inputs). The waterborne inputs to the marine environment in these countries were in 1996 larger than the airborne inputs.

115. Transport of heavy metals released to the environment may be taken up in migrating fauna, however, this issue have not been covered by this review.

CHAPTER 8 - Prevention and control technologies and practices

116. This chapter summarizes information about prevention and control technologies and practices, and their associated costs and effectiveness, which might reduce and/or eliminate releases of lead, including the use of suitable substitutes, where applicable.

117. Releases due to natural mobilisation of lead and remobilisation of anthropogenic lead previously deposited in soils, sediments and water bodies are not well understood and are largely beyond human control. These are therefore not addressed here.

118. Reducing or eliminating anthropogenic lead releases may require:

- Investments in controlling releases from processes or substituting the use of lead-contaminated raw materials and feedstock, the main source of lead releases from unintentional uses;
- Reducing or eliminating the use of lead in products, enhancing recycling, or using other effective disposal methods to reduce releases for lead-containing products, the main source of releases caused by the "intentional" use of lead.

119. The methods for controlling lead releases from these sources fall generally under the following four groups:

- Reducing consumption of raw materials and products that include lead as an impurity;
- Substitution (or elimination) of products, processes and practices containing or using lead with lead-free alternatives;
- Controlling lead releases through low-emission process technologies and cleaning of off-gases and wastewater;
- Management of lead-containing waste.

Reducing consumption of raw materials and products that include lead as an impurity

120. Reducing the consumption of raw materials and products that include lead as an impurity is a preventive measure for reducing lead releases. This group of measures might potentially include the choice of an alternative raw material, such as using natural gas for power generation instead of coal, but the reduction of lead emissions would most probably not be the main driver for such a shift. No measures specifically addressing substitution of lead-containing raw materials have been identified.

Substitution of products and processes containing or using lead

121. Substitution of products and processes containing lead with lead-free products and processes are preventive measures which may influence the entire flow of lead through the economy and environment. It may substantially reduce lead in households, releases to the environment, the waste stream, incinerator emissions and landfills.

122. In this review, possible lead-free alternatives for a large number of different applications of lead are listed. The drivers for substitution of lead have typically been legal regulation, voluntary agreements with industry and trade, and for a few applications, development of technically or economically better alternatives.

123. Applications for which alternatives have been introduced in some countries include (with examples of alternatives in parentheses):

- Cable sheathing (alternative: polyethylene/cross linked polyethylene plastic);
- Flashing (zinc, aluminium combined with rubber/polymer, rigid metal profiles);
- Lead shot (steel, soft iron, wolfram, bismuth and tin);
- Solders (tin alloyed with, e.g., silver, copper, bismuth or indium);
- Fishing sinkers (e.g., iron, tin or zinc);
- Tubes and joints (iron, copper and plastic);
- Yacht keels/ballast (steel);
- Balancing weights for vehicles (steel, copper);
- Pigments (organic or inorganic pigments, e.g. tin-zinc-titanate or bismuth-vanadate);
- PVC stabilizers (calcium/zinc or organotin stabilizers);
- Rust-inhibitive primer (zinc phosphate or zinc oxide combined with iron oxide);
- Siccatives (drying agents) in paint (siccatives based on, e.g., zirconium, cobalt and barium);
- Gasoline additives (Refinery operating changes, high-octane gasoline components and/or additives, including oxygenates and others);

- Brake linings (graphite and other alternatives);
- Glazing and enamels (alkali boro-silicate glazing, zinc/strontium and bismuth glazing);
- Crystal glass (for semi-crystal glass: use of barium, potassium and zinc).

Controlling lead releases through low-emission process technologies and cleaning of off-gases and wastewater

124. Controlling lead emissions through end-of-pipe techniques, such as exhaust gas filtering, may be especially appropriate to raw materials with trace lead content, including fossil-fuelled power plants, cement production, the extraction and processing of primary raw materials such as iron and steel, ferromanganese, copper, zinc, and other non-ferrous metals and the processing of secondary raw materials such as iron and steel scrap. Many existing control technologies that reduce SO_2, NO_x and PM for coal-fired boilers, incinerators and other facilities also yield a high level of lead control due to particle retention. However, end-of-pipe control technologies, while mitigating the problem of atmospheric lead emission, still result in lead containing residues that are potential sources of future releases. Appropriate environmentally sound methods of disposal and/or reuse may be needed to prevent potential future releases of lead from these residues.

125. In non-ferrous metal operations, releases may be further reduced by the use of low-emission process technologies and fugitive emission control. According to European experience, fugitive emissions in many processes are very high, and they may greatly exceed those that are captured and abated. According to the EU BREF document, the hierarchy of gas collection techniques from all of the process stages is 1) process optimisation and minimisation of emissions; 2) sealed reactors and furnaces; 3) targeted flue gas collection; and as the last and least optimal option: 4) roofline collection of gaseous effluents, which is a very energy consuming option.

126. Applied dust emission control systems are generally the same across sectors. The reduction efficiencies of different abatement systems are presented in Table 1 with control measures for waste incinerators.

Table 1. Emission sources, possible control measures and reduction efficiencies for waste incinerators

Emission source	Control measure	Reduction efficiency for lead
Municipal, medical and hazardous waste incineration	High-efficiency scrubbers	> 98%
	Dry Electrostatic precipitator	80-90%
	Wet electrostatic precipitator	95-99%
	Fabric filters	95-99%

Lead waste management

127. Lead wastes, including those residues recovered by end-of-pipe technologies, constitute a special category of lead releases, with the potential for future releases to the environment. The current main principle for responsible lead waste management is separate collection and recycling of products and process waste containing lead, and stabilisation of residues from the various waste treatment procedures. Most countries accept disposal of lead-containing products in ordinary landfills except for a few product categories, e.g. lead batteries.

128. A number of options exist for the treatment and disposal of solid waste, depending on the waste types in question and the characteristics of the waste. The dominant waste management practices relevant to lead are recycling, incineration, biological treatment and dumping/landfilling. The overall input of heavy metals to waste streams in society is indicated in Figure 10 below. It should be noted that in practice, each step in the figure may consist of several minor steps, and that steps related to the treatment of wastewater, for instance, are not indicated in the figure.

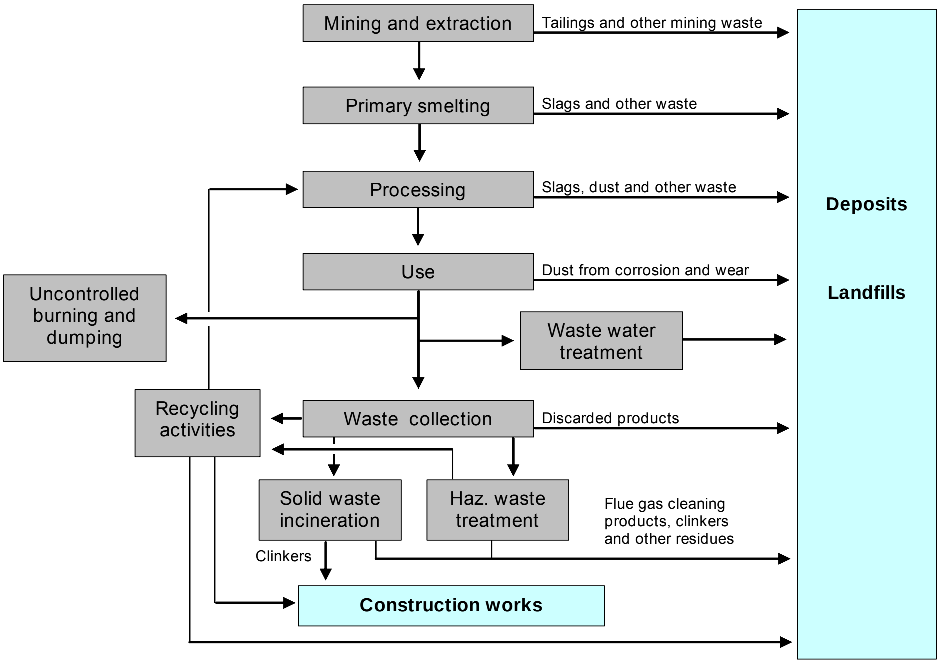


Figure 10 Schematic illustration of the overall flow of heavy metals to waste

129. Separate collection and recycling - Approximately 45 percent of present lead consumption worldwide is estimated to be recovered by recycling, with spent lead-acid batteries constituting the dominant input source. High collection rates close to 100 percent for lead batteries are reported in some countries. Other recycled products include lead pipes, sheets, cable sheathing and process wastes from manufacturing. By applying best available techniques for recycling, less than 0.1 percent of the lead is lost by the recycling activities. In many countries, however, breakage of the batteries and re-melting of the lead result in significant exposure of workers and local contamination of soil and surface water. The report provides examples from Honduras, Brazil and Costa Rica, among other countries.

130. **Landfilling** is a waste management option that can be used for all types of waste. In the global context, landfills range from unlicensed simple dumpsites without any leachate control to highly controlled landfills for hazardous waste. Compared to the total amount of heavy metals disposed of in landfills, the content of heavy metals in leachate is relatively low. In developed countries, leachate is typically collected and directed to wastewater treatment, from which sludge is generally redirected to landfills, at least for a period of time. One notable issue is that landfills can be a long-term source of releases of lead to the environment. Over time, landfills will be abandoned and may become highly contaminated areas of the environment or they may be exposed to construction works, erosion by flooding, or other disruption.

131. **Waste incineration** - Combustible waste will in many cases be directed to incineration in order to reduce the volume of waste and recover the energy contained in the waste. By use of best available techniques, the emission of lead to air from modern incineration plants is usually less than 1 percent of the lead in the waste. Lead is collected with clinker (bottom ash) as well as with air cleaning residues which must be managed carefully to avoid future releases. Application of clinkers for unpaved road construction and other construction work, may be a route of releases of lead to the surroundings.

132. **Uncontrolled burning and dumping** - Uncontrolled burning and dumping of waste is known to take place in many countries worldwide, although the amount of waste disposed of and the emissions caused are generally not quantified. Lead present in the waste e.g. in pigment and stabilisers in plastics or in batteries must be expected to some extent to be released to the atmosphere by uncontrolled burning of waste, primarily attached to particulate matter.

CHAPTER 9 - Initiatives for preventing or controlling releases and limiting exposures

National initiatives

133. A number of countries have implemented national initiatives and actions, including legislation, to manage and control releases, and limit use and exposures of lead within their territories.

134. The overall aims of existing initiatives on lead are to reduce or prevent the release of lead to the environment, and to avoid direct/indirect impacts on human health and the environment. Many common features can be found among countries from which information is available. The initiatives can generally be grouped as follows:

- Environmental quality standards, specifying maximum acceptable lead concentrations for different media such as drinking water, surface waters, air, soil, and for foodstuffs and feed;
- Environmental source actions and regulations that control lead releases into the environment, including limits on air and water point sources, promoting the use of best available technologies and waste treatment, and waste disposal restrictions;
- Product related actions and regulations for lead-containing products, such as petrol, ceramic glazing, ammunition, paints, vehicles, electrical and electronic equipment, etc.;
- Other standards, actions and programmes, such as regulations or guidance on exposures to lead in the workplace, requirements for information and reporting on uses and releases of lead in industry, and consumer safety measures.

135. Table 2 gives a general overview of types of implemented measures that are of importance to the management and control of lead, as related to its production and use life-cycle, including an indication of their status of implementation. As can be seen from the table, existing measures cover most phases in the life-cycle of lead products and processes from which lead is emitted.

Table 2 Overview of implemented measures of importance to lead, as related to its production and use life-cycle, and an indication of status of implementation, based on information submitted for this report.

TYPE AND AIM OF MEASURE		STATE OF IMPLEMENTATION
Production and use phases of life cycle and/or releases from sources that mobilize lead from raw materials		
POINT SOURCES	Apply emission-control technologies to limit emissions of particulate matter (dust) and adhered pollutants (including lead) from combustion of fossil fuels and processing of mineral materials	Implemented in many countries
	Prevent or limit the release of lead from industrial processes to the wastewater treatment system	Implemented in many countries
	Require use of best available techniques to reduce or prevent lead releases	Implemented in some countries, especially OECD countries
PRODUCTS	Prevent or limit products containing lead from being marketed nationally	General bans implemented in a few countries only. Bans or limits on specific products are more widespread, such as gasoline and paint.
	Limit the allowed contents of lead in commercial foodstuffs and feed.	Implemented in some countries, especially OECD countries. WHO guidelines used by some countries.

TYPE AND AIM OF MEASURE	STATE OF IMPLEMENTATION
Disposal phase of life-cycle	
Prevent lead in products and process waste from being released directly into the environment, by efficient waste collection	Implemented in many countries, especially OECD countries
Prevent lead in products - especially batteries - and process waste from being mixed with less hazardous waste in the general waste stream, by separate collection and treatment	Implemented in many countries
Prevent or limit lead releases to the environment from treatment of household waste, hazardous waste and medical waste by emission control technologies	Likely implemented to varying degree in all countries where organised waste treatment is taking place.
Set limit values for allowable lead content in sewage sludge and other organic waste products used for land application	Implemented in a number of countries
Set limit values for lead in solid incineration residues used for road-building, construction and other applications	Implemented in some OECD countries

International conventions and treaties

136. A number of international agreements have been established that enhance the management and control of releases of lead and other hazardous substances to the environment, and limit human and environmental exposure to lead. An overview of international initiatives specifically addressing lead identified in this project, and their main characteristics, is given in Table 3. The individual agreement's relevance to lead are summarised in the review and more information can be found in the indicated sections.

Table 3 Overview of international agreements containing provisions relating to lead

Section	International agreement or instrument	Geographic coverage	Relevance to lead	Types of measures addressing lead
9.2.1	LRTAP Convention and its 1998 Aarhus Protocol on Heavy Metals	Europe, Canada United States of America, and Commonwealth of Independent States	Addresses lead and lead compounds in releases, petrol, wastes, etc.	Goal definition, emissions reporting, and application of best available techniques and emissions limit values, binding commitments on release reductions.Under LRTAP parties shall encourage research and monitoring
9.2.2	OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic	Northeast 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
9.2.3	Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area	Baltic Sea (including entrance to 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
9.2.4	The Convention on Co-operation for the Protection and Sustainable Use of the River Danube	Danube river basin	Addresses lead and lead compounds in releases	Goal definition, binding commitments on release reductions, recommendations, monitoring, information
9.2.5	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal	Global	Any waste containing lead, excluding metal waste in massive form. Lead and its compounds are considered 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
9.2.6	Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade	Global	Addresses tetraethyllead and tetramethyllead	Binding commitments regarding import/export of those lead compounds covered, procedures for information exchange and export notification
9.2.7	Agreement on the Conservation of African-Eurasian Migratory Waterbirds	Europe, parts of Asia and Canada, the Middle East and Africa.	Addresses use of lead shot in wetlands	Parties shall endeavour to phase out the use of lead shot for hunting in wetlands

International organizations and programmes

137. A number of international organizations and programmes also have activities that address the adverse impacts of lead on health and the environment. An overview of such international organizations and programmes is given in Table 4. The individual organizations' activities of specific relevance to lead are summarised in the review and more information can be found in the indicated sections.

Table 4 Overview of international organizations and programmes with activities addressing adverse impacts of lead on health and the environment

Section	International organization or programme	Geographic coverage	Organization's or programme's relevance to lead	Types of activities addressing lead
9.3.1	International Agency for Research on Cancer (IARC)	Global	Addresses the evaluation of carcinogenic risk of chemicals, including lead, to humans	Evaluations of individual chemicals, information, guidelines
9.3.2	International Labour Organization (ILO)	Global	Addresses occupational health and safety issues linked to use of chemicals, including lead	Information, guidelines, capacity building
9.3.3	International Programme on Chemical Safety (IPCS)	Global	Addresses health and environmental aspects of heavy metals (including lead)	Information (risk evaluations, scientific data and precautionary information)
9.3.4	World Health Organisation (WHO)	Global	Addresses health and environmental aspects of heavy metals (including lead)	Information, guidelines, capacity building
9.3.4	Organization of Economic Cooperation and Development (OECD)	OECD member States	Addresses lead and lead compounds in releases, products, wastes, etc.	Information, recommendations
9.3.6	UNEP Global Programme of Action for the Protection of the Marine Environment from land-based Activities	Global	Addresses heavy metals, including lead	Goal definition, guidelines
9.3.7	UNEP Partnership for Clean Fuels and Vehicles	Global	Addresses lead in petrol	Information, assistance, recommendations, capacity building
9.3.8	United Nations Industrial Development Organization (UNIDO)	Global	Addresses environmentally sustainable industrial activities	Information, guidelines, capacity building
9.3.9	World Bank (WB)	Global	Addresses environmentally sustainable industrial activities and leaded petrol	Information, capacity building, assistance

Sub-regional and regional initiatives

138. Finally, a number of governments have found it beneficial to cooperate across national borders in order to address the adverse impacts of lead and other hazardous substances on health and the environment in a specific sub-region or region. An overview of such sub-regional and regional initiatives identified in this project that have activities relevant to lead are given in Table 5. The individual initiative's specific relevance to lead are summarised in the review and more information can be found in the indicated sections. A number of initiatives that indirectly have relevance to lead may exist besides those listed in the table.

Table 5 Overview of sub-regional and regional initiatives addressing the adverse impacts of lead on health and the environment

Section	Sub-regional or regional initiative	Geographic coverage	Initiative's relevance to lead	Types of measures addressing lead set out in the initiative
9.4.1	Arctic Council	Arctic region (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the U.S.A.)	Addresses heavy metals, including lead	Information, monitoring
9.4.2	Great Lakes Binational Toxics Strategy	Canada and the U.S.A.	Addresses use of alkyl-lead	Goal definition, information
9.4.3	Clean Air Initiative	Each of four regions: Asia, Latin America, Sub-Saharan Africa, Eastern Europe and Central Asia	Addresses phase-out of leaded gasoline	Goal definition, information, capacity building
9.4.4	Commission for Environmental Cooperation of North America	North America (Canada, Mexico and the U.S.A.)	In the final stage of the process of development of Action Plan for lead	Goal definition, information
9.4.5	North Sea Conferences	North Sea (Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, Switzerland, United Kingdom and EC)	Addresses heavy metals, including lead	Goal definition, information
9.4.6	South Asia Co-operative Environment Programme	South Asia (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka)	Addresses transboundary air pollution	Goal definition, information, capacity building
9.4.7	International commissions for the protection of rivers	Different river basins e.g. the Elbe river and the Oder river basins	Addresses transboundary water pollution	Goal definition, information

CHAPTER 10 – Data and information gaps

National research and information gaps

139. A number of countries have in their submissions expressed the need for creating or improving their national data base on various aspects of lead management in society and in the environment. Also, capacity building and awareness raising activities are needed, for which technical and financial assistance is a necessity. Some examples of national research, training and information and are summarised below:

- Development of exposure assessments, substance flow assessments (import, export, consumption etc.), and release inventories;
- Technical and financial assistance for - and implementation of - strategies development and legislation, capacity building activities, awareness raising workshops, performing pilot project for data collection, training workers about health risks and safer work procedures, training authorities in risk assessment, etc;
- Methodologies and guidelines for capacity building, release reduction and prevention, abatement strategies, hazardous residues management plans, evaluation of interventions made, etc.

Data gaps of a general, global character

140. The following general needs and data gaps have been pointed out as general data gaps in this report and in review comments (in summary only):

- The need for updated global release inventories for lead including data from developing countries;
- The release inventory database needs to be improved also in the developed regions: Emission factors, contributions of natural sources and re-suspension of historical depositions, improved data quality of release inventories;
- The need to develop atmospheric transport models for lead in the Southern hemisphere;
- The need to examine the role of long-range transport, the contribution of anthropogenic sources versus natural sources and the influence of local, regional and global sources;
- There is a need for more investigation of ocean transport as a means of long range environmental transport of lead;
- Guidelines for monitoring activities (air, soil, precipitation, human blood etc.) are needed;
- While the toxicity of lead is documented, the mechanism of lead toxicity is still not well understood and needs clarification;
- The need to develop and improve exposure assessments and use and release inventories, especially for developing countries;
- The general lack of data from developing countries where environmental and health problems related to production, trade, use and disposal of lead may be more common and have a different nature that in other regions;
- The need to monitor and assess lead levels in various media (such as soil and sediment) and data associated with impacts on humans, ecosystems and animals, including impacts from cumulative exposures to different forms of lead, as well as further emission data that help overcome the uncertainties in the results of the current models;

- The need to collect data regarding accidental spills from mine tailings on a global scale and the real extent of these events, especially in developing countries, where capacity building is needed;
- The need to improve the information on the level of contamination of drinking water by lead as a result of leaching from landfills, especially in developing countries;
- The need to collect data on concentration levels in large migrating marine mammals;
- The need to examine the global flow of lead in products.

1 Introduction

1.1 Background and mandate

141. The Governing Council (GC) of the United Nations Environment Programme (UNEP), in connection with its discussions relating to the need for global action to deal with the adverse impacts of mercury pollution, has discussed the possible need for global action with regard to other heavy metals, such as lead and cadmium, on several occasions.

142. The focus of discussions in 2001 and 2003 was to accelerate the process of eliminating the use of lead in gasoline, in which UNEP has played a key role. In 2003, the decision also urged commitment to phase out lead-based paint and lead in other sources of human exposure, to prevent exposure to lead, in particular children's exposure to lead, and to strengthen both the monitoring and surveillance and the treatment of lead poisoning.

143. In 2005, the UNEP Governing Council, in GC decision 23/9 III, requested UNEP to undertake the development of reviews of scientific information on lead and cadmium, focusing especially on long-range environmental transport, in order to inform future discussions of the Governing Council on the need for global action in relation to lead and cadmium.

144. The Governing Council requested that the review focus especially on long-range environmental transport however, summarized information on a number of other supporting issues is also provided in order to allow the Governments to consider the problems associated with this heavy metal in its full context[1].

145. By its decision 24/3 III of 9 February 2007 on lead and cadmium, the Governing Council of UNEP

> *"Acknowledges the data and information gaps identified in the United Nations Environment Programme Interim Scientific Reviews on Lead and Cadmium and that further action is needed to fill those data and information gaps, taking into account the specific situation of developing countries and countries with economies in transition;*
>
> *Encourages efforts by Governments and others to reduce risks to human health and the environment of lead and cadmium throughout the whole life cycle of those substances;*
>
> *Requests the Executive Director to provide available information on lead and cadmium to address the data and information gaps identified in the Interim Reviews and to compile an inventory of existing risk management measures".*

146. In 2009, the the UNEP Governing Council, in GC decision 25/5 II, requested UNEP to finalize the scientific review taking into account the latest available information in line with decisions 24/3 of 9 February 2007 and 23/9 of 25 February 2005 and to report to the Governing Council at its twenty-sixth

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[1] In this interim review, Chapters 7, 5, 4 and 3 were felt by the working group to respond directly to the Governing Council request. Chapter 6, relating to production, use and trade, and Chapter 2, related to chemistry were considered by the Working Group to be necessary information to provide a more comprehensive understanding of the issues and related factors. The Working Group considered that, while chapters 8, 9 and 10, and the appendices, fell outside the mandate of the Governing Council decision, they provided useful information and could be retained. They were not, however, reviewed by the Working Group

session with a view to informing discussions on the need for global action in relation to lead and cadmium.

1.2 Process for developing the review

147. UNEP has used a similar process to that followed in developing the 2002 UNEP Global Mercury Assessment report when undertaking this review of scientific information on lead.

148. This process initially involved, in May 2005, the establishment of a working group involving nomination of members by Governments, intergovernmental and non-governmental organisations as well as a call to these groups to submit information. Working Group members assisted, first through a comment round by mail, then through the First Meeting of the Lead and Cadmium Working Group, which took place 18-22 September 2006 in Geneva, Switzerland. 46 Governments, 7 intergovernmental organizations (IGOs) and 4 non-governmental organizations (NGOs) had submitted, by 17 September 2006, information for or comments to this review. Additional sources of information for the review included publications, articles and reports of relevance to lead identified through a literature search in scientific literature as well as information, publications and reports publicly available on websites of various Governments, intergovernmental and non-governmental organizations

149. Members of the Working Group assisted UNEP in the development of the scientific reviews, first through two comment rounds by correspondence and then through the First Meeting of the lead and cadmium Working Group.

150. The lead and cadmium activities web page was established at http://www.chem.unep.ch/Pb_and_Cd/Default.htm. All relevant documents, comments and input from Governments and intergovernmental and non-governmental organizations, together with the meeting documents and the draft reviews of scientific information developed by the secretariat, were made publicly available on the web page.

151. A first draft of the reviews of scientific information on lead and cadmium were circulated to Working Group members on 24 May 2006, attracting comments from 14 Governments, 4 intergovernmental and 3 non-governmental organizations. Following incorporation of these comments, the revised drafts of 18 August 2006 were also circulated for comment either in advance of or during the meeting of the Working Group.

152. A more detailed compilation of national initiatives, including legislation, in each individual country is contained in an appendix to this report, entitled “Overview of existing and future national actions, including legislation, relevant to lead”. The Appendix is published in a separate document. The information compiled therein has been extracted from the national submissions received from countries under this project.

153. References for the information used to develop this review, including reference to submissions that have been provided by the specific Government or organization are given as far as possible in the text.

154. Because of the large volume of reports, articles, abstracts, etc. relating to lead that were submitted/collected, it was not possible to review all the information in detail in the time available. Priority was given to country-specific information that might add to the global understanding of the use and regulation of lead, especially from non-OECD countries, and information that might add to the general knowledge of the various issues linked to lead, based on the recently published authoritative reviews on such issues.

155. As a follow up to UNEP GC decision 24/3 III adopted by the twenty-fourth session of the Governing Council/Global Ministerial Environment Forum on 9 February 2007, UNEP invited members of the working group to provide available information on lead to address the data and information gaps identified in the Interim Review by 31 December 2007.

156. Following the call for information, UNEP received responses from 22 Governments, 2 intergovernmental and 7 non-governmental organizations. The interim reviews were updated based on the submitted information and an interim review of scientific information on lead - Version of March 2008- was produced and circulated for comments by 13th June 2008. Submissions from this last round of comments were incorporated into the draft final version of the review of scientific information on lead, which was presented for the information of the Governing Council in its 25th session on February 2009.

157. All Governments and members of the Lead and Cadmium Working Group with new or additional information responding to the data and information gaps identified in the draft final reviews of scientific information on lead (and cadmium -versions of November 2008), were requested to submit that information to the Chemicals Branch of the Division of Technology, Industry and Economics. In total, 17 submissions were received from Governments, intergovernmental organizations and non governmental organizations. The draft final reviews of scientific information on lead (and cadmium), together with their relevant companion documents, were amended and circulated to the Working Group members. The present final reviews of scientific information on lead (and cadmium), and their companion documents (versions of December 2010), incorporating the Working Group's final comments are to be presented for the information of the Governing Council in its 26th session on February 2011.

158. A need to examine the global flow of lead and cadmium in products was identified as a data and information gap in the draft final reviews of scientific information on lead (and cadmium -version of November 2008-. In response to this, results of studies, prepared with support by the Nordic Council of Ministers and the assistance of Grupo GEA and the International POPs Elimination Network, on the possible effects on human health and the environment of the trade of products containing lead, cadmium and mercury in Latin America and the Caribbean and in Asia and the Pacific, respectively are also to be presented for the information of the Governing Council in its 26th session on February 2011.

159. All related information about the process for finalizing this review, including relevant submission can be found at http://www.chem.unep.ch/Pb_and_Cd/Default.htm [2].

1.3 Scope and coverage in this review

160. The review responds to Governing Council Decisions 23/9 III and 24/3 III. It compiles and provides an overview of evaluations, assessments and authoritative reviews already made and conclusions already drawn by the scientific community, national Governments, intergovernmental organizations, etc. relevant to lead, in order to inform future discussions of the Governing Council on the need for global action in relation to lead and cadmium.

161. It draws mainly on recently published authoritative reviews on the various topics relevant to lead, supplemented by national information. As a large part of the previously published reviews focus on OECD-countries, where much of the current research is ongoing/has been performed and some reduction measures implemented, an attempt has been made to identify and include relevant information from non-OECD countries.

1.4 Working Group considerations

162. During its meeting of 18 to 22 September 2006, the Working Group agreed that in view of the limited time available and the specific mandate of the Working Group, its discussions should focus primarily on the scientific aspects of the reviews and that priority should therefore be given to the consideration of the chapters of each review relating to: long-range transport in the environment (chapter 7); sources and releases to the environment (chapter 5); impacts on the environment (chapter 4); and human exposure and health effects (chapter 3), in that order. The Working Group did not discuss Chapter 8, on prevention and control technologies and practices, Chapter 9 on initiatives for preventing or controlling releases and limiting exposures, and the appendices, which provided an overview of existing

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[2] Additional web address: http://www.unep.org/hazardoussubstances/ Lead and Cadmium section

and future national actions relevant to lead and cadmium, as the information that they contained fell outside the mandate of the Governing Council decision. The Working Group agreed, however, that they provided useful information and could be retained.

163. Acknowledging the need to proceed with particular caution with regard to chapter 3 of each of the reviews, which dealt with human exposure and health effects, the Working Group agreed that all the information presented in that chapter should be reviewed by WHO and the chapter finalised after the meeting by WHO and UNEP.

164. In addition, it was agreed during the meeting that consideration would be given to the chapters of each review relating to chemistry (chapter 2) and production, use and trade patterns (chapter 6), as those chapters placed in context the environmental effects of lead and cadmium.

165. It was noted during the meeting that, while it might be difficult to finalize the reviews, given the limited time available, the Working Group should endeavour to provide as comprehensive a basis as possible for the UNEP report to the Governing Council, in particular with regard to key findings which are presented at the beginning of this review.

166. The October 2006 version of the review was considered as interim and, was subject to the outcomes of discussions at the Governing Council in 2007.

167. The final reviews of scientific information on lead (and cadmium), and their companion documents (versions of December 2010), incorporating the Working Group’s final comments are to be presented for the information of the Governing Council in its 26th session on February 2011.

2 Chemistry

2.1 General characteristics

168. Lead is a metallic element belonging to group IV A of the Periodic Table (atomic number: 82, and relative atomic mass: 207.2). As summarised by U.S. EPA (1998), pure lead is a silvery-white metal that oxidizes and turns blue-grey when exposed to air. It is soft enough to be scratched with a fingernail. It is dense (11.3 g/cm^3), malleable, and readily fusible. Its properties include: a low melting point; malleable; ductile; easy to cast; high density; low strength; easy to work; acid resistance; electrochemical reaction with sulphuric acid; chemical stability in air, water and earth; and the ability to attenuate sound waves, ionising radiation and mechanical vibration. Lead is hardened by alloying it with small amounts of arsenic, copper, antimony, or other metals. These alloys are frequently used in manufacturing various lead-containing products.

169. The use of lead, and the process of extracting lead from ore, date back to ancient times; the earliest known example of metallic lead is a metal figure recovered from the Temple of Abydus in Upper Egypt, considered to date from 4000 BC (Thornton *et al.*, 2001).

170. The toxicological effects of lead on humans have been known since antiquity; according to Xenophon (434-359 BC) and Lucretius (98-55 BC), the smoke of lead mines in Attica was harmful to human health (Weeber, 1990, as cited by Makra and Primblecombe, 2004).

171. There are three chemical forms of lead: metallic lead, inorganic lead compounds and organic lead compounds (containing carbon). Organic lead compounds are distinctive, with at least one lead-carbon bond. Natural lead is a mixture of four stable isotopes: ^{208}Pb (51 percent–53 percent), ^{206}Pb (23.5 percent–27 percent), ^{207}Pb (20.5 percent–23 percent), and ^{204}Pb (1.35 percent–1.5 percent) (U.S. ATSDR, 2006). The mixture of isotopes varies somewhat and is specific to the original geological deposits. This fingerprint can be used to trace the origin of lead deposited in the environment (AMAP, 2004), although there are uncertainties associated with the approach.

172. Lead exists in three oxidation states: Pb(0) - the elemental form, Pb(II) and Pb(IV). Lead is not a particularly abundant element, making up only about 0.0013% of the Earth's crust. Metallic lead, Pb (0), exists in nature, but its occurrence is rare. Lead is usually obtained from sulphide ores, often in combination with other elements such as zinc, copper and silver. The main lead mineral is galena (PbS). Other common varieties include cerussite ($PbCO_3$), plattnerite (PbO_2) and angelsite ($PbSO_4$).

173. Organo-lead chemistry is dominated by the tetravalent (Pb(IV)) oxidation state and it is only with rare exceptions that Pb(II) organo-metallic compounds form (Pelletier, 1995; Greenwood and Earnshaw, 1984, as cited by U.S. EPA, 2005a). All simple alkyl-lead compounds are composed of Pb(IV). There are, overall, more than 200 known organo-lead compounds (Harrison, 1985, as cited by U.S. EPA, 2005a). Of these, only two types of organo-lead compounds have found large-scale commercial applications: tetramethyl-lead (TML) and tetraethyl-lead (TEL); both used as petrol additives (U.S. EPA, 1998a).

174. The usual valence state in inorganic lead compounds is Pb(II) (IPCS, 1995). In relation to the other Group IV metals in the periodic table, lead forms the least stable and most reactive organo-metallic derivatives. This is largely due to the weak bond between lead and carbon - consistent with its large atomic size - and the influence of the relativistic effect on its valence orbitals (U.S. EPA, 2005a).

175. Metallic lead is sensitive to environmental acids, but after exposure to environmental sulphuric acid (H_2SO_4), metallic lead becomes impervious to corrosion due to weathering and submersion in water (U.S. EPA, 2005a). This effect is due to lead sulphate ($PbSO_4$), the relatively insoluble precipitate

produced by the reaction of lead with H_2SO_4, which forms a protective barrier against further chemical reactions. This aspect of its chemistry makes lead especially convenient for roofing, containment of corrosive liquids, and until the discovery of its adverse health effects, construction of water supply systems (U.S. EPA, 2005a). Like most metals, the solubility of lead is increased at lower pH (Stumm and Morgan, 1995, as cited by U.S. EPA, 2005a), suggesting that enhanced mobility of lead should be found in ecosystems under acidification stress.

176. In moist air, lead quickly tarnishes, forming a thin layer of lead oxide on the surface. This can further react with carbon dioxide in the air to form lead carbonate. This surface layer provides a high degree of protection against further reaction under normal atmospheric conditions (Thornton *et al.*, 2001).

177. As described further in section 4.3, lead is known to bioaccumulate in terrestrial and aquatic plants and animals, in particular in biota feeding primarily on particulate matter.

2.2 Lead in the atmosphere

178. As the melting point of elemental lead is 328°C and the boiling point at atmospheric pressure is 1,750°C, elemental lead will deposit on surfaces or exist in the atmosphere as a component of atmospheric aerosols at ambient atmospheric temperatures. In the atmosphere, lead exists primarily in the form of $PbSO_4$ and $PbCO_3$ (U.S. ATSDR, 2005). The residence time and transport of atmospheric lead is therefore linked to the characteristics of aerosols.

179. Non-organic compounds of lead exist primarily in the particulate form in the atmosphere (U.S. ATSDR, 2005). The median particle distribution for lead emissions from smelters was in a study from 1977 reported to be 1.5 µm, with 86 percent of the particle sizes under 10 µm (Corrin and Natusch 1977, as cited by U.S. ATSDR, 2005). It should be noted that the particle size distribution for lead emission from smelters may be different today. The smallest lead-containing particulate matter (<1 µm) is associated with high-temperature combustion processes (U.S. ATSDR, 2005).

180. Tetra-alkyl lead compounds have atmospheric residence times ranging from a few hours to a few days (Pelletier, 1995, as cited by U.S. EPA, 2005a). Lead particles from automobile emissions are quite small (<0.1 µm in diameter) but may coalesce in the atmosphere, resulting in larger particles (Chamberlain *et al.*, 1979, as cited by U.S. ATSDR, 2005). Tetra-methyl lead and tetra-ethyl lead react with OH in the gas phase, following pseudo-first-order kinetics, to form a variety of products that include ionic trialkyl-lead (TriAL), dialkyl-lead (DiAL) and metallic lead. Trialkyl-lead is slow to react with OH and is quite persistent in the atmosphere (Hewitt and Harrison, 1986; Harrison and Laxen, 1980, as cited by U.S. EPA, 2005a).

181. As reported by U.S. ATSDR (2005), large particles, particularly those with aerodynamic diameters of >2 µm, settle out of the atmosphere fairly rapidly and are deposited relatively close to emission sources (e.g., 25 meters from the roadway for particles of this size emitted in motor vehicle exhaust in the past); smaller particles may be transported thousands of kilometres. The dry deposition velocity for lead particles with aerodynamic diameters of 0.06–2.0 µm was estimated to range between 0.2 and 0.5 cm/second in a coniferous forest in Sweden, with an overall particle-size weighted dry deposition velocity of 0.41 cm/second (Lannefors *et al.,* 1983, as cited by U.S. ATSDR, 2005).

182. Aspects of lead's chemistry in the atmosphere which are important for long-range transport mechanisms are also dealt with in section 7.1 on atmospheric transport.

2.3 Lead in aquatic environments

183. In the aquatic environment, lead can occur in ionic form (highly mobile and bio-available), organic complexes with dissolved humus materials (binding is rather strong and limits availability), attached to colloidal particles such as iron oxide (strongly bound and less mobile when available in this

form than as free ions), or to solid particles of clay or dead remains of organisms (very limited mobility and availability) (OECD, 1993).

184. The speciation of lead in the aquatic environment is controlled by many factors, such as: pH, salinity, sorption and biotransformation processes. Lead is typically present in acidic aquatic environments as $PbSO_4$, $PbCl_4$, ionic lead, cationic forms of lead hydroxide and ordinary hydroxide $Pb(OH)_2$ (U.S. EPA, 2005a).

185. The speciation of lead differs in fresh water and seawater. The following text refers to U.S. ATSDR (2005), where the speciation chemistry of lead and lead compounds in water is described in more detail. In fresh water, lead may partially exist as the divalent cation (Pb(II)) at pHs below 7.5, but complexes with dissolved carbonate to form insoluble $PbCO_3$ under alkaline conditions (Long and Angino, 1977, as cited by U.S. ATSDR, 2005). Even small amounts of carbonate ions formed in the dissolution of atmospheric CO_2 are sufficient to keep lead concentrations in rivers at the 500 µg/L solubility limit (Callahan *et al.,* 1979, as cited by U.S. ATSDR, 2005). Lead chloride and lead carbonate are the primary complexes formed in seawater (Long and Angino, 1977, as cited by U.S. ATSDR, 2005). The speciation of lead in water is also dependent on the presence of other ligands in water. Lead is known to form strong complexes with humic acid and other organic matter (Denaix *et al.,* 2001; Gao *et al.,* 1999; Guibaud *et al.,* 2003, as cited by U.S. ATSDR, 2005). Lead-organic matter complexes are stable to a pH of 3, with the affinity increasing with increasing pH but decreasing with increased water hardness (Callahan *et al.,* 1979, as cited by U.S. ATSDR, 2005). In sea water, there is the presence of lead complexed to Fe-Mn oxides, which is due to the content of these oxides in sea water (Elbaz-Poulichet *et al.,* 1984, as cited by U.S. ATSDR, 2005). Sorption of lead to polar particulate matter in fresh water and estuarine environments is an important process for the removal of lead from these surface waters. The adsorption of lead to organic matter, clay and mineral surfaces, and co-precipitation and/or sorption by hydrous iron and manganese oxides increase with increasing pH (Callahan *et al.,* 1979, as cited by U.S. ATSDR, 2005).

186. In water, tetraalkyl-lead compounds, such as tetraethyl-lead and tetramethyl-lead, are subject to photolysis and volatilization. Degradation proceeds from trialkyl species to dialkyl species, and eventually to inorganic lead oxides. Removal of tetraalkyl-lead compounds from seawater occurs at rates that provide half-lives measurable in days (DeJonghe and Adams 1986, as cited by U.S. ATSDR, 2005). Some of the degradation products include trialkyl-lead carbonates, hydroxides, and halides. These products are more persistent than the original tetraalkyl-lead compounds.

187. As stated by U.S. EPA (2005), lead in surface water is derived from four different sources: biogenic material, aeolian particles, fluvial particles and erosion (Ritson *et al.*, 1994, as cited by U.S. EPA, 2005a). About 90 percent of the lead in the open ocean is in the dissolved phase (Reuer and Weiss, 2002). Organic ligands are complexed with 50-70 percent of this lead, with the balance found in inorganic compounds (Reuer and Weiss, 2002, as cited by U.S. EPA, 2005a). Biological particles in the open ocean scavenge a significant portion of the lead complexes, which according to Reuer and Weiss (2002) have an estimated two-year residence time in ocean waters. According to Gobeil *et al.* (2001, as cited by Macdonald *et al.*, 2005), the specific residence time of lead in surface water is <5 years.

188. In alkaline waters, common species of lead include anionic forms of lead carbonate $Pb(CO_3)$ and hydroxide $Pb(OH)_2$. In fresh water, lead typically forms strong complexes with inorganic OH^- and CO_3^{2-} and weak complexes with Cl^- (Bodek *et al.*, 1988; Long and Angino, 1977, as cited by U.S. EPA, 2005a). The primary form of lead in fresh water at low pH (≤6.5) is predominantly Pb^{2+}, and less abundant inorganic forms include $Pb(HCO)_3$, $Pb(SO_4)_2^{2-}$, PbCl, $PbCO_3$ and $Pb_2(OH)_2CO_3$. At higher pH (≥7.5), lead forms hydroxide complexes ($PbOH^+$, $Pb(OH)_2$, $Pb(OH)_3^-$, $Pb(OH)_4^{2-}$). Lead speciation in seawater is a function of chloride concentration, and the primary species are $PbCl_3^- > PbCO_3 > PbCl_2 > PbCl^+ >$ and $Pb(OH)^+$ (Fernando, 1995, as cited by U.S. EPA, 2005a).

189. Corrosion of lead in water, as with other metals, is an electrochemical reaction, and the dissolution of lead in water is called plumbosolvency (Thornton *et al.*, 2001).

190. The solubility of lead compounds in water varies, lead sulphide and lead oxides being poorly soluble, and nitrate, chlorate and chloride salts reasonably soluble in cold water. Lead also forms salts with such organic acids as lactic and acetic acids (IPCS, 1995).

191. In solution, organo-lead compounds decompose in the presence of UV radiation (1 hr/254 nm) and sunlight (Gomez Ariza *et al.*, 2000, as cited by U.S. EPA, 2005a).

192. Changes in water chemistry (e.g., reduced pH or ionic composition) can cause sediment lead to become re-mobilized and potentially bioavailable to aquatic organisms (Weber, 1993, as cited by U.S. EPA, 2005a). Methylation may result in re-mobilization and reintroduction of lead into the aqueous environment compartment and its subsequent release into the atmosphere (SRC, 1999, as cited by U.S. EPA, 2005a). However, methylation is not a significant environmental pathway controlling the fate of lead in the aquatic environment.

193. Lead sorption to suspended or bed sediments or suspended organic matter typically increases with increasing pH, increasing amounts of iron or manganese; and with the polarity of particulate matter (e.g., clays). Adsorption decreases with water hardnes (Syracuse Research Corporation (SRC, 1999; as cited by U.S. EPA, 2005a). At higher pH, lead precipitates as $Pb(OH)^+$ and $PbHCO_3^+$ into bed sediments (Weber, 1993, as cited by U.S. EPA, 2005a). Conversely, at low pH, lead is negatively sorbed (repelled from the adsorbent surface) (U.S. EPA, 1979; Gao *et al.*, 2003; as cited by U.S. EPA, 2005a).

194. Due to the binding capacity of soil minerals and humus, groundwater usually contains very low concentrations of lead, and the diffusion of lead from deposits to the groundwater must be expected to be a relatively slow process (Hansen *et al.*, 2004a). The mobility of lead in the soil depends on the soil's pH and organic content. In general, the sorption and relative immobility of lead in soil decreases its bioavailability to humans and other terrestrial life (OECD, 1993).

2.4 Lead in soil

195. In general, lead is not very mobile in soil. The downward movement of elemental lead and inorganic lead compounds from soil to groundwater by leaching is very slow under most natural conditions (NSF, 1977, as cited by U.S. ATSDR, 2005). Soil pH, content of humic acids and amount of organic matter influence the content and mobility of lead in soils (Hansen *et al.*, 2004a). Furthermore, Hansen *et al.* (2004a) state that only a very small portion of the lead in soil is present in solution, which is the immediate source for lead in plant roots; soil acidification, however, is associated with increased mobility and bioavailability of lead. More acidic conditions (lower pH) not only increase the solubility of lead, but also of other heavy metals.

196. The fact that relatively concentrated acids, reducing agents, oxidizing agents, or chelating agents are required to liberate the majority of lead from soils is used as one line of evidence that lead migration and uptake by plants in soils is expected to be low (U.S. EPA, 2005a). The low uptake in plants results in the relatively low concentrations of lead in foodstuffs as discussed in Chapter 3

197. Lead is strongly adsorbed to organic matter in soil. Clays, silts, iron and manganese oxides, and soil organic matter can bind lead and other metals electrostatically (cation exchange) as well as chemically (specific adsorption) (U.S. ATSDR, 2005). Lead adsorbed in a soil matrix may enter surface waters as a result of erosion of lead-containing soil particles.

198. Data on lead in different soils is illustrated in Figure 2-1. Further details and references to the data can be found in Annex 1. The lead content in uncontaminated soils of remote areas is generally within the range of 10-30 mg Pb/kg. Lead concentration in soil beside roadways and in towns is reported to be up to several thousands mg Pb/kg, whereas soils adjacent to smelters and battery factories are reported at up to 60,000 mg Pb/kg.

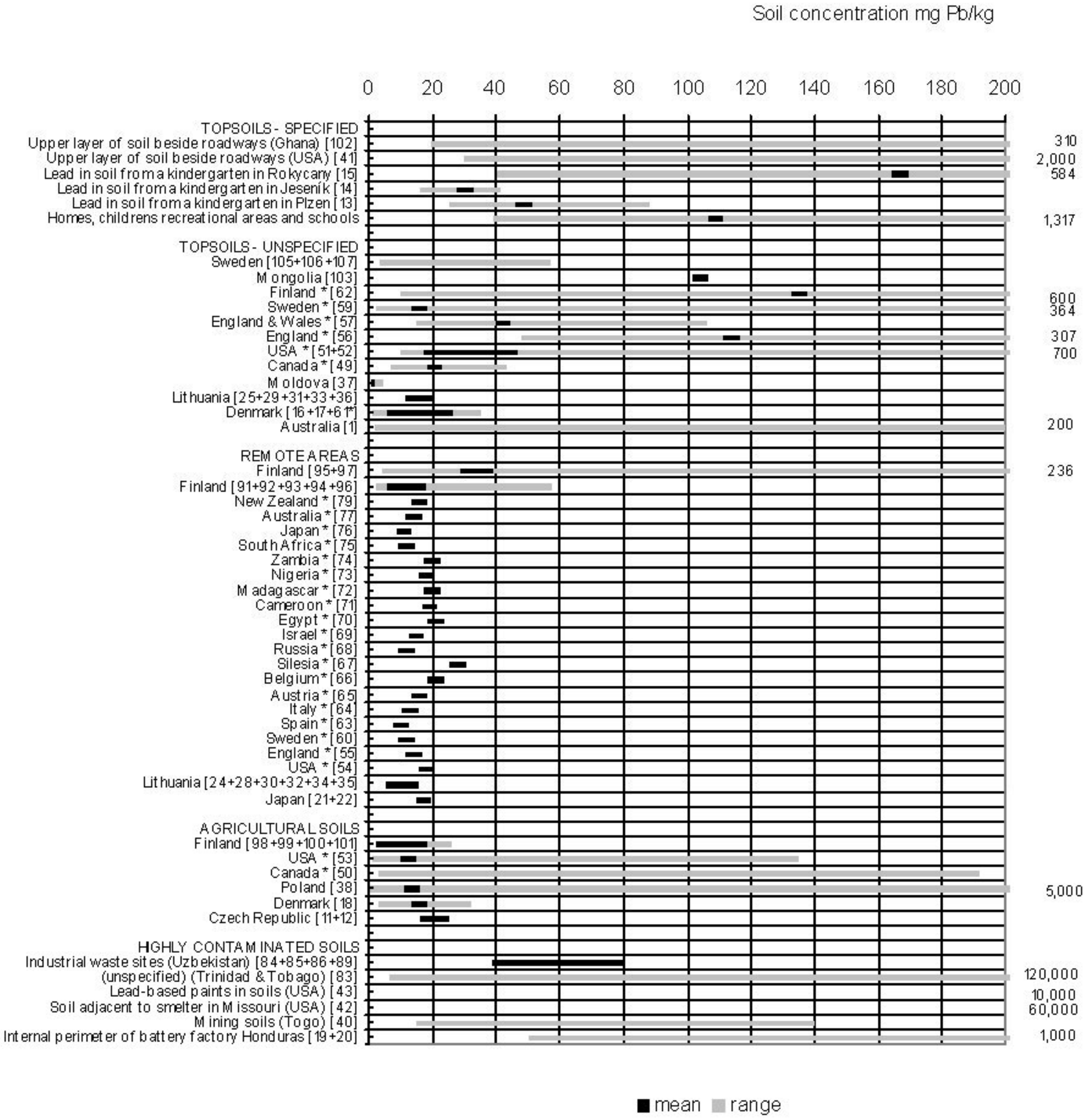

Figure 2-1 Lead in soils. More details and references to data sources can be found in Annex 1. The number in square brackets after the country name refers to the numbers in the table in Annex I. Concentrations out of scale are indicated to the right of the bars.

3 Human exposure and health effects

3.1 Human exposure

199. **Exposure of the general population** –Exposure to lead occurs as a result of ingestion of foodstuffs, water and other beverages, and from air. Ingestion of contaminated soil, dust and old lead-based paint due to hand to-mouth activities may also be important regarding lead intake in infants and young children. When tap-water systems with leaded pipes are used, lead intake via drinking-water can be an important source, especially in children. Inhalation exposure may be significant when lead levels in the air are high. (WHO/UNECE, 2007)

200. **Susceptible population groups –** Susceptibility in the general population depends on many factors, including age, genetic characteristics, nutritional status, tobacco smoking, alcohol consumption and health status. Young children (below 6 years old) are most susceptible to lead exposure, even at low levels. Lead may also be transferred to the fetus *in utero*, both from exogenous sources, and as a result of its mobilization from the bones of the mother. Such mobilization can occur in women whose exposure ceased many years earlier, and even at low blood lead levels (Bellinger, 2005). In some children the habit of *pica* (the compulsive, habitual consumption of non-food items such as soil, paint flakes and chips) predisposes them to exposure if lead is present in the substances ingested. Susceptibility to lead exposure and, more specifically, to retained lead may also be linked to a genetic factor, as the gene which codes for aminolevulinic acid dehydrogenase, a critical enzyme in the production of haeme may be altered (Bergdahl, 1997; Kelada, 2001). People working with lead under unsafe conditions are especially exposed and may be considered as another susceptible population group, especially if they are children or young adults (Ide and Parker, 2005).

201. **Lead absorption –** Absorbed lead is rapidly taken up by blood and soft tissue, and then slowly redistributed to bone. Bone accumulates lead during much of the lifespan and may then serve as an endogenous source, releasing lead slowly back into the blood after the exposure stops. Lead is readily transferred to the human fetus throughout gestation (IPCS, 1995). The human skeleton begins to accumulate lead during fetal development and continues up to about 60 years of age (Pounds *et al.*, 1991). Interest in bone lead, and its measurement in vivo, stems from concern that skeletal lead is not metabolically inert, but can be mobilized by physiological and pathological states, for example, during pregnancy and lactation (Silbergeld, 1991) and osteoporosis (Silbergeld *et al.*, 1988), with possible adverse effects. Recent research indicates that re-release of stored lead from bones into the blood and soft tissues may occur as bones become thinner with age. A number of potential health effects associated with this re-release have been identified in the elderly. In this way, lead exposure that occurred decades earlier may be a source of ill-health in the elderly (Garrido Latorre *et al.*, 2003)

202. **Occupational exposure –** Airborne lead may contribute significantly to occupational exposure (especially if the workers are smokers). Inhalation is the dominant pathway for lead exposure of workers in industries producing, refining, using or disposing of lead and lead compounds (IPCS, 1995). Occupational exposure in industrial facilities and workshops has been addressed in a number of reports, in particular from developing countries. High lead levels in blood have been reported for people working in lead industries and mines (Morocco's submission, 2005**),** in manufacture of lead fishing sinkers (Honduras' submission, 2005)**,** in manufacture and recycling of batteries (Honduras' submission, 2005), in manufacture of pottery (Mexico's submission, 2005**)** and in spray painting, panel beating, metal cutting and welding and motor vehicle mechanics (Kimani, 2005)**.** Elevated blood lead levels were found in workers at two printing factories, a research institute and a glass factory (Armenia’s submission, 2007).

203. In Hungary, the rules of occupational exposure assessment are laid down at the workplace and are governed by both Act No XCIII of 1993 and Act No XXV of 2000 and according to EüM-SzCsM

joint decree No. 25/2000. (IX.30.). The employers are obliged to notify the authorities regarding cases of over-exposure as well as cases of poisoning of their employees. This data is collected and sorted by the authority. The information in table 3-1 indicates the exposure of workers to lead in the years 1998 through 2006 (Hungary's submission, 2007). Further details (in Hungarian only) can also be found at: the http://www.mvkepviselo.hu/egeszsegugy.html.

Table 3-1 Exposure of workers to lead in years 1998 through 2006(Hungary's submission, 2007).

	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Number of persons exposed over the limit	154	63	53	35	25	37	48	8	3

204. **Lead in the diet –** The daily intake of lead varies by country, as shown in Table 3-2, and the sources vary with the diet. According to data from Australia and the United States of America (Table 3-2), small children have a significantly higher daily intake per kg of body weight than adults. In the European Union, fruits, vegetables, cereals, bakery wares and beverages are the major sources of dietary lead, together accounting for most of the intake (EU SCOOP, 2004). In Japan, the daily intake of lead per person in 2004 was estimated at 26.8µg (Japan's submission, 2005**).** The main contribution came from rice (25 percent), vegetables and seaweeds (20 percent), seasonings and beverages (18 percent), and fish and shellfish (4 percent) (Japan's submission, 2005). The average dietary lead intake of an adult Finnish person is estimated to be 17 µg/day. The sources of dietary lead in the Finnish population are fish, including canned fish (23 percent), root crops, vegetables, fruits and berries (17 percent), grain and grain products (15 percent), juices and other drinks (12 percent), milk and milk products (11 percent), meat and meat products (9 percent), alcohol (7 percent) and other food sources (6 percent) (NFA, 2002**)**. Some reports refer to lead-contaminated flour (Panariti and Berxholi, 1998)*,* imported spices (Woolf and Woolf, 2005) and also candy (MMWR, 2002)**.** Food surveys in European countries have shown that lead contamination of foodstuffs in general has declined over the years (Tukker *et al.*, 2001). In Armenia lead levels in fruit and vegetables in the vicinity of mining areas and cement plants exceeded the maximum allowable concentration by 2 to 25 times. Further details can be found at the Armenia's submission 2007

205. **Lead from food containers** – In older food basket surveys, the influence of lead-soldered tin cans used for storage of food was noticeable (Tukker *et al.*, 2001). Glazes on ceramics, earthenware, bone china, and porcelain often contain lead and are a potential source of exposure (MMWR, 2004a)**.** Reports from Brazil, Mexico, Morocco, Tunisia, and other countries refer to some traditionally manufactured pottery, in which the glazing materials contain lead (Belgaied, 2003; Mexico's submission, 2005; Morocco's submission, 2005). If the manufacturing process is carried out at low temperatures, the lead in the glaze is not fixed and may subsequently leak into food and beverages (Mexico comments, 2006). In Honduras, a study of lead released from ceramics revealed that, in 43 pieces out of 186 analysed, the amounts exceeded the maximum allowed level (Honduras' submission, 2005).

206. **Ingestion of soil and dust –** For infants and young children, dust and soil often constitute a major exposure pathway due to behaviour patterns such as hand to mouth activities. Levels in dust and soil may be a concern regarding the exposure of the general population. The intake of lead is influenced by the age, and biological and behavioural characteristics of the child, and the bioavailability of lead in the source material. Dust (in homes and streets) and soil may contain high concentrations of lead; this is particularly the case for dust in homes where paint with lead pigments has been used, and soil around lead-emitting industries (IPCS, 1995; U.S. CDC, 2002, 2005). The maximum uptake in children seems to occur around 2 years of age; uptake is higher in the summer than in the winter (Baghurst *et al.*, 1992; Yiin *et al.*, 2000). The hand-to-mouth behaviour of children increases their lead intake (Lanphear *et al.*, 1998), and even small babies who are unable to grasp objects receive much of their lead exposure from putting their own fingers in their mouth (Kranz *et al.*, 2004). According to a study undertaken in India where samples of dust were taken from floors in Delhi houses for analysing lead content, it was suggested that the lead content is at a level that poses a hazard to children (Kumar, 2008). Reference levels

used were 40 or more micrograms of lead in dust per square foot on its floors; or 250 or more micrograms of lead in dust per square foot on its interior windowsills. Additional information on lead in household dust in Delhi can be obtained from that study.

207. **Lead in paint** – Paint dust is a primary source of lead exposure in the USA, for children living in homes with lead-containing paint. Although the sale of lead-based paint for residential use was banned in the United States in 1978, flaking paint, paint chips, and weathered powdered paint, which are most commonly associated with deteriorated housing stock in urban areas, remain a major source of lead exposure for young children, particularly those with pica (Bornschein *et al.*, 1986; US EPA, 1986). Lead concentrations of 1–5 mg/cm^2 have been found in chips of lead-based paint (Billick and Gray, 1978), suggesting that consumption of a single chip of paint would provide greater short-term exposure than any other source of lead (US EPA, 1986). In addition to the substantial hazard of eating paint chips or chewing on painted surfaces, significant exposures can occur as the result of ingestion of dusts from lead-based paints and contaminated soils (U.S. CDC, 2005; U.S. ATSDR, 2007). For example, the State of Massachusetts reports that children are poisoned more often by ingesting dust from lead paint than by eating chips or chewing on painted surfaces. Lead dust covers surfaces and objects that children touch and clings to their hands and toys. Children ingest lead dust when they put their hands or toys in their mouths, which is normal behaviour for all young children (Mass DHHS, 2008). Exposure to lead-based paints in old houses has also been reported from Burkina Faso (Burkina Faso's submission, 2005).According to a study undertaken in India, water-based paints had lead levels below the Indian standard of 1000 ppm, however in the enamel paints examined, all except one brand had lead levels above that limit (Kumar, 2007). Additional information on lead in paints in India can be obtained from that study.

208. Some recent studies (Clark C.S. *et. al.*, 2006 and 2005; Mathee *et. al.,*2003 and 2007; and Adebamowo E.O., *et. a*l., 2006a, and 2006b, and Adebamowo E.O. *et. al.*2007) indicate that lead-based paints are still being used in some countries in Asia and Africa. For example, the abstract from Clark *et. al*, 2006, states the following: "Worldwide prohibitions on lead gasoline additives were a major international public health accomplishment, the results of which are still being documented in parts of the world. Although the need to remove lead from paints has been recognized for over a century, evidence reported in this article indicates that lead-based paints for household use, some containing more than 10 percent lead, are readily available for purchase in some of the largest countries in the world. Sixty-six percent of new paint samples from China, India, and Malaysia were found to contain 5000 ppm (0.5 percent) or more of lead, the US definition of lead-based paint in existing housing, and 78 percent contained 600 ppm (0.06 percent) or more, the limit for new paints. In contrast, the comparable levels in a nearby developed country, Singapore, were 0 percent and 9 percent. In examining lead levels in paints of the same brands purchased in different countries, it was found that some brands had lead-based paints in one of the countries and paints meeting US limits in another; another had lead free paint available in all countries where samples were obtained. Lead-based paints have already poisoned millions of children and likely will cause similar damage in the future as paint use increases as countries in Asia and elsewhere continue their rapid development. The ready availability of lead-based paints documented in this article provides stark evidence of the urgent need for efforts to accomplish an effective worldwide ban on the use of lead in paint (Clark, C.S. *et.al.,* 2006)."

209. Another example of exposures to lead from paints is described in the article by Mathee *et. al*, 2007, which reports the following: "A survey was conducted by the South African Medical Research Council of the lead concentrations in paint samples collected from dwellings located in randomly selected Johannesburg suburbs. Of 239 dwellings included in the survey, 20 percent had paint lead concentrations > 5,000 µg/g (the U.S. reference level). Paint with high lead levels was found in old as well as newly constructed dwellings (Montgomery and Mathee, 2005). Suspecting the ongoing use of lead in paint in South Africa, researchers from this study purchased paint samples directly from Johannesburg and Cape Town stores, for lead content analysis. Although no lead was found in water-based or white shades of enamel paint, alarmingly high lead concentrations (up to 189,000 µg/g) were measured in samples of pigmented enamel paints. In total, 83 percent of the samples of pigmented enamel paints were lead based. High lead concentrations were found in popular as well as lesser-known brands of

enamel paint, and only 2 of 25 samples of lead-based paint displayed warnings of the high lead content. Similarly high lead concentrations (up to 145,000 µg/g) were found in paint removed from widely used children's toys (such as building blocks) that were purchased from major toy, supermarket, and stationery chain stores as well as flea and craft markets. High lead levels were found in locally manufactured as well as imported toys. On presentation of evidence of the elevated lead concentrations in paint on children's toys, the Ministry of Health in South Africa acted to initiate a process, still ongoing, of drafting legislation to limit the use of lead in paint in the country."

210. Another study (by Adebamowo *et. al.,* 2007) reported lead in paints in Nigeria. In the abstract of the paper they state the following: "We studied lead levels of paints manufactured in Nigeria in 2006. Lead levels in 5 colours of paints, each from different manufacturers were measured using flame-atomic absorption spectroscopy. We found that 96 percent of the paints had higher than recommended levels of lead. The mean lead level of paints ranged from 84.8 to 50,000 ppm, with mean of 14,500 ppm and median of 15,800 ppm. The main determinant of lead levels was colour of the paint. As lead levels in paint sold in the past years in Nigeria are likely to be at least as high as that currently sold, it is likely that many existing houses contain dangerously high levels of lead. Efforts need to be undertaken to assess the presence of high lead levels in existing housing and if detected, intervention programs for eliminating risk of exposure should be developed in addition to measures to increase awareness and enforce regulations leading to the elimination of lead based domestic paint.."

211. **Lead intake via inhalation of ambient air** – Airborne lead may contribute significantly to exposure, depending on factors such as use of tobacco, occupation, proximity to busy roads, lead smelters, repair workshops, and leisure activities (e.g., arts and crafts, sports involving firearms) (IPCS, 1995) and also waste burning. For example in Pakistan, a study carried out on children living near automobile and battery workshops showed that the children had blood lead levels varying between 11.4 to 20.0 µg/dl higher than the WHO recommended level of 10.0 µg/dl (Pakistan submission, 2010). In countries where leaded petrol is still used [3], inhalation of vehicle emissions is a major lead exposure pathway, particularly close to high-traffic roads. Kenya was set to use unleaded petrol from January 2006, however leaded petrol might remain more easily accessible in rural areas (Kimani, 2005). In some countries, candles with lead wicks may be a source of exposure. For example, in Mexico it is reported that some candles used in the context of traditional customs and rituals in homes, churches, cemeteries and funeral rooms may have "pabilo" threads containing lead, and emit up to 3000 µg of lead per hour when burning (Mexico's submission, 2005).

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[3] At the beginning of 2008, 19 countries worldwide were still using leaded gasoline. Within the year, three countries – Jordan, Lao People's Democratic Republic, and Mongolia as well as the Occupied Palestinian Territory – have ceased using leaded gasoline and an additional two countries – Afghanistan and Morocco – are expected to phase out its use at the end of 2008. Tunisia, expected to phase out such use at the end of 2008, in the Partnership national awareness raising activity, committed to phase out leaded gasoline at a date in the near future to be communicated. Reference can be found at the Partnership for Clean Fuels and Vehicles (www.unep.org/pcfv).

Table 3-2 Daily intake of lead via food: country examples [4]

Country	Type of consumption data/intake study	Average dietary intake (µg of lead per kg body weight per day)	Population group	Information source
Australia	Range of mean estimated dietary exposures to lead. Recalculated form Australia's submission, 2005, reporting the intake as percentage of the tolerable limit of 25 µg/kg of body weight per week	0.06–0.39	Adult males 25–34 years	Australia's submission, 2005
		0.02–0.35	Adult females 25–34 years	
		0.02–0.43	Boys 12 years	
		0.01–0.34	Girls 12 years	
		0.03–0.93	Toddler 2 years	
		0.01–1.19	Infant 9 months	
Burkina Faso	Calculated from a reported average daily dose of 52 µg Pb per day (Burkina Faso's submission) assuming an average weight of 60 kg	0.9		Burkina Faso's submission, 2005
Finland	Calculated from a reported average daily dose of 17 µg Pb per day (Finland comment, 2006) assuming an average weight of 70 kg	0.24	Adult	NFA 2002 as cited by Finland's comments, 2006
Mexico	Calculated in Mexico comments (2005) based on a general value of 3 µg/kg of food.	3.5		Mexico's comments, 2006
Poland	In 1997 the intake of students of the Medical Academy in Lublin was studied. Calculated from a reported average daily intake of 103.5 µg per person for males and 88.5 µg per person for females (Poland's submission, 2005), asuuming an average weight of 70 kg for men and 60 kg for women	1.48	Males	Poland's submission, 2005
		1.48	Females	
USA	Average intake calculated with a Dietary Exposure Potential Model (DEPM) and data obtained from Combined National Residue Database (CNRD) to estimate dietary lead intake based on food consumption patterns in 19 subpopulation groups. The food items used in the model are based on 11 food groups consisting of approximately 800 exposure core foods that represent 6500 common food items. Estimates based on other approaches are presented by US ATSDR (2005) as well	0.918	Males over 55 years	(US ATSDR, 2005)
		0.895	Males over 20years	
		0.890	Males 13–19 years	
		0.946	Females over 55 years	
		0.920	Females over 20 years	
		0.824	Females 13–19 years	
		1.164	Children 7–12 years	
		1.952	Children 1–6 years	
		3.117	Non-nursing infants	
		1.009	US population	

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[4] The joint FAO/WHO Expert Committee on Food Additives has established a provisional tolerable weekly intake (PTWI) of 25 µg/kg of body weight (equivalent to 3.5 µg/kg of body weight per day). Further reference can be found in section 3.3

212. **Lead intake via drinking-water –** Piped water supplies may be contaminated through lead pipes, lead-soldered copper-pipes, lead-containing brass joints on plastic pipes, or from other parts of the water system. Lead dissolves particularly easily in acidic or soft water. The final concentration depends on the time the water stays in contact with the lead components (WHO/UNECE, 2007). The lead content of drinking-water varies considerably. Intakes of about 1 µg/day or less have been reported from Sweden (Svensson *et al.*, 1987). A study in Hamburg, Germany, in an area where lead pipes are common in old plumbing systems, showed a large variation in the lead concentration in tapwater, from less than 5 µg/l to 330 µg/l (Fertmann *et al.*, 2004), with a mean of 15 µg/l. High concentrations of lead in drinking-water are of concern for children, especially for bottlefed babies if the formula feed is prepared from tap water (WHO/UNECE, 2007). Recent percentage values for those sites failing to achieve recommended limits for lead in drinking water across the United Kingdom can be found in the Chief Inspectors annual report ‘Drinking Water 2006’ at the Drinking Water Inspectorate website (www.dwi.gov.uk). The current standard set out in the national legislation for drinking water in the United Kingdom is 25 µg/L, due to be tightened to 10 µg/L from 2013 (United Kingdom’s submission, 2007). Levels registered in drinking water in Norway are in general well below the maximum acceptable concentration (MAC) for lead of 10 µg/L (Norway’s submission, 2007). In Morocco, according to a number of reports, the lead content of tapwater varies significantly from city to city and according to the age of the buildings (Morocco's submission, 2005). In Agadir, Casablanca and Tangiers, for example, the lead concentration in tapwater is relatively high (compared with other cities in the country) with an average of 28 µg/l and a maximum of 123 µg/l. The lead concentration in the groundwater generally does not exceed 6 µg/l (Morocco's submission, 2005). In Niger, the limit fixed for lead in drinking water is 50µg/L (Niger’s submission, 2007). In Hungary, the quality of drinking water shall comply with the requirements stipulated in the Government Decree No. 201/2001. ((X.25.) Korm). The suppliers of the drinking water are obliged to analyse their water regularly according to different parameters, including lead. The limit values appearing in the said decree mentioned above are identical with those published in the European Directive 98/83/EGK, which for lead is 10 µg/l. Of 398 samples taken in 2004 only 5 were above the limit (Hungary’s submission, 2007).

213. **Other sources of exposure –** Some lead-containing traditional medicines and cosmetics may result in exposure to high levels of lead. Indeed, lead compounds are used as major ingredients in a number of traditional medicines in some parts of the world. These products may even be exported, particularly as use of alternative medicine becomes widespread in developed countries (Saper *et al.*, 2004; Muzi *et al.*, 2005)**.** Lead poisoning due to the use of traditional cosmetics and medicines has been identified among infants (Ernst, 2002), children and adults (Mitchell-Heggs *et al.*, 1990). In some countries, leaded kohl, also called *al kohl*, is traditionally applied to the umbilical stump of newborns in the mistaken belief that it has a beneficial astringent action (Fernando *et al.*, 1981). In other countries, irritable children are made to inhale the fumes (*bokhoor*) produced from heating lead metal or lead sulfide on hot coals, in the belief that this will calm them (Fernando *et al.*, 1981; Shaltout *et al.*, 1981)**.** A review of data on traditional Indian remedies identified a number of reports and case series documenting the presence of heavy metals, particularly lead (Ernst, 2002)**.** Latin American countries also report the use of traditional medicines with high lead concentrations, e.g. the Mexican traditional remedies *azarcon* (lead chromate) and *greta* (mixed lead oxides), which may contain more than 70 percent lead (Trotter, 1990; MMWR 1993). Metallic toys and trinkets containing lead have been reported as a source of exposure for young children (MMWR, 2004b, 2006). In a study undertaken in India, 20 per cent of toy samples from Mumbai showed lead concentrations from 878.6 to 2104 ppm (Kumar and Pastore, 2007). Clinical lead poisoning can also result from gunshot wounds (Manton and Thal, 1986; Meggs *et al.*, 1994) or ingestion of lead shots (Bygdnes *et al.*, 2005). Data on addressing lead contamination at Superfund sites (including certain mining sites) and estimating impacts can be found at http://www.epa.gov/superfund/health/contaminants/lead United States’ submission, 2007). Information on exposures in China (Huo, X. *et. al*., 2007) indicate an elevation of blood levels in children living in the local environment which may be due to the electronic waste (e-waste) recycling which has remained primitive in Guiyu, China.

214. **Toxicokinetics –** Depending on the chemical speciation, particle size, and solubility in body fluids, up to 50 percent of inhaled lead compounds may be absorbed. In adults, approximately 10 per-

cent of dietary lead is absorbed, and the proportion is higher under fasting conditions. However, in infants and young children, as much as 50 percent of dietary lead is absorbed. Absorption rates for lead from dusts, soils and paint chips may be lower, depending on its bioavailability (IPCS, 1995). The absorption routes and rates are highly dependent on particle size. Approximately 95 percent of inorganic lead inhaled as submicron particles is absorbed (Hursh *et al.*, 1969; Wells *et al.*, 1975). Rates and amounts of absorption of inhaled lead particles larger than 2.5 µm are determined primarily by rates of transport to, and absorption from, the gastrointestinal tract. Dermal absorption of inorganic lead is insignificant (but organic lead may be readily absorbed through the skin) (U.S. ATSDR, 2005). The half-life of lead in blood is estimated to be 20–40 days. Lead is excreted mainly in urine, very slowly. As a result, even low-level, chronic exposure leads to the accumulation of lead in the body (U.S. ATSDR, 2005). Lead accumulates in bone up to 50–60 years of age, then declines as a result of age-related changes in diet, hormone concentrations and metabolism (Pounds *et al.*, 1991). Bone contains more than 90 percent of the body burden of lead in adults and over 70 percent in children (Barry, 1975)**.** Lead mimics several elements found in bone, such as calcium, radium, strontium and fluorine. These elements have different turnover rates in bone, which in turn affects lead uptake and release (Rabinowitz, 1991). The lead in blood and bone is in equilibrium, and metabolic changes alter this equilibrium (Mushak, 1993)**.**

215. **Mechanisms of action –** There are a number of toxic mechanisms of lead, and more is becoming known about its molecular effects. Lead binds to the sulfhydryl (SH) groups of proteins, altering their structure and function. Among other effects, lead substitutes calcium and zinc, affecting various biological processes, such as metal transport, energy metabolism, apoptosis, conduction of ions, cell adhesion and signalling, enzymatic processes, protein maturation, and genetic regulation. Lead has an affinity for the cell membrane, interferes with mitochondrial oxidative phosphorylation, and impairs the activity of calcium-dependent intracellular messengers and protein kinase C. Lead may inhibit DNA repair, have genotoxic effects, and affect sodium, potassium and calcium ATPase (Lidsky and Schneider, 2003; Toscano and Guilarte, 2005). The toxic effects of lead may, therefore, involve several organ systems and functions.

216. **Genetic polymorphisms**[5] – Genetic polymorphisms are important in environmental health, because they can be useful in detecting differences in levels of risk and in responses to toxic exposures within specific populations (Kelada *et al.*, 2003; US EPA, 2006; US ATSDR, 2005). Recent research indicates that susceptibility to lead toxicity may depend on genetic factors. For example, a polymorphic variant of delta-aminolevulinic acid dehydratase may influence the level of lead in blood and bone (Hu *et al.*, 2001). Three genes have been identified as potentially influencing the accumulation and toxicokinetics of lead in children and adults: aminolevulinic acid dehydratase (ALAD), the vitamin D receptor (VDR) gene, and the haemochromatosis gene (HFE). It has been suggested that at least two genetic polymorphisms, of ALAD and the vitamin D receptor gene, play a role in susceptibility to lead (US EPA, 2006). One study of African-American children reported a relatively high proportion of the children as being homozygous for alleles of the vitamin D receptor gene thought to contribute to greater blood lead levels. This work is preliminary and further studies are needed to determine the implications of this and other genetic differences for susceptibility to lead exposure (US EPA, 2006). Relatively few studies of genetic polymorphisms have been reported in children, compared with the substantial body of studies on adults with high lead exposure.

217. **Trends in lead exposure** – Current data on the concentration of lead in air, the daily intake of lead with food, and blood lead levels suggest that exposure to environmental lead is decreasing. In many areas there have been major decreases in blood lead levels in recent decades, mainly because of the phasing out of leaded petrol but also because of reductions in other sources of exposure (WHO/UNECE, 2007). Reduced blood lead levels with reduced use of leaded petrol have been demon-

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[5] Genetic polymorphisms are natural variations in a gene, DNA sequence, or chromosome that, under normal conditions, have no adverse effects on the individual and occur with fairly high frequency in the general population. The different variations in the gene usually express different phenotypes (http://en.wikipedia.org/wiki/Polymorphism and http://ghr.nlm.nih.gov/ghr/glossary/polymorphism).

strated throughout the world. Figure 3-1 shows results from a number of studies in Australia, from 1979 to 1999, reflecting the correlation between blood lead levels in children and the phasing out of leaded petrol. In Thailand, longitudinal studies showed reduced blood lead levels in children following the reduction of air lead levels resulting from increased use of unleaded petrol. (Ruangkanchanaset and Suepiantham, 2002). Similar trends have been observed in studies in Trail, British Columbia (Canada), which examined blood lead levels in preschool children. These studies compared the current situation with historical information, to determine the trends in environmental lead contamination and provide a basis for identifying appropriate precautions and protection against lead exposure in the future. The Trail study found that lead levels in soil and, secondarily, house dust were the main determinants of high blood lead (Hertzman *et al.*, 1991). Reduction of emissions from a local smelter resulted in reduced lead loadings and concentrations in outdoor dustfall, street dust and indoor dustfall, causing a dramatic decline in blood lead levels in children (Hilts, 2003**.** In the United States of America in the 1970s, over 80 per cent of children had blood lead levels exceeding 10 µg/dl, but in a 1999–2002 study fewer than 2 per cent exceeded this level. In general, Pb exposure in the United States has fallen with the elimination of leaded gasoline, Pb-based paint and Pb solder in cans (U.S. EPA, 2006). As reported in WHO/UNECE 2007, data indicate exposures have also declined substantially in a number of European countries (WHO/UNECE, 2007).

218. The following paragraphs make reference to some geographical differences and time patters (WHO/UNECE, 2007), as follows:

219. There are large variations in lead exposure on both a global and a local scale. Because leaded petrol has long been a significant source of environmental lead, living close to a road with heavy traffic may be a determinant of exposure level (Strömberg *et al.*, 2003), as well as living close to a lead-emitting industrial plant or in an area with lead-painted houses. People living in city centres have higher B-Pb levels than people living in rural areas.

220. On a global scale, the highest B-Pb levels occur in South and Central America, the Middle East, parts of eastern Europe and the countries of the former USSR. Using data from published studies, Fewtrell *et al.* (2004) assessed mean B-Pb concentrations in different parts of the world (Table 3.3) and estimated that about 25 percent or more of the children in these areas have B-Pb levels above 100 µg/l. In Australia, North America and western Europe, the corresponding proportion of children was less than 10 percent.

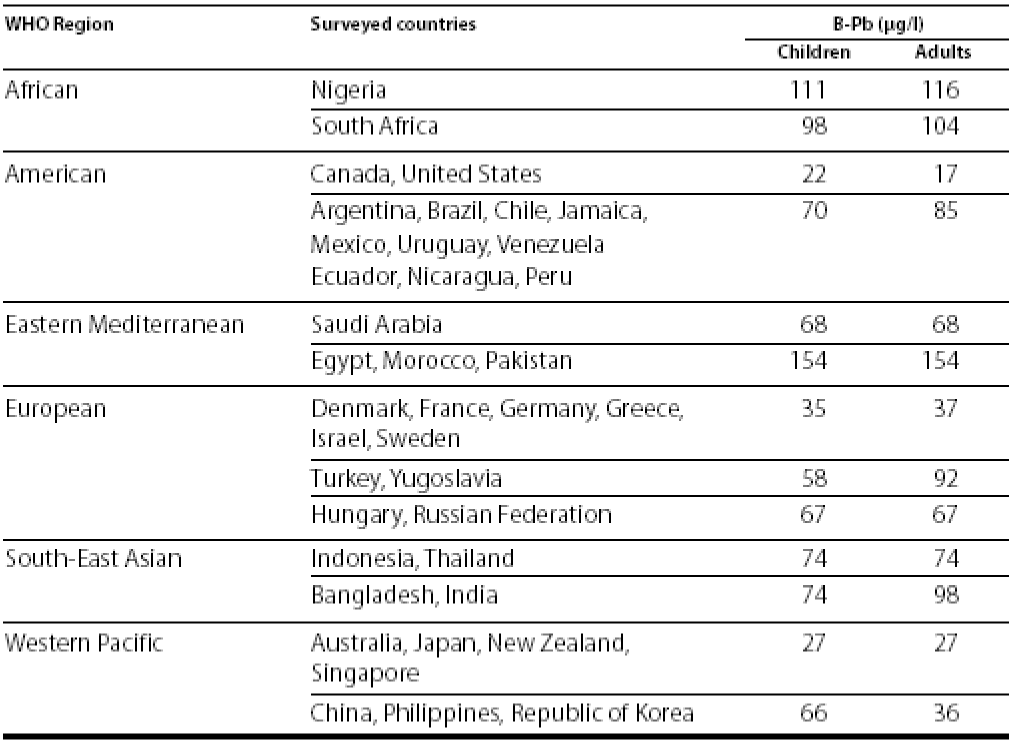
221. The lead body burden of the general population in the 1990s was estimated to be three orders of magnitude higher than that of prehistoric humans (Patterson *et al.*, 1991). Historically, lead emissions peaked during the 1970s, with annual emissions estimated at 400 000 t/a (Nriagu, 1996).

222. There has been a significant, and well-documented, decrease in B-Pb in the developed world during recent decades. For example, the mean B-Pb in a sample of adults living in the United States dropped 78 percent (from 128 µg/l to 28 µg/l) between 1976 and 1991, and a similar decline was seen among children (Pirkle *et al.*, 1994). By 1999–2002, the overall percentage of B-Pb levels exceeding 100 µg/l was down to 0.7 percent. In the 1970s, as many as 80 percent of children in the United States had B-Pb levels greater than 100 µg/l. Between 1999 and 2002, 1.6 percent of children aged 1–5 years had B-Pb levels exceeding 100 µg/l – the highest percentage of any age group (CDC, 2003, 2005a,b; USEPA, 2005).

223. In Turin, Italy, the mean B-Pb in adults dropped by 58 percent (from 153 µg/l to 64 µg/l) between 1985/1986 and 1993/1994 (Bono *et al.*, 1995), and in Swedish children a dramatic decline was observed between 1978 and 2005 (Strömberg *et al.*, 2003; Fig. 3.17). In German adults, the geometric mean B-Pb levels decreased from 62 µg/l in 1985/1986, to 46 µg/l in 1990/1992, and to 31 µg/l in 1998 (Becker *et al.*, 2002). For German schoolchildren (n = 3964) in the period 1979–2000, the geometric mean B-Pb levels decreased from 190 µg/l to 31 µg/l in an industrialized area and from 120 µg/l to 21 µg/l in a rural area (Wilhelm *et al.*, 2005b, 2006). Erythrocyte samples from adults indicated that there was decrease in Swedes throughout the 1990s (about a 4 percent annual decrease; Wennberg *et al.*, 2006). In all these cases, the decrease in or removal of lead in petrol was certainly the main reason for

the declining B-Pb levels, though the removal of lead from soldered cans probably also played a role. The phasing-out of leaded petrol is not yet complete. As of 1 January 2004, leaded petrol was still being used in most African countries, parts of eastern Europe and the former USSR (though not in the Russian Federation), as well as a number of other countries, i.e. Cuba, Indonesia, Iraq, Lebanon, Paraguay, Peru, the Syrian Arab Republic, Turkey and Uruguay (EIA, 2004). However, it was subsequently reported that several of the nations in sub-Saharan Africa are now phasing out leaded petrol (Burke, 2004).

Table 3.3. Mean B-Pb concentrations in urban children and adults in different



WHO Region	Surveyed countries	B-Pb (µg/l)	
		Children	Adults
African	Nigeria	111	116
	South Africa	98	104
American	Canada, United States	22	17
	Argentina, Brazil, Chile, Jamaica, Mexico, Uruguay, Venezuela Ecuador, Nicaragua, Peru	70	85
Eastern Mediterranean	Saudi Arabia	68	68
	Egypt, Morocco, Pakistan	154	154
European	Denmark, France, Germany, Greece, Israel, Sweden	35	37
	Turkey, Yugoslavia	58	92
	Hungary, Russian Federation	67	67
South-East Asian	Indonesia, Thailand	74	74
	Bangladesh, India	74	98
Western Pacific	Australia, Japan, New Zealand, Singapore	27	27
	China, Philippines, Republic of Korea	66	36

Source: Fewtrell et al. (2004).

224. In addition to the exposure from the general environment, many work environments imply exposure to lead. Hence, between 100 and 200 different lead-exposing occupations have been identified (cf. Skerfving, 2005).

225. In other recent studies in relation to exposure levels in various populations (Mathee and Mthembu, 2004) the following ideas has been reported: “Lead exposure is a particular environmental health concern in South Africa, and Africa in general (Tong 2000, Nriagu1996). Currently in many African countries, and until 1986 in South Africa, the lead concentration in petrol was amongst the highest in the world. Until the early 1990s, epidemiological studies conducted in the Cape Town area showed that the vast majority (more than 90 percent) of children had blood lead levels which exceeded the internationally accepted action level for lead in blood of 10 µg/dl (von Schirnding *et al.,* 2002). Similiarly, a study undertaken in Johannesburg in 1995 showed that 78 percent of the study sample had elevated blood lead levels (Mathee *et al.,* 2002). Since then, following reductions in the maximum permissible lead content of petrol, and the partial introduction of unleaded petrol, children’s blood lead levels have declined. However, large proportions of urban children continue to have unacceptably high blood lead concentrations, associated in general with leaded petrol, lead-based paint in homes and schools, the use of lead solder in cottage industries, and para-occupational lead exposure, when workers transfer lead particles from their workplaces into their homes on their hair, skin and clothing (Mathee unpublished data). For example a 2002 study of blood lead concentrations amongst first grade school children in Johannesburg showed that around one-third of the sample had elevated blood lead concentrations.”

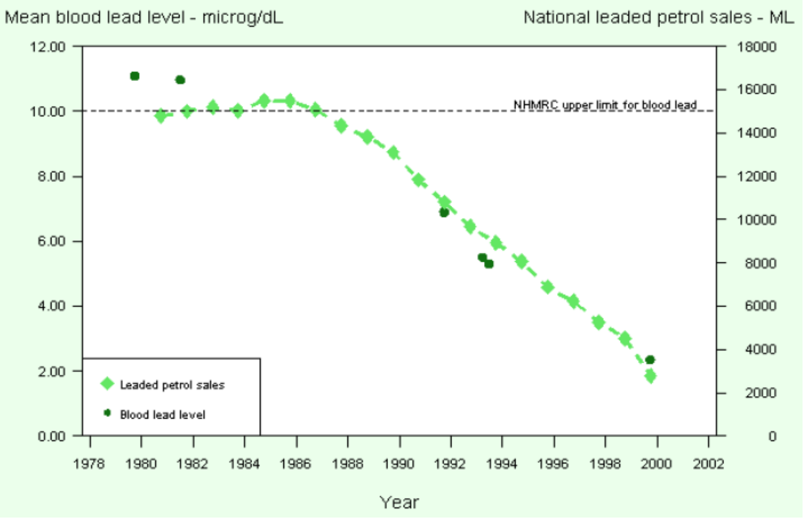


Figure 3-1 Blood lead levels in children and leaded petrol sales in Australia 1979 to 1999 (Australia's submission)

3.2 Health effects in humans

226. Exposure to lead can result in a wide range of biological effects, depending on its level, duration and timing. Lead is toxic to multiple organ systems, and effects may range from enzyme inhibition and anaemia to disorders of the nervous, immune and reproductive systems, impaired kidney and cardiovascular functions, and even death. Effects occur over a broad range of doses (IPCS, 1995). Because of their rapid growth and maturation, biological characteristics and behaviour, children are more vulnerable than adults to the effects of lead exposure.

227. Lead is a well known neurotoxicant. Impaired neurodevelopment in children is one of its most critical effects, and may result from exposure *in utero* and during early childhood. Lead accumulates in the skeleton, and its mobilization from bones during pregnancy and lactation causes exposure to fetuses and breastfed infants. Hence, the lifetime exposure of woman before pregnancy is important (WHO/UNECE, 2007). Lead exposure in children is linked to a lower intelligence quotient (IQ), behavioural effects and learning disabilities. Epidemiological studies have consistently shown that effects in children are associated with lead levels in blood of 10–15 µg/dl. However, recent reports indicate that lead is harmful even at blood lead concentrations below 10 µg/dl and that there may be no threshold (Canfield *et al.*, 2003). For example, some available data suggest that there may be Pb effects (e.g., IQ deficits) associated with blood lead levels less than 5 µg/dL, but the evidence is less definitive at these lower exposure levels (U.S. EPA, 2006). Extremely high blood lead levels in children (above 70 µg/dl) can cause severe neurological effects, leading to lethargy, convulsions, coma and death. Lead may also affect the nervous system in adults. Long-term exposure to lead at work has been found to decrease performance in some tests of nervous system function, and to cause weakness in fingers, wrists, or ankles (lead polyneuropathy) (US ATSDR, 2005). Measures to reduce the dispersal of lead in Sweden have been successful. They have resulted in reduced blood levels of lead over the last 20 years. The mean value of lead in the blood of Swedish men at present is approximately 0.2 µmol/l [6]. The mean value is lower in women, adolescents and children. The average level of lead in the blood of children in areas without activities that result in major emissions is approximately 0.1 µmol/l. The lowest lead level in blood that has shown effects on health in the general population is 0.3 µmol/l. At this level, and just above it, effects are observed on the metabolism, kidneys and cardiovascular system. These effects are

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[6] To convert from a conventional unit i.e. µg/dL to a SI Unit (International System of Units) i.e. µmol/L, multiply by the conversion factor of lead of 0.0483

based on data from a large number of epidemiological studies. They are mild effects and do not constitute a serious risk to the health of the individual (Sweden's submission, 2007).

228. The signs and symptoms of lead toxicity are variable in both adults and children, and may involve the gastrointestinal system (vomiting, colic, constipation), the blood (anaemia), or the neurological system (irritability, convulsions). Chronically exposed individuals may have a blue line on the gum margins and anaemia. Children often appear asymptomatic even with elevated blood lead concentrations (U.S. CDC, 2002).

229. **Effects on the nervous system –** Children are at particular risk of nervous system effects, resulting in reduced IQ, poor school performance, low impulse control and attention deficits (Schwartz, 1994; Winneke and Krämer, 1997). In studies on children, delayed development, lower IQ and behavioural disorders have been observed at blood lead levels of around 0.5 µmol/l. The neuropsychological effects on children are severe, and lead levels in the blood of children and women of childbearing age should therefore be lower than 0.5 µmol lead per litre of blood. However, there are indications that these effects do not have a threshold, which means that it is not possible to establish a "safe" level of lead in the blood of children and foetuses. Severe adverse health effects on a large number of organs begin to appear in adults at a lead level in blood of around 1.5 µmol/l (Sweden's submission, 2007).

230. Chronically exposed children can develop neurological and cognitive sequelae, including reduced cognition and behaviour scores, changes in attention, visual-motor and reasoning skills, social behaviour and reading ability (WHO, 2006). Adults with neurological sequelae usually have peripheral neuropathy, characterized by wrist drop due to radial paralysis (Perlstein and Attala, 1966). Peripheral sensory nerve impairment in adults have been reported for blood levels of about 30 µg/dL. Lead encephalopathy, which is rare and affects especially children, can occur at higher exposure levels (such as 70–100 µg/dL) (U.S. ATSDR, 2007) and manifests as vertigo, ataxia, headache, insomnia, restlessness, confusion, tonic–clonic convulsions and coma leading to death (due to severe cerebral oedema and raised intracranial pressure). For adults, encephalopathy occurs at somewhat higher exposure levels (such as 100-120 µg/dL) (US ATSDR, 2007).Before metal-binding agents became available, the mortality rate from lead encephalopathy in children was 65 percent (Chisolm and Barltrop, 1979). Mortality and the incidence of sequelae are greatest in those who present with severe symptoms. Re-exposure and continued exposure increase morbidity and mortality. In children who survive lead encephalopathy, 82 percent have sequelae, including cognitive and neurological deficits, seizure disorders, blindness and hemiparesis (Perlstein and Attala, 1966; Chisolm and Baltrop, 1979; Al Khayat *et al.*, 1997). Behavioural, cognitive and neurological deficits appear to persist into adulthood.

231. The doubling of blood lead level from 10 to 20 µg/dl has been associated with an average loss of 1–3 points of IQ (Winneke and Kramer, 1997; Pocock *et al.*, 1994).In the Port Pirie Study, children from urban and rural communities surrounding a smelter were followed from birth to the age of 11 or 13 years. However, other studies have found a somewhat different dose-response relationship. For example, a large international pooled analysis of 1,333 children from seven different cohorts by Lanphear *et al.* (2005) estimated a decline of 6.2 points (95 percent CI: 3.8, 8.6) in full scale IQ for an increase in concurrent blood-Pb level from 1 to 10 µg/dL (as cited in U.S. EPA, 2006). An inverse relationship between blood lead levels and IQ was described by Lanphear *et al.* (2000) and by Canfield *et al.* (2003), who followed a group of children from birth to the age of 5 years and found that blood lead levels were inversely associated with children's IQ scores at 3 and 5 years of age, and associated declines in IQ were greater at these concentrations than at higher ones. These authors reported that the cognitive deficit occurred at blood lead levels below 10 µg/dL. A number of other studies provide evidence of IQ loss due to lead exposures (U.S. EPA, 2006).Therefore, the relationship between IQ and lead exposure is very strong, even at low levels. A small deficit in IQ may have large effects in a population at the lower end of the IQ distribution, thus potentially posing a substantial public health risk, as postulated by T. Schettler (GBPSR, 2000) (see Figure 3-2**).** Prospective studies support the hypothesis that changes resulting from lead exposure are irreversible, or at least long-lasting up to adulthood (Needleman, 1991; Bellinger *et al.*, 1992; Shen, 2001; Rogan *et al.*, 2001). In addition to reducing IQ, widespread exposure to lead is likely to have profound implications for a wide array of undesirable social behaviours (Nee-

dleman *et al.*, 1996). Social and emotional dysfunction and academic performance deficits have been correlated with lead exposure (Bellinger *et al.*, 1994). Evidence from prospective longitudinal studies suggests that neurobehavioural effects, such as impaired academic performance and deficits in motor skills, may persist even after blood lead levels have returned to normal (Needleman *et al.*, 1990).

232. Experimental studies have shown that stress can significantly alter the effects of Pb, effects that could potentially be mediated through alterations in the interactions of glucocorticoids with the meso-corticolimbic dopamine system of the brain. Elevated stress, with corresponding elevated glucocorticoid levels, has been postulated to contribute to the increased levels of many diseases and dysfunctions in low socioeconomic status populations (White *et al.,* 2007)

233. Extensive experimental evidence from the laboratory of Cory-Sletcha (2008), have demonstrated that stress can modify Pb effects, that Pb can modify stress responsivity, and, notably, that Pb + stress effects can occur in the absence of an effect of either alone in rats. Furthermore, maternal only Pb exposure can permanently alter basal corticosterone levels, stress responsivity (i.e. permanent modification of HPA axis function) and brain catecholamines in offspring of both genders. Interactive effects of Pb + stress are not limited to early development: even Pb exposures initiated post-weaning alter basal corticosterone and stress responsivity. Outcomes differ in relation to gender, brain region, stressor and time of measurement, making Pb + stress interactions complex.

234. **Anaemia –** The effects of lead on the haematopoietic system result in decreased haemoglobin synthesis and anaemia. Anaemia is caused via several mechanisms, including reduced erythrocyte survival, thought to be due to increased membrane fragility (Hasan *et al.*, 1967) and decreased haemoglobin synthesis (US ATSDR, 2005). Lead affects haem synthesis in several ways (US ATSDR, 2005). It also increases coproporphyrin concentrations in the blood and disrupts mitochondrial enzymes that control the insertion of iron into protoporphyrin to form the haem component of haemoglobin and other haem-containing enzymes, such as cytochrome C (Goyer, 2001). Basophilic stippling may occur as a result of the aggregation of undegraded or partially degraded ribosomes as the breakdown of ribonucleic acid (RNA) is reduced (Goldberg, 1972; Valentine *et al.*, 1976).

235. **Renal effects –** Renal effects of lead have been described in exposed individuals, and even among the general population when sensitive indicators of function are measured. Lead is known to cause proximal renal tubular damage, characterized by aminoaciduria, alteration in the elimination of phosphates, and glycosuria The proximal tubular epithelial cells are altered (nuclear inclusion bodies, mitochondrial changes and cytomegaly), even after relatively short-term exposures; changes are generally reversible. However, chronic exposure to high lead levels may result in non-reversible sclerotic changes and interstitial fibrosis, which leads to decreased kidney function and possible renal failure. Increased risk of nephropathy has been noted in workers with a blood lead level of over 3.0 µmol/litre (about 60 µg/dl) (IPCS, 1995).

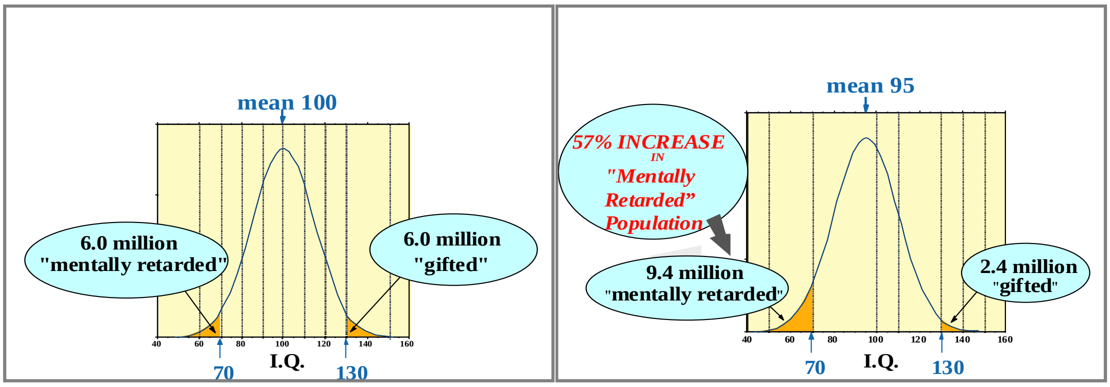


Figure 3-2 Original figure from Schettler et al.(2000) - adapted from B. Weiss (1997).

236. **Cardiovascular effects** – The effect of lead on the heart is indirect and occurs mainly through the autonomic nervous system. The effects of high concentrations of lead on blood pressure have been clearly demonstrated in occupational settings (Hu *et al.*, 1996, Glenn *et al.*, 2003) and animal studies, but effects in the general population are less evident. It has been suggested that lead-induced hypertension and essential hypertension may have a common mechanism (Batuman, 1993). The association between blood lead level and blood pressure is clearest for systolic blood pressure in adult males. A decrease in blood lead from 10 to 5 µg/dl has been associated with a decrease of 1.25 mmHg in systolic blood pressure (Schwartz, 1995**.** This link was also demonstrated in other studies (Pirkle *et al.*, 1985). In women the association is weaker. However, women with blood lead levels from 4.0-31.1 µg/dl had increased risk of diastolic hypertension and a moderately increased risk for general hypertension (Nash *et al.*, 2003). A study on the effects of lead levels in blood and bone in normotensive pregnant women between 1995 and 2001 showed that each 10 µg/g increase in calcaneus bone lead was associated with a 0.7 mmHg increase in the systolic pressure and a 0.54 mmHg increase in diastolic pressure in the third semester (Rothenberg *et al.*, 2002).

237. **Gastrointestinal effects –** Some of the early signs of lead poisoning can be non-specific and are usually gastrointestinal. Symptoms include abdominal pain, constipation, nausea, vomiting, anorexia and weight loss. Lead-induced colic may result from effects on the visceral autonomic nervous system, causing changes in smooth muscle tone, alterations in sodium transport in the mucosa of the small intestine, or lead-induced interstitial pancreatitis (Janin *et al.*, 1985).

238. **Effects on reproduction –** High blood lead levels (>40 µg/dl or >25 µg/dl for a period of years) in men appear to reduce fertility and to increase the risks for offspring of spontaneous abortion, reduced fetal growth and preterm delivery. Maternal blood lead levels of approximately 10 µg/dl have been linked to increased risks of hypertension in pregnancy, spontaneous abortion, and impaired neurobehavioral development in the offspring. Higher maternal lead levels have been linked to reduced fetal growth; there is still uncertainty regarding links to malformations and the dose–response relationship (Bellinger, 2005). Environmental lead exposure has been associated with male reproductive impairment **(**Naha and Chowdhury, 2006). Impotence and decreased libido have occasionally been reported in lead-poisoned patients (Cullen *et al.*, 1984). One study has suggested that lead not only affects the sperm count, but also damages the sperm structure and membrane integrity, motility and functional activity (Naha and Chowdhury, 2006). Other studies report reduced sperm counts, concentration and quality, including adverse effects on sperm chromatin and increased abnormalities in males exposed to lead (Cullen *et al.*, 1984; Alexander *et al.*, 1998; Bonde *et al.*, 2002). These effects occur in the absence of changes in hormone concentrations (Telišman *et al.*, 2000) and appear to be unlikely to occur in individuals with blood lead concentrations below 40–50 µg/dl (Bonde *et al.*, 2002; US ATSDR, 2005; Bonde and Apostoli, 2005). Various adverse, slight effects are presented in the following table. It is the reader's discretion to judge whether these effects are adverse or not, the conclusion of the study's author was that they were adverse (although slight), which has been accurately reflected in this text.

Table 3-4 Overall summary of information on at which lowest blood concentrations (average in studied populations; µmol/l) various adverse, slight effects of lead have been reported with some consistency. ? = Limited data, inconsistent results and/or possible/probable confounding. - = Not relevant or not sufficiently studied. (original table courtesy of Skerfvinging, 2005)

		Population		
			General	
Organ	Effect	Occupational	Adults	Children
Nervous system				
Central	Encephalopathia[1]	>4.0	>4.0	>4.0
	Slight symptoms	1.5-2.0	-	-
	Neurobehavioural	1.5-2.0	-	<0.5[2]
Peripheral	Symptoms	1.5	-	-
	Neurophysiological	1.5	-	-
Complex effects	Evoked potentials	1.5	-	-
	Posture	1.5	-	-
	Hearing	-	-	0.5
Autonomous	Heart rate variability	1.5	-	-
Blood	Anemia[1]	>3.0	>3.0	>3.0
	Hemoglobin concentration	2.0-2.5	-	-
	Heme metabolism	0.1-0.3	-	-
	Nucleotide metabolism	≈0.3	-	-
Kidneys	Tubular	1.5	-	0.5?
	Glomerular	2.0?	0.5?	0.5?
Cardiovascular	Blood pressure	1.5-2.0?	0.4	1.8?
	Heart rate variability	1.5	-	-
Endocrine system[3]	Hypothalamus/pituitary/ thyroid/adrenal axes	1.5-2.0	-	-
Immune system	Immunosuppression	2.0	-	-
Mutagenicity	Chromosome aberrations, Micronuclei, SCEs	1.5-2.0	-	-
Cancer	Kidney, lung[4]	?	-	-
Reproduction				
Female	Abortion	?[5]	0.5?	-
	Fetal growth	-	0.1?	-
	Neurobehavioural	-	-	<0.5[2]
Male	Endocrine function	1.5	-	-
	Sperm quality	2.0	-	-
	Fertility	2.0?	-	-
Gastro-intestinal tract[1]	Obstipation, abdominal pain	>3.0	>3.0	>3.0

[1] See Skerfving 1992 and 1993.

[2] Uncertainty whether effects are mainly due to exposure in utero or after birth.

[3] Except for reproduction.

[4] Uncertain.

[5] Levels not clear, probably high.

239. Time-to-pregnancy studies in the partners of lead-exposed men have produced inconsistent results. Some have suggested that lead exposure is associated with reduced fertility (Sallmén *et al.*, 2000, 2000b; Shiau *et al.*, 2004); others have found no effect (Joffe *et al.*, 2003); while still others have produced inconclusive results (Apostoli *et al.*, 2000). Using fertility ratios, some studies have found that workers exposed to lead had a lower than expected number of births (Gennart *et al.*, 1992b). However, Coste *et al.* (1991) found no such association. Lead exposure has been linked to delayed sexual maturity in girls (Selevan *et al.*, 2003).

240. **Cancer** - There is no proof that lead causes cancer in humans. However, a number of studies have suggested an association between lead exposure and lung cancer (Fu and Boffetta, 1995; Steenland and Boffetta, 2000; Lustberg and Silbergeld, 2002; RoC, 2003) and, to a lesser extent, stomach cancer (U.S. DHHS, 2003). Lead is hypothesized to be a co-carcinogen, allowing or augmenting the genotoxic effects of other agents (Silbergeld *et al.*, 2000; Silbergeld, 2003). Kidney tumours have developed in rats and mice given large doses of some lead compounds (US ATSDR, 2005), and several animal studies have shown that lead increases the tumour yield or genotoxicity of known carcinogens (Kobayashi and Okamoto, 1974; Hiasa *et al.*, 1983; 1984; Tanner and Lipsky, 1984). The Department of Health and Human Services in the USA has determined that lead and lead compounds are “reasonably anticipated” to be human carcinogens, based on limited evidence from studies in humans and sufficient evidence from animal studies. The US Environmental Protection Agency has determined that lead is a probable human carcinogen (US EPA, 1993).

3.3 Reference levels

241. **Provisional tolerable weekly intake** – The joint FAO/WHO Expert Committee on Food Additives has established a provisional tolerable weekly intake (PTWI) of 25 µg/kg of body weight (equivalent to 3.5 µg/kg of body weight per day). The Committee considered the results of a quantitative risk assessment and concluded that the concentrations of lead currently found in food would have negligible effects on the neurobehavioural development of infants and children. The Committee noted, however, that some foods with high levels of lead remain commercially available (WHO, 2000b).

242. **Drinking-water guideline** – A drinking-water guideline value for lead of 0.01 mg/l (10 µg/l) has been established by WHO (WHO, 2004). Concentrations in drinking-water are generally below 5 µg/l, although much higher concentrations (above 100 µg/l) have been found where lead fittings are present (WHO, 2004). The EPA regulations for drinking water (also known as the Maximum Contaminant Level [or MCL]) limits lead in drinking water to 0.015 milligrams per liter (mg/L), although the EPA also has established a MCL Goal (or MCLG) goal for lead of zero, which is a goal for is that drinking water to contain no be free of lead (U.S. EPA, 2008b; Office of Water, MCL regulations, available at: http://www.epa.gov/safewater/contaminants/index.html; and U.S. ATSDR, 2007).

243. **Lead in air** - the WHO Air Quality Guidelines (WHO, 2000a) established guideline values for lead as a time-weighted average of 0.5 µg/m^3 (annual averaging time). Also, an ambient standard as established by the European Commission in 1999, known as the "1st Daughter Directive (1999/30/EC)", which apparently covers all EU countries, is 0.5 ug/m3 (based on an annual average). In 1978 the U.S. EPA established the National Ambient Air Quality Standard (NAAQS) for lead which requires that the concentration of lead in air that the public breathes be no higher than 1.5 micrograms per cubic meter (µg/m^3) averaged over 3 months. However, this lead NAAQS is currently under review by the U.S. EPA. The review includes an assessment of the current health effects evidence that was published in the Air Quality Criteria Document for Lead (U.S. EPA, 2006) and a risk assessment for several case studies, including the one primary lead smelter currently operating in the U.S. (U.S. EPA, 2007b). The review of the NAAQS is proceeding on a court-ordered schedule, with the notice of final rulemaking concerning any revisions to the NAAQS required to be signed by September 15, 2008. In addition, the Clean Air Act Amendments (CAAA) of 1990 banned the sale of leaded gasoline as of December 31, 1995 (ATSDR, 20057) and requires EPA to regulate lead compounds as a hazardous air pollutants under Section 112 of the Act for various industries through application of maximum achievable control technologies.

244. **Codex Alimentarius maximum levels** - Table 3-5 summarizes the Codex Alimentarius maximum levels for lead.

Table 3-5 Codex Alimentarius maximum levels for lead (Codex Alimentarius, 2001)

Code No.		Food	Maximum level (mg/kg)	Remarks
FC1	FP9	Fruit	0.1	
FS12	FB18			
FT26	FI30	Small fruit, berries and grapes	0.2	
JF175		Fruit juices, including fruit nectars	0.05	Ready to drink
VA35	VO50	Vegetables	0.1	Including peeled potatoes
VC45	VR75	except brassica (VB), leafy vegetables (VL), mushrooms, hops and herbs		
VB40		Brassica	0.3	
		except kale (480)		
VL53		Leafy vegetables (except spinach)		
C81		Cereal grains	0.2	
VD70		Pulses		
VP60		Legume vegetables		
MM97		Meat of cattle, sheep and pig	0.1	
PM100		Poultry meat		
MF97		Fat from meat	0.1	
PF111		Fat from poultry		
OC172		Vegetable oils (except cocoa butter)		
OR 172				
MO97		Edible offal of cattle, pig and poultry	0.5	
ML107		Milk1)	0.02	Also secondary (82) milk products (as consumed)
FF269		Wine	0.2	
LM (unspecified)		Infant formulae	0.02	Ready to use

1) A concentration factor applies for partially or wholly dehydrated milk

3.4 Costs related to human health

245. Exposure to lead may have negative health effects and associated costs for society. Children may be exposed to lead from many different sources, including petrol, paint, contaminated soil and workplaces. Children with a high body burden of lead may have lower IQ scores and poorer school performance than other children of the same age: they tend to be less attentive, hyperactive, disorganized, and less able to follow directions, show increased aggression and may be prone to delinquent behaviour. For a country, this results in a loss of intellectual capacity.

246. According to a recent WHO study, the burden of disease caused by widespread exposure to relatively low levels of lead is often underestimated by policy-makers (Fewtrell *et al.*, 2003). For example, reduced IQ is not considered a disease per se, yet it reflects subtle neurological impairment that will

have most effect on the social and psychological development of children who already have a low IQ score. Subtle effects on IQ are expected with blood lead levels as low as 5 µg/dl, and the effects gradually increase with increasing levels of lead in the blood. The results of some recent studies suggest that there may be no threshold for the effects of lead on intellectual function (US ATSDR, 2005)

247. The effects of lost IQ points will be greater in children with a low IQ score (below 70) than in children with a higher IQ. At higher levels, lead exposure also leads to gastrointestinal symptoms and anaemia (about 20 percent of children are affected when blood lead levels exceed 60–70 µg/dl) (Fewtrell *et al.*, 2003).

248. According to the WHO study, the greatest improvements in estimating the disease burden caused by lead will come from better characterization of the exposure–response relationships for health effects. To reduce the disease burden caused by exposure to lead, it is important to determine the groups at highest risk and the main pathways of exposure. Assessment of exposure could be refined by assessing various subgroups and, if necessary, collecting parallel measurements of lead levels in the environment (Fewtrell *et al.*, 2003).

249. U.S. EPA has undertaken several regulatory actions that consider lead (proposed NAAQS, renovation and repair rule) and have considered monetized IQ effects. The economic losses attributed to lead exposure in the USA have been estimated by Landrigan *et al,*.2002. The mean blood level in the studied birth cohort of 5-year-old children was reported in 1997 to be 2.7 µg/dl. Each microgram per deciliter of blood lead concentration was considered to be associated with a reduction in IQ of 0.25 points at these levels of lead exposure. Assuming a loss of 1.61% of earnings potential for an IQ deficit of 0.675 points and an annual growth in productivity of 1 percent, and applying a 3 percent discount rate and a value of lifetime expected earnings of US$ 881 027, the economic losses attributable to lead exposure in the study group were estimated to amount to US$ 43.4 billion per year (Landrigan *et al.*, 2002).

4 Impacts on the environment

4.1 Environmental behaviour and toxicology

250. In the aquatic environment, lead can occur in ionic form (highly mobile and bio-available), in organic complexes with dissolved humus materials (binding is rather strong and limits availability), attached to colloidal particles such as iron oxide (strongly bound and less mobile when available in this form than as free ions), or attached to solid particles of clay or dead remains of organisms (very limited mobility and availability) (OECD, 1993).

251. In soil, lead is retained in organic complexes or adsorbed to hydrous oxides near the soil surface. The mobility of lead in the soil depends on the soil's pH and organic content. In general, the sorption and relative immobility of lead in soil decreases its bioavailability to humans and other terrestrial life (OECD, 1993).

252. Over time, elemental (metallic) lead in the environment can be dissolved – probably, e.g., as lead oxides - and therefore become available, but the extent and rate at which this transformation occurs are not known in detail (Hansen *et al.*, 2004a).

253. Many metals are converted to organic forms by microorganisms in soil. The transformation of inorganic lead to tetramethyllead (TML) has been observed in aquatic systems, particularly in sediments. In the Environmental Health Criteria (IPCS, 1995) it was reported that it was still unclear whether the TML formed is produced abiotically or by biotransformation.

254. Organo-lead compounds, such as trialkyl-lead and tetraalkyl-lead compounds, are more toxic than inorganic forms of lead. Organo-lead compounds may bioaccumulate in plants and animals, though biomagnification of organo-lead compounds has not been found to occur (U.S. ATSDR, 2005).

255. Lead is known to bioaccumulate in organisms, in particular in biota feeding primarily on particulate matter, but biomagnification of inorganic lead in the aquatic food chain is not apparent, as the levels of lead, as well as the bioaccumulation factors, decrease as the trophic level rises. This is partly explained by the fact that in vertebrates, lead is mainly stored in bone, which reduces the risk of lead transmission to other organisms in the food chain (Tukker *et al.*, 2001).

256. 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. This might be related to the calcium metabolism (IPCS, 1995). The lead uptake by fish reaches equilibrium only after a number of weeks of exposure. Lead is accumulated mostly in gill, liver, kidney, and bone (IPCS, 1989).

257. Lead is not an essential element, and many studies have shown adverse sub-lethal effects of this metal such as modification of the function and structure of kidney, bone, the central nervous system, and the production and development of blood cells (U.S. EPA, 1994).

258. The phenomenon of hormesis, i.e. that exposure to a substance induces stimulation at low concentrations and inhibition at higher concentrations, has also been demonstrated for lead. Hormetic-type responses in the environment include organism groups such as bacteria, sea algae and polychaete worms (Calabrese and Baldwin, 2003).

4.2 Environmental exposure

259. In general, lead decreases in concentration from rainwater (generally acidic (pH<5.5); about 20 µg/L) to fresh water (generally neutral (pH=7); about 5 µg/L) to seawater (alkaline (pH>8.2); below 1 µg/L). In the course of this decreasing concentration gradient, lead is removed to bottom sediments. Concentrations of lead in rivers are mainly dependent upon local source inputs, as residence times in the water column are short. In areas of lead mineralization, rivers can contain lead concentrations as much as ten times higher than in un-mineralised areas where levels are normally well below10 µg/L (OSPAR, 2004).

260. Infiltration of rainwater into groundwater and entry into surface waters normally involve passage through soil. As lead binds to soil minerals and humus, groundwater normally contains very low concentrations of lead, typically below 10 µg/L (OECD, 1993).

261. In Japan, the Ministry of Environment has reported monitoring data on the environmental quality of soil and groundwater (Japan's submission, 2005). It was reported that exceeding the environmental quality standard (EQS) for lead in groundwater (0.01 mg/L) was rare; only 0.2-0.6 percent of all samples from the period 1999-2003 exceeded this value. The maximum value reported was 0.16 mg/L.

262. In a study from the United Kingdom, values for "uncontaminated" rural soils were reported to be in the range of 15-106 mg/kg, with a geometric mean of 42 mg/kg (Davies, 1983), while in a survey comprising 2,780 soil samples, a geometric mean of 48 mg/kg was found (McGrath, 1986). Data for over 3,000 surface soils from cropland in the U.S.A. gave a median concentration of lead of 11 mg/kg and a mean of 18 mg/kg (Holmgren *et. al*, 1983). Probably the higher values found in the United Kingdom are due to contamination accumulated over centuries of industrial and metallurgical activity (OECD, 1993).

263. Lead concentrations in soil are typically significantly elevated near point sources (e.g. smelters), and in urban areas as compared with rural areas, including agricultural land. In the U.S.A., soil lead levels of between 200 and 3,300 mg/kg were recorded in a study of city parks (US EPA, 1989). A survey in the United Kingdom of lead in urban garden soils from 53 representative towns and city boroughs also showed elevated concentrations of lead in surface garden soils, compared with agricultural soils. Lead concentrations ranged from 13 mg/kg to 14,100 mg/kg (geometric mean 230 mg/kg) in locations excluding London, and in areas affected by mining and smelting. In seven London boroughs, the mean value was 654 mg/kg (Culbard *et al*., 1988).

264. Typical concentrations in soil in the Netherlands range from 10-30 mg/kg dry weight (dw) in relatively clean areas to a few dozen mg/kg dw. According to Tukker *et al.* (2001), concentrations in urban soil in Denmark range between 30 and 500 mg/kg.

265. Near Alaverdi, Armenia, the site of a mining metallurgical combine, at a distance of up to 2 km from the combine, lead levels in soil exceeded 20-40 times the maximum allowable concentration of 20.0 mg/kg soil and exceeded 10-15 times at distances of 3-5 km. Lead levels in soils at the site of the combine have been reported to exceed the norms by 81-109 times (Unanyan, 1987). In soils from the vicinity of the Hrazdan (Armenia) cement plant and State distribution electric station, lead levels in soil were 23-71.6 mg/kg dry weight and 44.7 mg/kg dry weight at 3 km distance. Similarly in soil neara the Ararat cement plant lead levels were 24-28 mg/kg dry weight and 16-20 mg/kg at 2-5 km (Armenia’s submission, 2007).

266. Lead content in air in Yerevan, Armenia is at 1.2 to 1.3 times the maximum allowable concentration of 0.003 mg/m^3 while at busy highways it reaches 16-19 times the maximum allowable concentration. At Kirovakan city the concentration exceeds 15-20 times and in Alaverdi it exceeds 10 times (Armenia’s submission, 2007).

267. In a case study undertaken on blood lead levels in children and adolescents in selected areas of Nairobi and Olkalou, Nyandarua district in Kenya lead levels in soil were also analyzed. In the Nairobi Central Business District levels ranged from 265.918 mg/kg in soil, 5.054 mg/kg in kale, 1.948 mg/kg

in maize and 0.046 mg/kg in milk. Corresponding values for the Thika Central Business District were 133.79 mg/kg, 2.243 mg/kg, 1.352 mg/kg and 0.044 mg/kg (Kimani, 2005).

268. In Poland, monitoring of gaseous and particulate air emissions and of waste water discharges is managed by the Chief Inspectorate for Environmental Protection under the National Environmental Monitoring Scheme. For waste water discharges the relevant data is provided by the business entities in relation to the charges they are obliged to incur for use of the environment. Moreover, data sets on lead emissions are prepared by the National Administrator of the Emission Allowance Trading Scheme and forwarded to the European Commission for reporting purposes. Data are currently only available on lead concentrations in PM10 particulate matter in atmospheric precipitation and in surface waters (Poland's submission, 2007).

269. In Hungary, a Soil Information and Monitoring System (IMS) was jointly established by the Ministries responsible for agriculture and for the environment in 1992. Sampling points of IMS cover the entire territory of Hungary without limitation as regards land use, property rights and other considerations. The monitoring system comprises 1236 sites. Samples taken in 1992 were analysed, among others, for lead concentration. Based on the results Hungary is characterised by the following lead concentration depending on the type of soil: Sand – 9mg/kg, lean silty clay – 16 mg/kg and clay 26mg/kg (Hungary's submission, 2007).

270. In Hungary, after phasing out of lead in petrol, the concentration of lead in air has not been regularly measured. Sampling and measurement campaigns have however been conducted from time to time. The last campaign was performed in 2005 by the network of environment authority. Samples taken in many different towns were analysed for As, Ni, Cd, Pb and benzo(a)pyrene in the PM10 fractonfraction of dust. The results are shown briefly in figure 4-1 (Hungary's submission, 2007).

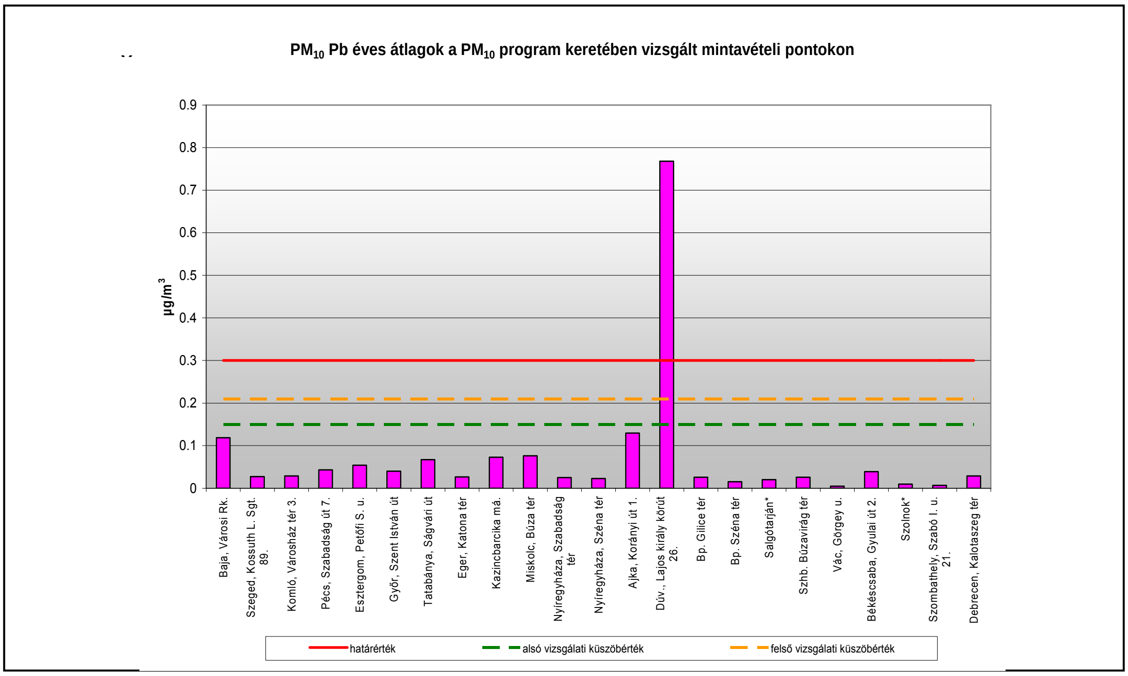


Figure 4-1 Yearly average concentration of Pb in PM10 from sampling points of PM10 campaign

271. In Madagascar, a study on air pollution was carried out (in 1996) covering some localities with high traffic densities. As seen in Table 4, Pb concentrations, determined in particulate matters of different sizes (PM 2.5 to PM 10), varied between 10 and 1791 µg/m^3 (Madagascar's submission, 2010).

272. In another study carried out in winter 2006 in Lahore, Pakistan, airborne PM$_{2.5}$ particulate matters were found to contain an average 953.3 ng/m^3 of Pb with a range of 11.7 to 6948 ng/m^3 (Pakistan's submission, 2010).

Table 4: Air pollution, Pb levels in particulate matter in Madagascar, 1996 (Madagascar' submission, 2009)

Location	Pb concentration in particulate matter: µg/m^3		
	PM 2.5	PM 2.5 - 10	PM 10
Avaradoha	350	15	365
Soarano	1268	523	1791
Ampasamadinika	1035	38	1073
Ambohidahy	537	10	547
Route Digue	142	10	152

273. In the Netherlands, lead concentrations in water tend to be not much higher than a few µg per litre at the most. In the rivers Rhine and Meuse, concentrations have declined from some 20-30 µg/L in the mid-1970s to below 10 µg/L in the mid-1980s, which is below the Dutch Maximum Tolerable Risk Level (MTR) of 11 µg/L (Tukker *et al.*, 2001).

274. In 2001, shot used for hunting or other outdoor shooting was determined to be the largest remaining source in Norway of lead to the environment, constituting 72 percent of the total emissions from land-based sources. Sampling of rainwater runoff at shooting ranges showed lead concentrations at 10-150 µg/L (surface waters with more than 5 µg/L are regarded as "strongly polluted" in Norway) (SFT, 2001).

275. In the Table 4-1, Japanese monitoring data from 1997 and later (Japan's submission, 2005) for lead residues in some aquatic organisms are reported. The levels are generally rather low, though in some cases, birds feeding on mussels may be exposed to higher levels.

Table 4-1 Japanese monitoring data from 1997 and later (Japan's submission, 2005).

Species	**Analyzed part**	**Average concentration (ppm, dw)**	**Note**
Bluefin tuna	liver	0.0 - 2.0	Average value range in the researches in 1999-2000
Sagittated calamary	liver	0.9 - 2.6	Average value range in the researches in 1997
		0.6	Average value range in the researches in 1999
		0.1	Average value range in the research in 2000
		0.2 - 1.1	Range of average value in the research in 2001
Mussel (small size)	soft tissue	2.16 - 4.57	Range of average value in the research in 1998 - 1999
Mussel (large size)	soft tissue	0.61 - 4.13	

Species	Location & period	Sample	Part	Concentration (μg/g) mean ±SD(range)	Ref.
Northern fur seal *Callorhinus ursinus*	off Sanriku 1997 and 1998	m=3, f=20	liver	0.149 ±0.124(0.062-0.667)	Horai *et al.*, 2003
			kidney	0.072 ±0.054(0.030-0.225)	
			muscle	0.088 ±0.086(0.005-0.263)	
			hair	7.68 ±5.60(2.38-26.1)	
Dall's porpoises *Phocoenoides dalli*	off Sanriku coast March-April 1999 January-April 2000	n=45 (m=25, f=20)	skin	all: 0.036 ±0.103(0.001-0.69) m: 0.025 ±0.033(0.001-0.17) f: 0.048 ±0.152(0.006-0.69)	Sato *et al.*, 2003
	inshore area of Sea of Japan in Hokkaido May-June 1999	n=31 (m=17, f=14)	skin	all: 0.12 ±0.15(0.025-0.72) m: 0.080 ±0.039(0.025-0.15) f: 0.17 ±0.21(0.030-0.72)	

Note: n = number of samples; f = number of samples in female; m = number of samples in male

276. The monitoring data from Japan (Japan's submission, 2005) also include a few samples of tissue from Sea and Golden eagles that differ widely in lead concentrations, i.e. from about 0.1 μg/g to more than 230 μg/g in the liver, the organ where most lead is concentrated. Shot was found in the stomachs of some of the birds. Mortality is believed to occur in birds at levels from 5 μg/g and above in the liver (U.S. EPA, 1994). European marine environment concentrations of lead in the period 1995 to 1999 were below the estimated upper limit for OSPAR background in blue mussels in areas far from local or regional sources. However concentrations of the metal were above background levels along most of the European coasts. At several locations, concentrations of lead in blue mussels were above the limits for human consumption indicating several hot spot areas. Lead concentrations were generally low in livers of Atlantic cod and in herring muscle in the Baltic Sea. At nine coastal locations, increasing trends in lead concentration in mussels were observed, and in most cases these were different from the observed hot spots. A total of 266 temporal trends were analysed on a station-by-station basis, of which only 39 were significant, 30 down and 9 up (Green *et al.*, 2003 in Finland's submission, 2007).

277. Direct exposure of wildlife to lead in ambient air may be an exposure pathway, but this pathway has not been described in the Environmental Health Criteria for lead - environmental aspects (IPCS, 1995).

278. The concentration of lead in different environmental matrices and environmental quality objectives in Trinidad and Tobago is shown in Table 4-2. The data illustrates the wide ranges found in the concentration of lead in the media.

Table 4-2 Concentration of lead in environmental matrices and environmental quality objectives in Trinidad and Tobago (Trinidad and Tobago's submission, 2005)

Matrix	**Trinidad**	**Tobago**	**Environmental Quality Objectives**
Air (μg/m^3)	<0.14	-	1.5
Water (μg/L)			
- Seawater	0.5-775.6	1.0	210
- Freshwater	<2.0-1,100	-	65
- Groundwater	<0.01	<0.01	15
Soil and Sediment (μg/g)	6.6-120,000	7.6-20.1	30.2

279. Levels of lead in water in Moldova are shown in Table 4-3. Additional data on lead levels in aquatic sediments and soil were also provided in the submission from Moldova and are available on the UNEP Chemicals website. Content of Lead and its non-organic compounds (total and mobile forms) in

soil are restricted by established standards on maximum permissible concentration: 30.0 mg/kg (*total forms*) and 6.0 mg/kg (*mobile forms*).

Table 4-3 Levels of Lead in water in Moldova (Moldova's submission, 2007)

Year	**Prut river,** city Lipcani		**Prut river,** city Leova		**Prut river,** Conf. Danube - village Giurgiulesti		**Dniester river,** city Soroca,	**Dniester river,** villlage Olanesti	**Reservoir Dubasari,** city Dubasari	**Reservoir Ghidighici,** city Vatra
Pb µg/l	**Total**	**Dissolved**	**Total**	**Dissolved**	**Total**	**Dissolved**	**Dissolved**	**Dissolved**	**Dissolved**	**Dissolved**
2002	6.401	3.0	5.766	3.0	6.714	3.0				
2003	10.26	3.0	10.81	3.0	3.079	3.0				
2004	3.06	3.0	5.565	3.0	3.387	3.0				
2005	2.25	0.0	<3	3.0	1.25	0.0				
2006	0.0	0.0	0.0	0.0	0.0	0.0	<3	<3	<3	<3

Maximum permissible concentration (MPC) (dissolved) 30.0 µg/l for surface water of potable purposes;
100.0 µg/l for reservoirs of fish-breeding purpose

280. Concentrations of lead measured in different media at different sites in 2006 in Norway show annual mean ranges of 0.44 to 2.01 ng/m3 in air, 0.44 to 2.01 µg/L in precipitation and 133 to 1600 µg/m2 atmospheric deposition the lowest levels being in northern Norway; the annual range for levels in terrestrial mosses in 2005 was 0.49 to 34 µg/g and reflect deposition patterns; concentrations in sediment in 102 lakes sampled in 1995 showed a range of 6.44 to 2070 ppm dry weight (Norway's submission, 2007). The full details of the studies can be found at the website of the Norwegian Pollution Control Authority, www.sft.no.

281. Typical values of lead found in moss in Switzerland resulting from deposition of air particulates shows a downward trend from 1990 to 2000 with median values of 15.2 to 3.3 µg/g respectively. Levels in the Central Alps with low precipitation were much lower than those from Southern Switzerland with high precipitation values (Switzerland's submission, 2007).

282. In Hungary, industrial enterprises as well as municipalities are obliged to analyse the lead concentration of discharge waters. The data of their reports are maintained and made available through the National Database of Statistical Data. The information in table 4-4 for the year of 2005 is derived from that database. The lead concentration of rivers in Hungary is regularly analyzed. Based on that monitoring data the amount of dissolved lead entering and leaving the rivers are calculated. In 2005, total input to rivers was 152 tons and total output was 166 tons lead from the Duna, Tisza and Drava rivers (Hungary's submission, 2007).

Table 4-4 Discharges of lead to surface waters in 2005, kg/year

	Mining	**Processing industry**	**Total industry**	**Municipalities**		**Total**
				Direct discharge	**Discharge into sewage treatment plant**	
Total Pb	63,4	235,8	299,2	3603,0	4051,0	**7953,2**

283. In Besham, a small town 250 km north of Islamabad, Pakistan, a research study was carried out to determine lead levels in seven prominent plants and and their soils. The average concentration in the plants and the soils were 30.97 ppm and 367.81 ppm respectively (Pakistan's submission, 2010).

284. A recent case study being undertaken by UNEP UNDP in connection with heavy metals contamination in Mitrovica, Kosovo presents some of the environmental risks from abandoned minining and mineral processing operations. The case study can be consulted at:
http://www.chem.unep.ch/Pb_and_Cd/Documents/UNEP_Mitrovica_Case_Study.pdf .

4.3 Effects on organisms and ecosystems

4.3.1 Birds and terrestrial mammals

285. The environmental effect of lead contamination on waterfowl is well documented. Lead shot taken by birds into their gizzards is a source of severe exposure to lead. Also, lead sinkers used for angling have been demonstrated to be taken up 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 shot; ingestion of a single pellet of lead shot is fatal in some bird species, though the sensitivity varies between species and is dependent on diet (IPCS, 1989).

286. Lead sinkers ingested by birds become reduced in size and shape by dissolution in the acidic environment of the digestive system, as well as the physical grinding in the gizzard. Soluble toxic salts are formed that are absorbed into the circulatory system, causing toxicosis, neurological and behavioural changes, and eventual death (U.S. EPA, 1994).

287. Generally, 0.5 ppm is the level of lead in the blood of waterbirds that is considered toxic, though toxic symptoms may begin to appear at 0.2 ppm lead. The level of lead in the liver considered to be lethal to waterbirds is 5.0 ppm or more (10-14 µg/g expressed as dry weight). For some sensitive species of birds, reduced survival has been reported at lead doses of 75-150 ppm body weight, while reproduction was affected at dietary levels of 50 ppm. Sub-lethal signs of lead poisoning have been observed at doses of 7.5 ppm body weight. Mortality in waterbirds usually occurs at dose concentrations of 20-40 ppm lead in experimental studies with lethal levels ranging from doses of 5-80 ppm (U.S. EPA, 1994).

288. Poisoning of waterfowl resulting from ingestion of lead shot has been documented in at least 21 countries, e.g. Australia, Canada, France, Great Britain, Japan, the Netherlands, Spain and the U.S.A. (Beintema, 2001). Besides lead shot, waterfowl also ingest small sinkers. Because sinkers are generally much larger than shot pellets, a single lead sinker may induce acute poisoning. A U.S. study on the causes of mortality of 600 loons showed that fishing lures were responsible for about 10 percent of the deaths (Tufts, 2004).

289. In Canada, it has been determined that lead shot ingestion is probably the primary source of elevated lead exposure and poisoning of waterfowl and most other bird species. For some species (e.g., Common Loons), lead sinker ingestion is a more frequent cause of lead poisoning. Based on gizzard and wing-bone surveys of the species of ducks most commonly hunted, and extrapolation from U.S. estimates, up to 6 million of the approximately 50–60 million game ducks migrating from Canada every fall may ingest one or more spent lead shotgun pellets while in Canada. These individuals suffer either mortality (~200,000–360,000) or sub-lethal lead poisoning (several million) (Scheuhammer and Norris, 1995).

290. Studies in Canada and the U.S.A. indicate that secondary lead poisoning mortality of Bald and Golden eagles from eating lead shot-contaminated prey animals accounts for an estimated 10–15 percent of the recorded post-fledging mortality in these species. Several studies have demonstrated that probably 20 percent or more of healthy waterfowl carry embedded shot (Scheuhammer and Norris, 1995). Similar situations have now also been documented for a number of other raptor species in North America as well as in Europe (Beintema, 2001).

291. The U.S. EPA concludes that there is clear evidence that ingestion of lead fishing sinkers has resulted in toxic and often fatal effects to avian species, such as Common loons, Trumpeter, Mute and Tundra swans, and Sandhill cranes. Other birds with similar feeding habits living in exposed areas are at risk (U.S. EPA, 1994).

292. There are many reports on the levels of lead in wild mammals, but few reports of toxic effects of the metal in wild or in non-laboratory species. 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 (IPCS, 1995). Moose and reindeer samples were collected annually as part of a national residue control programme in Finland. The lead levels in muscle tissue had decreased in all studied animals and were currently near the limit of quantification, 0.01 mg/kg wet weight. The lead levels in liver and kidney samples had also decreased during the monitoring period and varied from 0.04 to 0.07 mg/.kg wet weight and 0.05 to 0.07 mg/kg wet weight respectively. In a corresponding study lead levels in Mountain hares were higher than in European hares (Venäläinen, 2007 in Finland's submission, 2007).

4.3.2 Terrestrial species including micro-organisms and plants

293. The lowest critical values for chronic exposure of various groups of terrestrial organisms appear to be in the range of 50-60 mg/kg soil dry weight, a value that has been suggested by the EU's scientific committee on environmental toxicology, CSTEE, as the Predicted No-Effect Concentration (PNEC). This implies that there may be harmful effects associated with soils that contain clearly higher amounts of lead than the normal background value (e.g. higher than the reference value of 85 mg/kg soil used in the Netherlands) (Tukker *et al.*, 2001).

294. 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 (IPCS, 1989).

295. Studies have shown that lead can hamper mineralization of nitrogen in the soil in acidified areas (Alloway, 1995). However, lead compounds are in general not very toxic to micro-organisms. Inorganic lead compounds are of lower toxicity to micro-organisms than are trialkyl- and tetraalkyl-lead compounds. There is evidence that tolerant strains exist and that tolerance may develop in others (IPCS, 1989).

296. Effects on micro-organisms are reported from soil lead concentrations down to 10 mg/kg soil, but for most organisms effect levels start at 50-100 mg/kg soil (Scott-Fordsmand *et al.*, 1995).

297. Tukker *et al.* (2001) provides, in the Table 4-5 and Table 4-6, a summary of chronic no-effect levels (NOECs) of lead on terrestrial invertebrates, micro-organisms and plants.

298. The Dutch Government establishes target and intervention values for soil sanitation. When such a level is exceeded, the functional properties that soil possesses for humans, plants or animals are considered to be seriously affected or threatened. For lead, an intervention value for soil/sediment of 450-575 mg/kg dry weight has been proposed (Tukker *et al.*, 2001).

299. 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 bioavailability of lead depends on, for example, the pH-level. In acidified environments, lead will be present as water-soluble salts that are bioavailable.

Table 4-5 Overview of chronic NOECs (mg Pb/kg soil dry weight.) for terrestrial microbe-mediated processes (Data summarised by Tukker et al., 2001 from Janus, 2000)

Toxicological endpoint	**NOEC (mg Pb/kg soil d.w.)** [1)]	
	Mean ± SD (n)	**Range**
C-mineralisation	1,123 ± 1,534 (11)	15-5,200
N-mineralisation	781 ± 473 (10)	180-1,500
Enzyme activities	1,062 ± 1,773 (28)	49-7,700

1) For standard soil.

(n) designates the number of samples.

Table 4-6 Overview of chronic NOECs (mg Pb/kg soil dry weight.) for terrestrial organisms (Data summarised by Tukker et al., 2001 from Janus, 2000)

Taxonomic group	**NOEC (mg Pb/kg soil d.w.)** [1)]		**Toxicological endpoints**
	Mean ± SD (n)	**Range**	
Plants	878 ± 538 (12)	120 - 1,500	Growth, yield
Oligochaetes	815 ± 663 (6)	170-2.00	Growth, reproduction
Gastropods	1,000 (1)	-	Survival, food consumption, growth (weight)
Crustaceans	40 (1)	-	Unspecified
Insects	1,100 (1)	-	Reproduction, growth
Mites	430 (1)	-	Reproduction, growth, survival

1) For standard soil.

(n) designates the number of samples.

300. 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 (IPCS, 1989).

301. A proportion - typically around 50 percent - of the lead content of vegetables and fruit crops can be removed by washing. Much of the remainder is incorporated into the cuticle and cell walls of the leaves or peel. It appears that much of the lead deposited on the leaves may be present as a surface coating which is not absorbed into the plant (OECD, 1993).

302. In their review of toxicity thresholds for lead, AMAP (2005) outlines tissue concentrations at which effects may occur. Table 4-7 lists general tissue concentrations and ranges at which various levels of poisoning have occurred in various animal studies. Subclinical poisoning refers to instances were no effects were observed, clinical poisoning involves obvious illness, and severe clinical poisoning suggests lethality. These thresholds have been derived from studies on animals that have been exposed to lead from contaminated sites or ingestion of lead fragments. The levels of lead observed in terrestrial wildlife that may be attributed in part to deposition from long-range atmospheric transport do not exceed these thresholds and are not expected to suffer adverse effects from lead toxicity (UNECE, 2005).

Table 4-7 Threshold concentrations for lead in biota (AMAP, 2005)

	Normal	Subclinical poisoning	Clinical poisoning	Severe clinical poisoning
Blood (µg/ dl)	<20	20 - <50	50 - 100	>100
Liver (mg/kg wet weight)	<2	2 - <2	6 - 15	>15
Bone (mg/kg wet weight)	<10	<10	>20	

4.3.3 Terrestrial ecosystems

303. In order to evaluate the potential effects at ecosystem level of exposures to pollutants the critical load approach has been developed within the framework of the UNECE Convention on Long-range Transboundary Air Pollution. A critical load has been defined as a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge (Slootweg *et al.*, 2005). The methodology is still under discussion and development. Other approaches to evaluate exposures exist; it has however been beyond the limits of this review to describe them here.

304. Preliminary critical load levels for lead in Europe have been calculated by the Working Group on Effects (WGE) of the UN ECE Convention on Long-range Transboundary Air Pollution based on national reports from 17 countries on the observed atmospheric deposition of this metal (Slootweg *et al.*, 2005). Critical loads of cadmium, lead and mercury were computed to establish maximum heavy metal depositions on different receptors at which eco-toxicological or human health effects do not occur. Critical limits for indicators of effects on human health and the functioning of ecosystems were established for use in the computation of critical thresholds (see Slootwer *et al.*, 2005 for details on indicators included).

305. The critical load for the occurrence of ecotoxicological effects in the soil was calculated for most of Sweden to be between 5 and 20 grams per hectare and year (based on median values). In 2000 the estimated critical load was exceeded in a large part of Sweden. However, 2000 was an extreme year from the meteorological point of view, leading to particularly high deposition. Deposition is expected to decrease over the next decade as a result of a continued reduction in global use of leaded petrol and it is anticipated that lead concentrations in forest soil will consequently also decrease (Sweden's submission, 2007).

306. Figure 4-2 shows the areas in which the critical load level for lead, i.e. the level above which terrestrial ecosystems are considered to be at risk, were exceeded in 1990 and 2000, respectively. The calculations are based only on atmospheric lead loads and do not take into account other anthropogenic lead loads to soil. As indicated by the figure, the areas with exceedance of the critical load significantly decreased during the period. The main reason for this has been the reduced emission due to reduced use of leaded gasoline and implementation of emission control measures as discussed in Chapter 5.

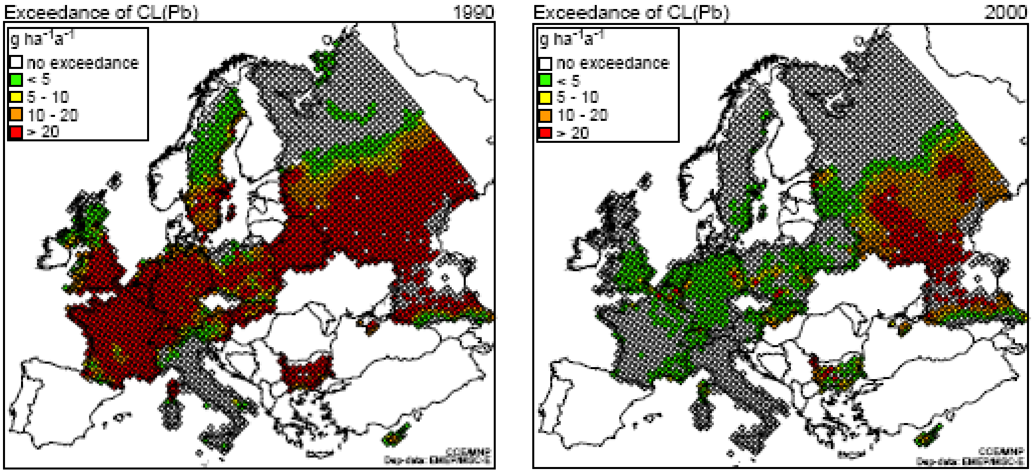


Figure 4-2 Areas in Europe in which the critical load level for lead were exceeded in 1990 and 2000, respectively, due to atmospheric emissions only (Slootweg et al., 2005). White grid cells (gray areas) indicate non-exceedance, whereas white areas without grid indicate no data.

307. The percentage of the area at risk of effects to the ecosystem by lead deposition in a number of European countries is shown in Table 4-8 .The results were calculated for Parties to the CLRTAP that had submitted critical loads data.

Table 4-8 Percentage of area at risk of effects to ecosystems caused by lead deposition in 2000 (based on TNO adjusted emission data) (ECE, 2006)

Country	**Area**	**Percentage of area at risk of effects to ecosystems caused by lead deposition in 2000**
Austria	61,370	25.27
Belgium	5,237	56.33
Belarus	121,127	18.19
Switzerland	9,410	60.04
Cyprus	8,147	89.96
Germany	290,003	48.38
France	170,638	71.67
Great Britain	50,074	17.80
Italy	278,155	62.04
Netherlands	22,311	58.55
Portugal	88,383	28.41
Russia	1,393,300	61.58
Sweden	151,431	27.59
Slovakia	19,253	36.76
EU-25	1,145,007	48.64
LRTAP area	2,668,845	53.44

4.3.4 Aquatic organisms

308. The toxicity of inorganic lead salts to aquatic organisms is strongly dependent on environmental conditions such as water hardness, pH and salinity, a fact that has not been adequately consid-

ered in most toxicity studies. Lead is unlikely to affect aquatic plants at levels that might be found in the general environment (IPCS, 1989).

309. 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 (IPCS, 1989).

310. Young stages of fish are more susceptible to lead than adults or eggs. Typical symptoms of lead toxicity include spinal deformity and blackening of the caudal region. The maximum acceptable toxicant limit (MATC) for inorganic lead has been determined in laboratory tests for several species (fresh water as well as salt water) under different conditions, and results range from 0.04-0.198 mg/L. There is evidence that frog and toad eggs are sensitive to nominal lead concentrations of less than 1.0 mg/L in standing water, and 0.04 mg/L in flow-through systems. For adult frogs, there are no significant effects below 5 mg/L in aqueous solution (IPCS, 1989).

311. The survival and behaviour of the water hyacinth *Eichhornia crassipes* was studied in Egypt (Soltan and Rashed, 2003) under varying heavy metal concentrations in different aquatic media. The results showed that the water hyacinth can survive in a mixture of heavy metal concentrations of up to 3 mg/L, and in a solution of lead of 100 mg/L. Higher concentrations of metals as mixtures led to rapid fading of the plants.

312. In the Netherlands, lead concentrations in freshwater are now normally below the national Tolerable Risk Level (MTR) of 11 µg/L. Thus, it seems that for freshwater, apart from hot spots and specific local emissions, environmental risk levels are not exceeded (Tukker *et al.*, 2001).

313. Concentrations in marine organisms in Norway gave annual median concentration ranges of 0.3 to 77.8 ppm dry weight in blue mussel soft body tissue, 0.0075 to 0.138 ppm dry weight in cod liver tissue and 0.02 to 1.35 ppm dry weight in other fish species liver tissue (Norway's submission, 2007). Additional data on lead levels in marine organisms may be found in the articles of Moore *et al.* from 1998 (United States' submission, 2007).

314. In Togo lead levels have been recorded in crustacea as follows: 10.04 ppm in Penaeus duorarum, 8.49 ppm in Callinectes pallidus and 8.4 ppm in Cardisoma armatum (Togo's submission, 2007).Table 4-9 provides values for lead concentration in fish in Togo.

Table 4-9 Concentration of lead (ppm) in fish(Togo's submission, 2007)

Species name	**Concentration of lead (ppm)**			
	Agbodrafo	**Kpeme**	**Goumou-Kope**	**Aného**
1*Chloroscombrus chrysurus*	10,37	8,10	5,99	8,19
2 *Sardinella aurita*	5,99	8,03	6,01	6,14
3 *Ilisha africana*	8,34	6,26	6,31	8,40
4 *Galeoides decadactylus*	8,23	6,27	8,49	8,04
5 *Caranx latus*		6,21	6,25	8,27
6 *Sphyraena barracuda*		6,13	6,18	6,75
7 *Selene dorsalis*		5,75	6,19	2,09
8 *Caranx crysos*		5,08	8,09	
9*Pellonula leonensis*		2,04	6,74	
10 *Trichiusus lepturus*		2,04	6,10	

Ref : K.D. Abbe, Thesis, University of Lomé

315. In table 4-10 below (prepared by Tukker *et al.*, 2001), a summary of data on chronic effects (NOECs) of lead on fresh water and saltwater organisms at different trophic levels is provided. The typical lead levels in aquatic environments in western European countries removed from specific point sources are found to be low (seawater: below 1µg/L; fresh water: below 5µg/L; section 4.3.2) compared to the levels causing effects.

Table 4-10 Overview of chronic NOECs (µg Pb/L) for freshwater and saltwater organisms (Data summarised by Tukker et al., 2001 from Janus, 2000.)

Taxonomic group	**NOEC (µg Pb/L)**		**Toxicological endpoints**
	Mean ± SD (n) 1)	**Range**	
Freshwater			
Bacteria	1,183 ± 683 (3)	450-1,800	Growth
Unicellular algae	10,005 ± 55,744 (15)	10-200,000	Growth
Multicellular algae	1,033 ± 945 (3)	300-2,100	Growth
Protozoas (fresh water)	403 ± 604 (4)	20-1,300	Growth, reproduction
Molluscs	204 ± 317 (3)	12-570	Hatching, survival
Crustaceans	502 ± 913 (8)	1-2,500	Reproduction, survival, growth
Fish	77 ± 74 (17)	7-250	Reproduction, survival, growth, abnormalities, development, hatching
Saltwater			
Algae	23 ± 32 (3)	0.1-60	Growth, reproduction
Protozoas	150 (1)	-	Population density
Coelenterates	300 (1)	-	Growth
Annelids	3,833 ± 5,346 (3)	50-10,000	Growth, reproduction
Molluscs	1,400 ± 2,400 (4)	200-5,000	Survival, growth
Crustaceans	269 ± 487 (4)	10-1,000	Growth, embryonic development, development, reproduction

1) (n) designates the number of samples.

5 Sources and releases to the environment

316. The important releases of lead to the biosphere can be grouped into the following categories:

- Natural sources - releases due to mobilisation of naturally-occurring lead in the Earth's crust and mantle, such as volcanic activity and weathering of rocks;
- Current anthropogenic (associated with human activity) releases from the mobilisation of lead impurities in raw materials such as fossil fuels – particularly ores, coal and other extracted, treated and recycled minerals;
- Current anthropogenic releases resulting from lead used intentionally in products and processes, due to releases by manufacturing, use, disposal or incineration of products;

317. Together with these categories may be considered remobilisation of lead deposited in soils, sediments, landfills and waste/tailings piles from historic anthropogenic releases as well as translocation of lead naturally occurring in the biosphere.

5.1 Natural sources

318. The major natural sources for mobilisation of lead from the Earth's lithosphere to the biosphere are volcanoes and weathering of rocks. In addition, insignificant amounts of lead enter the biosphere as meteorite dust. 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 results only rarely in elevated concentrations in any given environmental compartment.

319. As lead is an element that is naturally present in many minerals, it will be present in rocks and soils in low concentrations. The average concentration of lead in the continental crust is about 12 to 17 mg/kg (Wedepohl, 1978), whereas the lead concentration in various soil-forming rock types ranges from 7-150 mg/kg for black shales to 2-18 mg/kg for basaltic rocks (Adreano, 1986). The average global lead concentration in soil is reported to be 22 mg/kg (Richardson *et al.*, 2001). Global averages for different soil types range from 0.2 mg/kg in solonetz type soil to 115 mg/kg in terra rosa type soil (Richardson *et al.*, 2001). In some countries, elevated lead concentrations are found associated with lead deposits. Australia’s submission (2005) reports, e.g., those locations with elevated concentrations above the average in the global crust are widespread across the Australian continent. Anomalous concentrations of lead are associated with deposits in areas where they crop out of the surface and are subjected to weathering processes, followed by dispersion of the constituent base metals, including lead, into the overlying soils. Data extracted from the database of Geoscience Australia shows that 1200 samples out of 65,000 have a lead content of 100 mg/kg or more.

320. Through the weathering of rocks, lead is released to soils and aquatic systems and made available to the biota. This process plays a significant role in the global lead cycle, and results in locally elevated lead concentrations in soils.

321. Within the biosphere, lead is translocated by different processes, e.g. by wind transport of salt spray and soil particles. The major sources for emission to air by natural processes are volcanoes, airborne soil particles, sea spray, biogenic material and forest fires.

322. Very different estimates on total releases of lead to the atmosphere by natural processes have been reported and a debate on the source estimates is ongoing.

323. Table 5-1 shows two estimates of total emissions to the atmosphere from natural sources. Nriagu (1989) estimated the total emission in 1983 at 970-23,000 tonnes/year. These estimates are still frequently cited. In a more recent study by Richardson *et al.* (2001), the total emissions from natural sources were estimated at 220,000 – 4,900,000 tonnes/year. The tremendous difference is mainly due to very different estimates of the significance of the releases of soil particles to the atmosphere. The estimates of atmospheric releases due to soil particle flux in Richardson *et al.* (2001) are based on data on soil metal flux in scrubland of the south-central U.S.A. The soil particle flux for each ecoregion (regions with specific ecosystems: scrubland, desert, rainforest, etc.) is estimated on the basis of the frequency of dust storms in each ecoregion in comparison to scrubland. Due to the high frequency of dust storms in deserts (6 times the frequency in shrubland and 27 times the frequency in grassland), the desert ecoregion (19 percent of the global land area) accounts for the majority of the releases with soil particle flux. Together with the scrubland region, the desert region accounts for nearly 100 percent of the estimated emissions.

Table 5-1 Estimated global emissions of lead to the atmosphere from natural sources

Source category	**Lead emissions in 1000 tonnes/year**			
	Richardson *et al.*, 2001		**Nriagu, 1989**	
	Mean	**5-95th percentile**	**Mean**	**Range**
Release of soil particles, in particular during dust storms	1,700	200 - 4,900	3.9	0.3 - 7.5
Sea salt spray	13	2.7 - 31	1.4	0.02 - 2.8
Volcanic emissions	4.7	1.1 - 10	3.3	0.54 - 6.0
Natural fires	83	24 - 180	1.9	0.06 - 3.8
Vegetation, pollen and spores	-		1.74	0.05 - 3.33
Meteorite dust	2.2×10^{-7}	$0.5 - 5.4\ 10^{-7}$	-	-
Total	**1,800 1)**	**220 - 4,900**	**12**	**0.97 - 23**

1) Statistical figures for total emissions are derived by statistical calculations, and not by simple addition of source-specific figures (Richardson *et al.*, 2001).

324. The significance of natural releases on global lead cycles are highly dependent on the particle size of the release, as further discussed in Chapter 7 on long-range transport. Large soil particles are transported over relatively short distances. Furthermore, the concentration of lead in released particles is of importance when evaluating the potential for elevating the lead concentration in areas where the particles are deposited.

325. Releases of lead to the atmosphere by translocation of soil particles may also serve as a mechanism for remobilisation of lead originating from anthropogenic sources. According to U.S. EPA (2005), Harris and Davidson (2005) estimate that stationary and mobile source emissions account for only about 10 percent of total lead emissions in the South Coast Air Basin of California; the remaining 90 percent of emissions coming from re-suspended soil. The soil contains elevated lead levels because of the many decades of leaded gasoline usage. (U.S. EPA, 2005a)

Natural versus anthropogenic sources: long-range transport

326. The estimated figures for natural emissions may be compared to the estimated total global anthropogenic atmospheric emission. From 1983 to the mid-1990s, the total emissions of lead to air decreased from about 330,000 tonnes (average estimates of Nriagu and Pacyna, 1988) to 120,000 tonnes (Pacyna and Pacyna, 2001), further discussed in the next section. The decrease was mainly due to the decrease in the use of leaded fuel - a decrease that has continued over the last 10 years. The estimated anthropogenic emissions in 1983 were consequently on the order of 28 times the natural emissions as

estimated by Nriagu (1989), or about 20 percent the estimated natural emissions as estimated by Richardson *et al.,* (2001).

327. The significance of anthropogenic versus natural emissions causing contamination in remote locations due to long-range transport can be indicated by ice core records from the Greenland Ice Sheet. 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 percent of emissions in the Euro-Asiatic regions during the winter is deposited in the Northern Arctic (AMAP, 1997).

328. The largest single ice-core-based dataset used to reconstruct Arctic metal deposition is from the Greenland Summit deep-drilling program (Boutron, 1995). Data from a representative core is shown in Figure 5-1. The data shows that the lead levels increased significantly following the industrial revolution in the 19th century. Lead deposition in the 1960s and 1970s was eight times higher than in pre-industrial times (AMAP, 2002). With the phase-out of leaded petrol since 1970 and the implementation of emission controls, lead concentration in the ice core has decreased sharply and the levels in the late 1990s was at approximately the same level as in preindustrial times. The results indicate that anthropogenic emissions - and in particular, releases of lead through the use of leaded petrol - during a given period constituted more important sources than natural sources to lead deposited in Greenland.

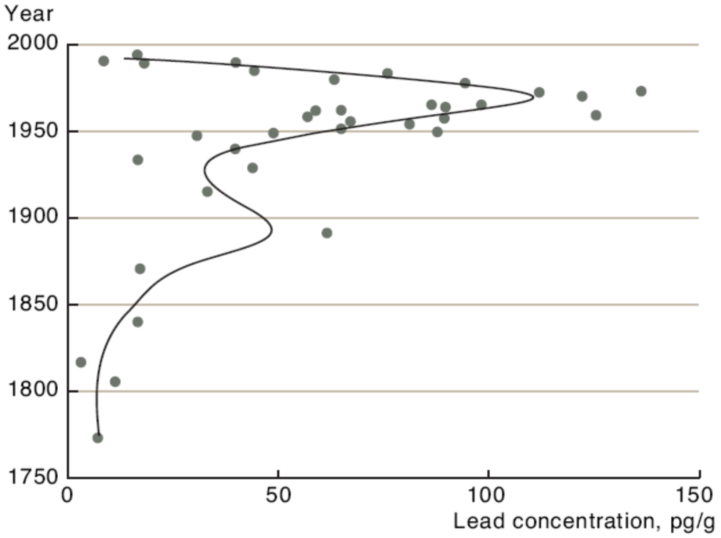


Figure 5-1 Lead concentrations in a Greenland ice core (Boutron, 1995 as cited by AMAP, 2005). Original figure presented courtesy of AMAP, Norway

329. Lead isotope compositions and lead concentrations have been measured in ice cores from Law Dome, east Antarctica, which provide data for the past 6500 years (Vallalonga *et al.*, 2002). This research concluded that "natural" background lead concentrations of approximately 0.4 picograms per gram (pg/g) were present until 1884 AD, after which increased lead concentrations occur, indicating the influence of anthropogenic lead emissions from the southern hemisphere. Between 1890 and 1908, the first influence of anthropogenic fluctuations in lead in Law Dome was observed, revealing a four-fold increase from natural levels in 1880. During that time, coal combustion and non-ferrous metal production were responsible for most anthropogenic lead emissions to the atmosphere. Since 1942, lead concentrations at Law Dome increased consistently, with concentrations of 1.5 pg/g observed from the mid-1950s to the mid-1970s, consistent with the introduction of leaded petrol and domestic automobile use (as cited by Australia's submission, 2005).

330. Atmospheric lead contamination was studied by Shotyk *et al.* (2005) using snow and ice from the Canadian arctic. Forty-five samples representing the snow accumulation during 1994 to 2004 on Devon Island contained an average of 45.2 pg/g of lead but only 0.43 pg/g of scandium. The average ratio of lead to scandium was far greater than that of soil-derived dust particles which indicates that approximately 95 to 99 percent of recent lead is anthropogenic. Isotopic analyses (^{206}Pb, ^{207}Pb, ^{208}Pb) confirmed that anthropogenic sources continue to dominate atmospheric lead inputs. Unlike snow from Greenland which receives lead predominantly from the U.S.A, snow from Devon Island is less radiogenic. There are pronounced seasonal variations, and the snow samples containing the greatest lead enrichments are from winter when the Arctic is dominated by air masses originating in Eurasia. Shotyk *et al.* (2005) concludes that while the elimination of gasoline lead additives in Europe, North America and Japan has helped to reduce lead emissions during the past two to three decades, aerosols in the Arctic today are still highly contaminated by industrial lead.

331. Studies of lake sediments, peat deposits and soil profiles in Sweden show clear peaks which match peaks in metallurgy activity in medieval Europe. With the Industrial Revolution, atmospheric lead pollution increased, though not as much as suggested elsewhere. Lead pollution increased markedly after World War II, peaked around 1970, and will, according to the authors, if the present trend continues, soon be back to medieval levels (Renberg *et al.,* 2000).

332. Due to deposition, lead concentrations have increased in the mor layer of Scandinavian soils during the twentieth century. Although atmospheric deposition has declined during more recent decades, the reduction is not sufficient to prevent further accumulation. The concentration of lead is still increasing by 0.2 per cent annually in the surface layer of forest soil in Sweden (Johansson *et al.*, 2001, Steinnes *et al.,* 1997).

333. In Hungary, anthropogenic sources of lead are investigated and assessed under the heading emission to air. Information regarding emissions by industry is compiled from reports submitted by the enterprises to the authority in compliance with the rules specified in the Government Decree No. 21/2001 ((II.14.) Korm). The major component of lead emission to air is due to pyrogenic emission from the burning of fossil solid and liquid fuels in boilers, internal combustion engines, turbines, etc. The consumption data is available in the form of energy statistics for the past and as energy prognoses for the future. Approximately 95-98 *percent* of all anthropogenic emissions are taken into account. Additionally it has to be noted that leaded petrol is no longer available in Hungary since 1999. This is one of the reasons for the significant decrease of yearly emissions (between 1995 and 2000), as it can be seen in the table 5-2 below (Hungary's submission, 2007).

Table 5-2 Emission of lead to the air, tons per year (Hungary's submission, 2007).

	1980	**1985**	**1990**	**1995**	**2000**	**2005**
From fossil fuels	500,0	471,0	616,8	102,8	20,4	13,2
From other technology	75,2	61,1	46,5	26,8	24,7	24,4
Total	575,2	532,1	663,3	129,6	45,1	37,6

5.2 Anthropogenic sources in a global perspective

334. Human activities significantly influence the global cycles of lead. In 2004, 3,150,000 tonnes of lead were extracted from the earth's crust by humans and brought into circulation in society (see Chapter 6). Besides this, a significant amount of lead ended up in metal extraction residues or was mobilised as an impurity by extraction of other minerals like coal and lime, however recent data could not been identified for this project. In 1983, a total of 400,000 - 1,000,000 tonnes of such mobilised lead were disposed of with waste from metal extraction and the use of coal (Nriagu and Pacyna, 1988). The main part of the extracted lead will not contribute to long-range environmental transport or be in a form that is readily bioavailable, but may later in the life cycle lead to local impacts if not managed properly.

In a number of developing countries including countries in Sub-Saharan Africa, Latin America and small developing island states, lead-containing products are commonly not disposed of in an environmentally sound manner, due to limitations in public awareness and waste management capacity. Examples of this include open burning, unofficial dumpsites and disposal in wetlands and rivers (Njai, 2006). There have been reported cases of lead poisoning due to inappropriate disposal and waste management practices (Rajkumar *et al.*, 2006). Data on quantities disposed in the United States can be found in the U.S. EPA Toxics Release Inventory at www.epa.gov/tri (United States' submission, 2007). In Hungary, certain compounds of lead are considered more hazardous from the health and environmental points of view, therefore limitation on manufacturing, marketing or use is more relevant to such products, like paints. The legal base of limitation is provided by the EüM-KöM joint Decree No. 41/200. (XII.20.), which transposes Directive 76/769/EEC of the European Community (Hungary's submission, 2007).

5.2.1 Emission to the atmosphere

335. The most comprehensive assessment of total global anthropogenic lead releases to all media dates back to 1983 (Nriagu and Pacyna, 1988). From 1983 to the mid-1990s, the total global atmospheric emission of lead decreased from about 330,000 tonnes (average estimates of Nriagu and Pacyna, 1988) to 120,000 tonnes (Pacyna and Pacyna, 2001). In 1983, leaded fuel additives were by far the main source, and by the mid-1990s, fuel additives still accounted for 74 percent of global lead emission to the atmosphere (see Table 5-2). Besides fuel additives, non-ferrous metal production and coal combustion were the major sources.

336. Due to the phase-out of leaded petrol for vehicles in most countries, it must be expected that this source is significantly lower today; however, updated global emission estimates do not exist. According to a recent survey by the International Lead and Zinc Study Group (ILZSG), the global reported lead consumption for gasoline additives was 14,400 tonnes in 2003. Total global consumption (including consumption not reported) may be higher. Virtually 100 percent of the lead in petrol additives is released to the atmosphere. Table 5-3 shows, besides the most recent global estimate, examples of national emission inventories based on country submissions. In many countries, emission inventories are based on Pollutant Release and Transfer Registers (PRTR), which mainly include data on point sources. For example, the European region is developing a European PRTR that will contain information relative to industrial and non-industrial releases including releases of lead into air, water, land and off-site transfers of waste water and waste. The European PRTR site can be accessed at the following link: http://www.oecd.org/env_prtr_data/. The report of a case study on lead releases from end product uses as a part of a project funded by the Nordic Council of Ministers is expected to be published late 2010 (OECD's submission, 2010).

337. For a full inventory, these data have to be complemented by estimates of emissions from diffuse sources, e.g. releases from products. The country data in Table 5-2 illustrate the large diversity in the relative magnitude of the different source categories dependent on the countries' industry structure. In Australia, with a large non-ferrous metal sector including primary production of lead, non-ferrous metal production and metal ore mining account for the major part of the emissions from point sources. Australia presents, besides point source emissions, estimates on emissions from diffuse sources; in particular emissions originating from paved and unpaved roads. Such emissions must be expected from other countries as well, but are usually not included in the emission inventories. In Denmark, without a significant metal industry, fireworks, waste incineration and the use of leaded fuels for aircraft are estimated to be significant sources of lead emissions (Table 5-3). In the Slovak Republic, with intense production of crystal glassware, glass production is the second major source of lead emissions.

338. As different criteria for inclusion of sources in the inventories and different estimation techniques are applied in the different countries, the datasets are not readily comparable across the countries.

339. Lead emissions estimates from the U.S.A in 2002 are shown in Table 5-4. In the U.S.A., one of the larger emitting source categories in recent years has been the iron and steel foundries, accounting

for about 7 percent of the reported emissions for 2002 (U.S. EPA, 2008a). Aviation gasoline used in piston-engine aircraft is the highest emitting category, accounting for about 40 percent of the total based on the 2002 inventory (U.S. EPA, 2008a).

340. All emission inventories are subject to uncertainty. To illustrate this, in Table 5-5, three inventories of atmospheric emissions of lead in Europe in 2000 are presented. The basis for all three inventories is data submitted by the countries to EMEP, the cooperative programme for monitoring and evaluation of long-range transport of air pollutants in Europe. The submission of data is part of the countries' obligations as parties to the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP). The official data are, for the different source categories, typically estimated either from actual measurements in the country, or by multiplication of activity rates by default emission factors from the EMEP/CORINAIR guidebook (latest edition: EMEP/CORINAIR, 2005). The official submitted data are in some instances subject to some uncertainties. Initial model calculations based on official emission inventories resulted in a significant underestimation of modelled concentrations and depositions, when compared with measurements (ESPREME, 2006). In order to obtain a more comprehensive inventory, the data can be reviewed and reconsidered by inventory experts. Table 5-5 includes two examples of revised inventories prepared by the Norwegian Institute for Air Research (NILU) and the Netherlands’ Organisation for Applied Scientific Research (TNO), respectively.

Table 5-3 Global atmospheric emission of lead in the mid-1990s and country examples based on country submissions

Source category	**Atmospheric lead emissions (tonnes lead/year)**					
	Global mid-1990´s 1)	**Canada 2) 2004**	**Australia 2003-4 3)**	**Japan 2003 4)**	**Slovak Republic 2003 5)**	**Denmark 2000 6)**
Energy production						
Power and heat production	11,690	13.8	8.4		4.3	0.2 - 0.59
Coal mining		0	5.6			
Manufacturing processes						
Metal ore mining		11.7	100			
Non-ferrous metal production	14,815	231.3	330	29.8	2.8	
Ore agglomeration (type not indicated)					25.0	
Iron and steel	2,926	17.9	4.9	2.0	1.3	0.51
Cement, lime, plaster and concrete	268	1.1	1.4			0.13
Ceramics, stone and clay				7.1		0.04 - 0.7
Glass and glass products manufacturing			1.6		14.2	0.05 - 0.4
Plastic product industry				0.1		
Ship and vessel manufacturing				6.5		
Other industrial sources		11	5.1	5.6		0.008-0.015
Use of products						
Fuel additives	88,739		85 (1995) 3)		2.0	1.6 - 2.0
Fireworks						1 - 8
Other diffuse sources		1.7	565 3)			
Waste disposal	821	0.4		<0.3 - 7,2	10.8	1.2 - 3.8
Total (rounded)	**119,259**	**288.9**	**1,022**	**51 - 59**	**61**	**5 -19**

Based on the following information sources:

1) Pacyna and Pacyna (2001).

2) (Canada's submission, 2006).

3) (Australia's submission, 2005). Data from national pollution inventory (NPI). Data on fuel additives have not been updated since 1995 and, considering that Australia completed the phase-out of leaded gasoline by 2002, are not included in the total in the table. The submission indicates that 80 percent of the diffuse source emissions originats from paved and unpaved roads, and 13 percent from motor vehicles (indicated as "fuel additives" in this table). Diffuse sources are estimated as average for the period between 1995 and 2004.

4) (Japan's submission, 2005). Industry data from PRTR register. Range of estimates only reported for waste incineration. The total must be expected to be subject to higher uncertainty than indicated, because only the uncertainty regarding waste disposal is included in the range of the total.

5) (Slovak Republic's submission, 2005).

6) (Lassen *et al.*, 2004), submitted by Denmark. The dataset is based on a detailed substance flow analysis and covers more emission sources than the inventories officially reported by Denmark.

Table 5-4 Country example - lead emission from the U.S.A. in 2002

Source category	**Atmospheric lead emissions**	
	(tonnes lead/year)	**Percentage of total**
Energy production		
Combustion of fossil fuels in utility boilers	21	2
Combustion of fossil fuels in industrial/commercial/institutional boilers	48	4
Manufacturing processes		
Primary lead smelting	54	5
Primary non-ferrous metals production (zinc, cadmium and beryllium)	5	0.4
Primary copper smelting	9.1	0.8
Secondary lead smelting	40	0.5
Secondary non-ferrous metal production	20	1.8
Primary iron and steel production	15	1.3
Secondary iron and steel production	15	1.43
Iron and steel foundries	75	7
Pressed and blown glass and glassware making	24	2
Portland cement manufacturing	16.4	1.45
Inorganic chemicals production	9	0.8
Pulp and paper production	9	0.8
Lead acid battery manufacturing	24.5	2
Sewage sludge incinerators	9	0.48
Medical waste incinerators	0.2	0.02
Hazardous waste incinerators	43	3.8
Municipal waste incinerators	30	3
Other stationary sources	213	21
Mobile sources	446	40
Total (rounded)	**1,126**	**100.0**

Table 5-5 Atmospheric emission of lead in Europe in 2000 - three inventory results 1)

Source category	Official EMEP data 2)		Official data supplemented by expert estimates NILU 3)		Official data supplemented by expert estimates TNO 4)	
	Tonnes Pb/year	Percentage 5)	Tonnes Pb/year	Percentage 5)	Tonnes Pb/year	Percentage 5)
Power plants	694	6	540	4	1,547	10
Residential and commercial boilers	682	6	1082	8	390	3
Cement production	0	0	645	5	4,466	30
Iron and steel production	0	0	2,282	17		
Non-ferrous metal production	1,471	13	1,471	11		
Waste disposal	116	1	116	1	134	1
Gasoline combustion	7,712	71	6,773	51	8,329	55
Other sources	247	2	247	2	154	2
Total	**10,923**	**100**	**13,157**	**100**	**15,021**	**100**

1) Europe, in this table, is defined as the 44 European countries that are partners to the UNECE Convention on Long-Range Transboundary Air Pollution (CLRTAP), including the Russian Federation and Turkey.

2) Based on EMEP official reported emission data and expert estimates, Dec 2004. Compiled by NILU within the EU project (ESPREME, 2006)

3) Experts' "base case" estimates prepared by the Norwegian Institute for Air Research (NILU) on the basis of EMEP official data as part of the EU project (ESPREME, 2006).

4) Estimates based on official EMEP data reviewed and revised in cooperation between experts from the Netherlands' Organisation for Applied Scientific Research (TNO) and national experts (Denier van der Gon *et al.*, 2005).

5) Indicates the rounded percentage of the sources included in the inventory.

341. Table 5-6 provides summary data on the anthropogenic emissions of lead to the atmosphere in the Republic of Moldova.

Table5-6 Anthropogenic lead emissions to the atmosphere in the Republic of Moldova
Units: tons per year (Moldova's submission, 2007)

1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
253.19	220.26	102.57	71.20	23.16	33.90	27.90	22.36	7.90	11.21	2.82	3.35	3.28	8.50	9.04	5.059

Trends in emission

342. In general, the atmospheric lead emission has decreased significantly in industrialised countries during the last 15 years, mainly due to restrictions and bans of the usage of leaded gasoline for vehicles, but also implementation of improved air pollution controls. The trends in atmospheric lead emission in

Canada and Europe (EMEP area including 24 countries) from 1990 to 2003 are shown in Figure 5-2. During that period, the lead emission in Europe decreased by about 92 percent, while the emission in Canada decreased to about one third of the 1990 level.

343. Data on the trends in atmospheric lead emission from developing countries have not been available for this review. The deficiency in data from developing countries is a major hindrance for the understanding of the trends in global emissions of lead.

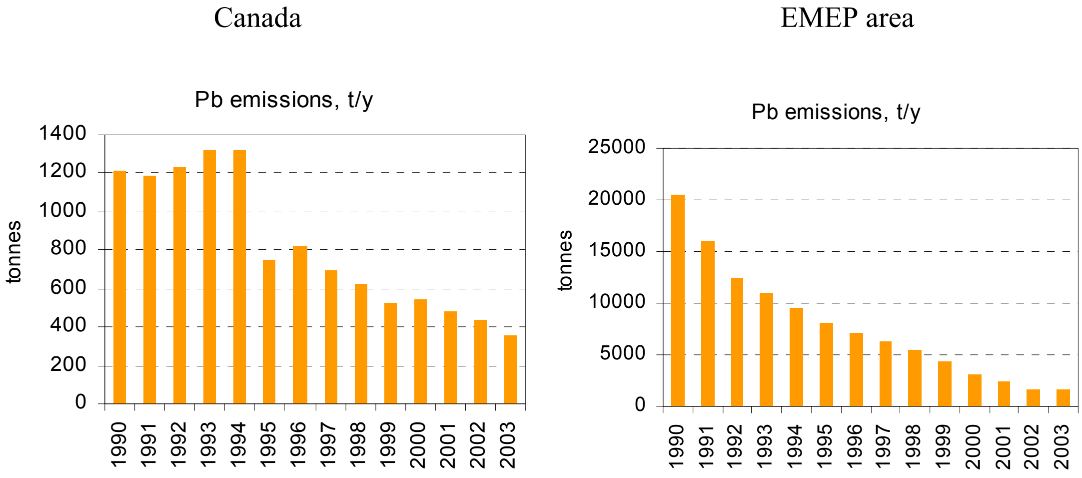
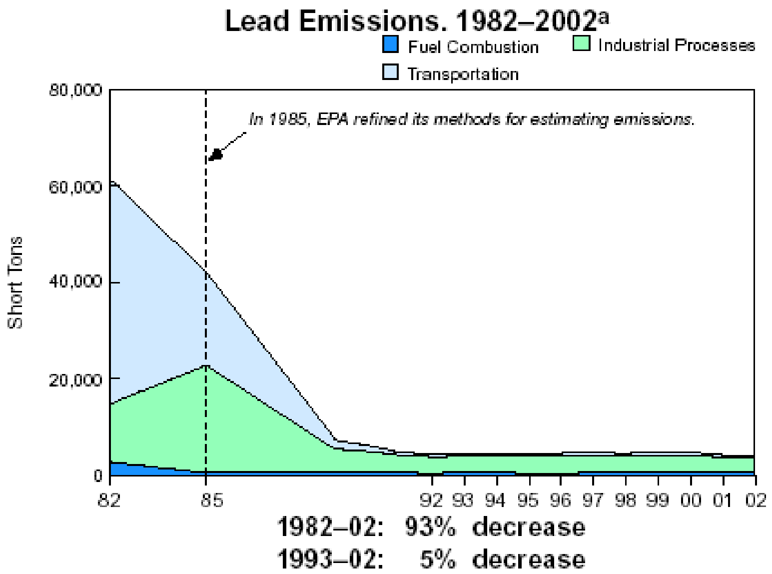


Figure 5-2 Trends in atmospheric emission of lead in Canada and the EMEP area (24 countries in Europe) 1990- 2003 (UNECE, 2006)

344. In the U.S.A., emissions decreased sharply during the 1980s and early 1990s due to the phase out of lead in gasoline and reductions from industrial sources (see Figure 5-3). Emissions continued to decline to a lesser extent in the mid-1990s to 2002. Overall emissions of lead decreased about 95 percent over the 21-year period 1982–2002 (U.S. EPA, 2003).



In 1985, EPA refined its methods for estimating emissions.

1982–02: 93% decrease

1993–02: 5% decrease

[a] As of 2002, lead emissions are included in the Toxic National Emissions Inventory.

Figure 5-3 Lead Emissions in U.S.A. from 1982 to 2002 (UNECE, 2006a)

345. The correlation between the average lead content of gasoline and the lead concentration in ambient air in Thailand is shown in Figure 5-4. From 1989 to 1998, the average concentration in ambient air decreased from about 0.44 to 0.02 µg/m^3 as a result of the phase-out of leaded gasoline.

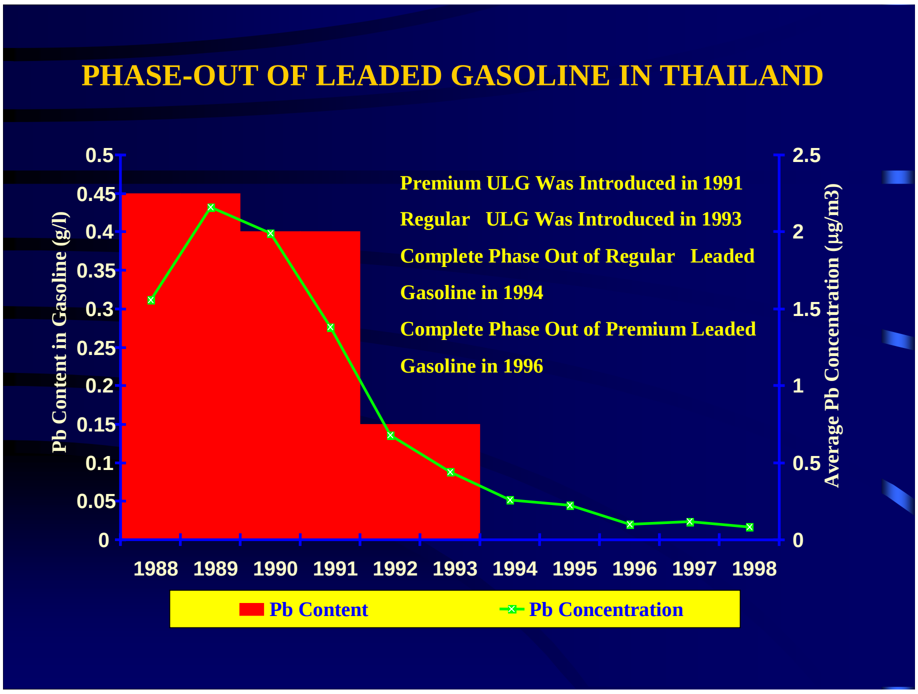


Figure 5-4 Average lead content of gasoline and average lead concentration in ambient air in Thailand (Thailand's submission, 2006)

346. Within the EMEP area, the most complete datasets on lead, cadmium and mercury emissions by source sectors (in Nomenclature for Reporting codes) for both 1990 and 2003 were reported by 8 European countries: Austria, Belgium, France, the Netherlands, Norway, Spain, Sweden, and the United Kingdom.

347. Table 5-7 shows estimates of lead emission by sector in 1990 and 2003 from the eight countries. In 1990, “Road Transportation”, mainly the use of leaded gasoline accounted for 85 percent of the total lead emission from the countries. In 2003, the contribution of this sector dropped to about 6 percent while the sector “Metal Production” became a leading source (representing about 28 percent). During the period, the emissions from waste incineration were reduced by 98 percent while it for the industrial sectors was reduced by 42-86 percent.

348. Additional information on emissions is available from the Netherlands with a report on “Heavy Metal Emissions, Depositions, Critical Loads and Exceedances in Europe”. The report summarizes knowledge of – and comparison between – heavy metal emission reduction scenario´s and resulting depositions and critical exceedances. The focus of this report is on the relative assessment of the effects of mercury, cadmium and lead and – more tentatively – of other heavy metals on human health and the environment. The report is available under: http://www.unece.org/env/lrtap/TaskForce/tfhm/COMBINED%20HM%20REPORT.pdf (Germany’s submission, 2007).

Table 5-7 *Trend in atmospheric emission of lead by sector in 1990 and 2003 in 8 European countries* [1)] (rounded figures based on UNECE, 2006)

Sector	**Sector code**	**1990**		**2003**		**Reduction**	
		Tonnes Pb	**Percentage**	**Tonnes Pb**	**Percentage**	**Tonnes Pb**	**Percentage**
Road Transportation	1 A 3 b	9,996	84.7	47	6.3	9,949	100
Metal Production	2 C	355	3.0	207	27.7	148	42
Waste Incineration	6 C	339	2.9	6	0.8	333	98
Iron and Steel	1 A 2 a	229	1.9	120	16.1	109	48
Public Electricity and Heat Production	1 A 1 a	203	1.7	39	5.3	164	81
Non-ferrous Metals	1 A 2 b	184	1.6	88	11.8	96	52
Other, Manufacturing Industries and Construction	1 A 2 f	138	1.2	137	18.3	0	0
Chemical Industry	2 B	98	0.8	14	1.8	85	86
Residential	1 A 4 b	93	0.8	41	5.5	51	55
Other sectors		160	1.4	49	6.5	111	70
Total		**11,796**	**100**	**749**	**100**	**11,047**	**94**

1) Austria, Belgium, France, the Netherlands, Norway, Spain, Sweden, and the United Kingdom.

349. In Hungary, information on lead emissions is periodically updated within the framework of the European Pollutant Emission Register (EPER,) http://www.eper.cec.eu.int/eper/default.asp). The EPER provides environmental information on emission data of major industrial activities. Data is provided through the compulsory reporting by all EU Member States and made accessible in a public register, which is intended to provide environmental information on major industrial activities. After the reporting period of 2007, EPER will be replaced by the European Pollutant Release and Transfer Register (E-PRTR) http://ec.europa.eu/environment/air/legis.htm#stationary. Detailed data on Hungarian lead emission, as it appears in EPER, is summarized in table 5-8 (Hungary's submission 2007).

Table 5-8 *Trends of lead emission in 2001 and 2004, as it appears on EPER Trend. (Hungary's submission 2007).*

	Pb release to air [kg/2001]	**Pb release to air [kg/2004]**	**Trend +/- [kg]**
Facility 1	3070		n.a.
Facility 2		230	n.a.
Facility 3		25800	n.a.
Facility 4		632	n.a.

350. Emission factors for combustion processes, and metal, cement and glass production have been proposed by Czech Republic (2010 submission). As seen in Table 5.81, for combustion the values of the emission factors are dependent on the capacity of the facility and also on the type of fuel used. As for metal, cement and glass production (Table 5.82), the emission factors are given with respect to each tonne of product manufactured.

Table 5.81: Emission factors for combustion processes and metal, cement and glass production (Czech's submission, 2010)

Capacity of facility	Fuel	Emission factors (mg Pb/GJ)
> 5MW	Brown coal	0.90 to 23.10
	Hard coal	0.27 to 4.49
	Heavy oil	147.05
	Other liquid fuels	0.10
0.2 – 5 MW	Brown coal	277.20
	Hard coal	11.23
	Coke	1076.40
	Liquid fuel	4.20
< 0.2 MW	Brown coal	277.2
	Hard coal	11.65
	Coke	1076.40
	Liquid fuel	1260.0

Table 5.82: Emission factors for metal, cement and glass production (Czech's submission, 2010)

Type of facility	NFR	Emission factors (mg Pb/tonne of product)
Sinter and pelletizing plants	1A2a	3373.0
Gray iron foundries	1A2a	163.0
Secondary Pb production	1A2b	40000.0
Secondary Zn production	1A2b	85000.0
Secondary Cu production	1A2b	90,000.0
Secondary Al production	1A2b	37.0
Cement production	1A2f	216.0
Glass production	1A2f	10000.0
Lead glass production	1A2f	27000.0
Coke production	1B1b	250.0
Pig iron tapping	2C1	287.8
Steel production	2C2	731.94

5.2.2 Releases to land (soil and waste deposits)

351. The only comprehensive assessment of global anthropogenic lead releases to soil and waste deposits dates back to 1983 (Nriagu and Pacyna, 1988). According to the estimates, a total of 800,000-1,800,000 tonnes of lead was directed to waste deposits or released to soil (see Table 5-9). It should be noted that the distinction between releases to soil and land is not quite clear, e.g. is coal fly ash most probably released to landfills and not to soil. The three major categories were: waste from commercial

products, mine tailings, and smelter slag and waste. Atmospheric fall-out has decreased significantly since then due to the reduced use of lead as a fuel additive.

Table 5-9 Global lead releases to land (soil and waste deposits) in 1983 (derived from Nriagu and Pacyna, 1988).

Source category	**1000 tonnes Pb/year**	**Percent of grand total to land (mean value)**
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 1)	195 - 390	22
Atmospheric deposition	202 - 263	17
Total to land excluding mining residues	**479 - 1,113**	
Mine tailings	130 - 390	19
Smelter slag and waste	195 - 390	22
Grand total to land	**804 - 1,820**	

1) The source (Nriagu and Pacyna, 1988) defines “wastage” as metals lost due to, e.g., corrosion or dispersion in soils from use of products. For lead, the sources are not specified further, but the majority may be the dispersion of lead through ammunition.

352. In a study undertaken in Kenya at the Dandora Municipal Dumping Site in Nairobi, soil samples around the dumpsite had lead levels ranging from 50-590 ppm while samples from within the dumpsite had a peak value of 13,500.00 ppm (UNEP, 2007). In Togo according to estimations by the International Fertilizers Group, the phosphate treatment factory at Kpémé releases approximately 3.5 millions tonnes of phosphate mining waste to the coastal waters of Togo. Those wastes show average lead contents of 69 ppm (Togo’s submission, 2007). In another study (1997) undertaken in Antananarivo the capital city of Madagascar, it was found that the lead content in soil at and near a landfill varied from 290 to 8550 ppm. (Madagascar’s submission, 2010).

353. In Hungary, sewage sludge may be applied to the agricultural fields if the rules of Government Decree No. 5/2001 ((IV.3.) Korm). The conditions set in the permit are complied with. Based on the data sent to the authority, the yearly amount of lead applied to the soil is estimated, as follows: 1.568 kg lead for 7.350 acre field size (2004), 1.581 kg for 7.069 acre field size (2005) and 1.188 kg for 6.406 acre field size (2006) (Hungary’s submission, 2007).

354. In Hungary, according to the Act No XLIII of 2000, enterprises are obliged to report to the authorites the yearly amount of wastes they produce. The report shall refer to European Waste Code (EWC), as it appears in the Annex of Community Decision 2000/532/EC (transposed to the national legislation by the KöM Decree No. 16/2001. (VII.18.) KöM. Table 5-10 below shows entries denoted by the EWC code and their respective denominations. These wastes are supposed to contain lead but,

due to lack of information on their composition, in most cases no information is available on the quantity of lead (Hungary's submission, 2007).

Table 5-10 Yearly amount [kg] of certain types of wastes produced in Hungary

Waste		Calendar year		
EWC code	**Denomination**	**2004**	**2005**	**2006**
060405	Waste containing other heavy metals	213.000	265.000	371.000
100401	Slags (first and second smelting)	18.500	128.000	90.900
100402	Dross and skimmings (first and second smelting)	264.000	182.000	172.000
100405	Other particulates and dust	10.200	7.300	8.700
101111	waste glass in small particles and glass powder containing heavy metals (for example from cathode ray tubes)	837.000	757.000	80.300
110101	Cyanidic (alkaline) waste containing heavy metals other than chromium	0	0	0
160601	Lead batteries	824.000	396.000	455.000

355. Compared with the total anthropogenic atmospheric lead emissions, which in the mid-1990s were estimated at 120,000 tonnes, and believed to be significantly lower today, the releases to land are on the order of ten times higher. One of the main questions is when and to what extent this lead in waste deposits will be mobilised and further released to the environment. According to data compiled by the Swiss Soil Monitoring Network (NABO), a first estimation indicates that 10 percent of the soil surface throughout the country shows values higher than the relevant guidance values for, amongst others, lead. The main inorganic pollutants monitored are a consequence of anthropogenic contamination primarily by lead, copper, cadmium and zinc. A combination of natural and anthropogenic processes of soil dynamics and monitoring procedures may influence the levels. After 10 years, 25 agricultural sites studied showed a high level of dynamics of the pollutants measured. The levels of lead measured in excess of guidance values in remote alpine and pre-alpine regions was attributed to long-range transport or to anthropogenic sources such as shooting ranges. Typical values of lead found in Swiss soils in the NABO monitoring campaign 1995-1999 show median lowest and highest values of 21.2 to 104.2 mg lead/kg soil and average lowest and highest values of 23.1 to 246.9 mg lead/kg soil. Further details of the Swiss soil monitoring network-changes in pollutant contents after 5 and 10 years can be found in Switzerland's submission, 2007.

356. A study entitled Potential Human Exposures from Lead in Municipal Solid Waste was prepared in May 1991 for the Lead Industry Association by Industrial Economics, Incorporated. The report focused on the potential exposures caused by the landfilling of unprocessed municipal solid waste and waste incineration, the two dominant refuse disposal practices in the United States. In the case of the disposal of unprocessed municipal solid waste, the potential for lead to leach from landfills and contaminate underground drinking water supplies was identified as the primary exposure pathway of concern. For waste combustors the likely routes of exposure included stack emissions, fugitive emissions and air monitoring data. Based on the results of the landfill and incinerator analyses the authors concluded "lead municipal solid waste does not pose a significant threat to public health, and as a result concerns about municipal solid waste should not be used as a basis for restricting uses of lead in consumer products that ultimately end up in the waste stream". A further study entitled Waste Analysis, Sampling, Testing and Evaluation (waste) Program: Effect of Waste Stream Characteristics on Municipal Solid Waste Incineration: the Fate and Behaviour of Metals examined the chemical concentration data and the disposition of lead and cadmium in waste management streams resulting from the incinera-

tion of waste in a municipal solid waste incinerator. This comprehensive four volume report provided detailed insight as to the levels of lead and cadmium entering the waste stream and their distribution throughout the incineration process (ILZRO's submission, 2007). With regard to information from the United States of America, data on disposal of lead as a hazardous waste can be found at http://www.epa.gov/osw/hazwaste.htm (United States' submission, 2007).

Accumulation of lead in farmland

357. The main sources of lead to farmland are atmospheric deposition and the use of lead shot. Based on an assessment of the loss of lead shot in the environment and the corrosion rate of lead shot in soil, Tukker *et al.* (2001) estimated that lead shot/ammunition will be responsible for 80 percent of total anthropogenic lead releases to soil in 2030 (EU15 countries). The report estimated that on average, lead releases may result in an annual enrichment of the upper 25 cm of the soil by 0.2-0.5 percent per year (0.048 mg/kg/year), which on average implies a doubling of the lead concentration in European soils in 200 to 500 years. For the estimate, an average natural background concentration of 10-30 mg/kg was assumed. For grasslands, in which the accumulation mainly takes place in the upper 5 cm, the report concluded that the lead content of the 5 cm top-layer may double in 40 years if a "clean" soil concentration of 10 mg/kg is assumed. However, according to ILZRO, the estimations of Tukker *et al.* study (2001) would be restricted to hotspots like firing ranges and not to all farmland of the EU states.

358. The lead content of soils varies considerably between countries, e.g. the geometric mean of soil lead content in England and Wales is shown to be 42 mg/kg (Thornton *et al.*, 2001), whereas in Danish agricultural soils (upper 30 cm) it is 11.3 mg/kg (Brønnum and Hansen, 1998). Reference is made to section 2.4 for further data on lead in the soils of different countries. The differences in background concentration reflect to some extent differences in mobility (and thus bioavailability) of lead in soils. In soils with low pH, and consequently high mobility of lead and relatively low background lead content, a load of 0.048 mg/kg/year would have a much more significant impact on the content of bioavailable lead than in soils with high pH and high background lead content.

359. Atmospheric lead deposition has been reduced significantly in the last decades, especially due to the elimination of leaded gasoline. In the developed regions, releases from other major sources have also been reduced.

Lead releases from the use of wheel balance weights

360. Lead is widely used for wheel-balancing weights for vehicles.. Some of the weights are lost when the weights "fly off" when a vehicle is jarred, or during suddenly velocity changes (U.S. EPA, 2005b). An annual loss rate of 10 percent has been calculated by Root (2000) on the basis of street surveys. The further fate of the lost balancing weights is uncertain (U.S. EPA, 2005b). The lost weights may end up in the soil along the road, in urban run-off, or be cleaned up by municipal street cleaners or, over time, be spread as windborne dust particles. In the U.S.A., about 23,000 tonnes of lead are used annually to make wheel-balancing weights (U.S. EPA, 2005b) and with an annual loss rate of 10 percent the total releases to soils and urban run-off would be approximately 2,300 tonnes.

Lead releases from the use of cable sheathing

361. A significant part of the lead used for cable sheathing is used for underground and undersea cables. Cables left in the ground or seafloor after the cable is abandoned can be considered a release to the environment. The global consumption of lead for cable sheathing in 2003 was about 75,000 tonnes (see section 6.3) but no data exist on the amount of lead dispersed in the environment with abandoned cables.

Lead in products directed to landfills

362. Studies from Denmark and the Netherlands indicate that about 10 percent of the total flow of lead with products is ending up in landfills (Hansen *et al.*, 2002). As lead compounds (which in most countries are hardly recycled) account for about 10 percent of global consumption, it is highly probable that at least 10 percent of the consumption is accumulated in landfills. With a global consumption of about 7 million tonnes (see section 6.3), the amount of lead ending up in landfills with discarded prod-

ucts could be 500,000-1,000,000 tonnes. In recent years, however, recycling of lead glass of cathode ray tubes (the principal use of lead compounds in 2001) in many countries may result in a significant decrease in the total amount of lead landfilled with products.

5.2.3 Particulars on lead in ammunition and sinkers

363. The use of lead shot and other ammunition where lead is used leads to significant releases of lead to terrestric and aquatic environments. Whereas releases to the terrestric environments result mainly in local impacts releases of lead shot in wetlands has a transboundary perspective.

Lead releases to soil

364. The major source of direct lead releases to soil is the use of ammunition. In 2003, the total global consumption of lead for ammunition was about 120,000 tonnes (in Table 6-5 the figure of 104,000 tonnes represents about 86 percent of the world total). Ammunition is partly used for hunting and lost to the environment, and partly used in shooting ranges, where the lead is either accumulated at the range or collected for recycling.

365. In a study conducted for the European Commission, Hansen *et al.* (2004a) estimated that in total, 39,000 tonnes of lead were used for ammunition in the EU15 in 2003. Through hunting activities, about 3,500 tonnes (best estimate) of lead were released to wetlands, and about 14,000 tonnes to other biotopes (grassland, forests, etc.) (best estimate). The remaining part was mainly used in shooting ranges. It should be noted that the breakdown of the total use of lead shot into the different application areas is quite uncertain, and consequently the actual releases to the different environmental compartments is also uncertain. In the EU15, consequently, about half of the used ammunition was released directly to the environment, although the percentage may vary among countries.

366. In Japan in 2004, 1,440 tonnes of lead were used in shooting ranges, whereas only 158 tonnes were used in field hunting (Japan's submission, 2005). Scheuhammer and Norris (1995) estimated that about 2,000 tonnes of lead were discharged with ammunition in Canada in the mid-1990s. Of this, about 780 tonnes were used for waterfowl hunting (wetlands) and about 1,110 tonnes for other hunting activities.

367. Lead accumulated in shooting ranges may represent a risk of contamination of groundwater and surface water and limit the future use of the area. A comprehensive survey of soil contamination of shooting ranges in Germany from 1998 (Working Group, 1998) demonstrated only a few cases of groundwater contamination in the vicinity of shooting ranges, but concluded that the lead accumulated in the soil in the long term, depending on the conditions at the site, represents a considerable risk for the surroundings. The extent of lead-contamination of shooting ranges was indicated by a calculation showing that 137 ranges in Lower Saxony, Germany, were contaminated with 2,722 tonnes of lead (as of 1990).

Release of lead shot and sinkers in wetlands and aquatic environments

368. The releases of lead shot and small fishing sinkers to wetlands are of particular concern due to the high risk of poisoning of birds ingesting the lead shot (further discussed in section 5.2.4). Besides the local impact, the lead pollution of wetlands has a transboundary perspective, as wetlands are important habitats for migrating birds. Reduction of the use of lead shot in wetlands is, for this reason, addressed in the Agreement on the Conservation of African-Eurasian Migratory Waterbirds as described in section 9.2.7. According to the Action Plan of the Agreement, Parties shall endeavour to phase out the use of lead shot for hunting in wetlands by the year 2000.

369. As quoted above, it is estimated with some uncertainty that about 3,500 tonnes of lead, corresponding to approximately 10 percent of the total lead consumption for ammunition, were released to wetlands in the EU in 2003 (Hansen *et al.*, 2004a). Scheuhammer and Norris (1995) estimated that about 780 tonnes were used for waterfowl hunting in Canada in the mid-1990s.

370. Small sinkers for angling may also be ingested by birds, which is the rationale behind the prohibition in the United Kingdom of the use of lead split shot and sinkers above 0.06 grams and below 28.35 grams (1 ounce) in freshwater (see section 9.1) (Hansen *et al.,* 2004a).

371. Besides the poisoning of birds, the loss of lead sinkers in inland waters is of concern in some countries. The fate of lead shot and sinkers in the aquatic environments is highly dependent on the chemistry of the water and mechanical disturbances. Highest corrosion rates are expected in rivers with acidic water and high velocity, whereas low rates are expected in sedimentation areas in the marine environment. Relatively high corrosion rates of about 1 percent per year have, e.g., been demonstrated in lead sinkers in Swedish rivers (pH 6.3-6.7) with a high velocity (Jacks and Bystöm; 1995). For this reason, the use of lead sinkers has been abandoned in many Swedish rivers (Hansen *et al.,* 2004a)

5.2.4 Releases to the aquatic environments

372. The direct releases to aquatic environments are considered to be relatively small compared to the releases to the atmosphere and land. The total releases to water in 1983, excluding atmospheric deposition, were estimated at 10,000-67,000 tonnes (Table 5-11). Added to this is the atmospheric deposition in aquatic environments estimated at 87,000-113,000 tonnes. Deposition has, in recent decades, decreased significantly due to the decrease in total atmospheric emission. Other major sources were: domestic wastewater, non-ferrous metal smelting and refining, metal manufacturing processes and dumping of sewage sludge.

373. In industrialised countries, the direct releases of lead to water environments have decreased significantly due to improved treatment of wastewater. Lead is mainly associated with particles in the water (see section 2.3) and through wastewater treatment, lead is effectively removed with the sludge. In Danish treatment plants for domestic wastewater, about 96 percent of the lead in wastewater ends up in the sludge. In this case, untreated urban run-off, and wastewater bypassing the treatment plants through heavy rainfall, may be higher in lead content than the releases with the outflow from the wastewater treatment plants (Lassen *et al.,* 2004).

Table 5-11 Global lead releases to the aquatic environments in 1983 (derived from Nriagu and Pacyna, 1988)

Source category	**1000 tonnes Pb/year**	**Percent of grand total to land (mean value)**
Domestic wastewater	1.5 - 12	4.9
Steam electric	0.24 - 1.2	0.5
Base metal mining and dressing	0.25 - 2.5	1.0
Smelting and refining:		
- Iron and steel	1.4 - 2.8	1.5
- Non-ferrous metals	1 - 6	2.5
Manufacturing processes:		
- Metals	2.5 - 22	8.8
- Chemicals	0.4 - 3	1.2
- Pulp and paper	0.01 - 0.9	0.3
- Petroleum products	0 - 0.12	0.0
Atmospheric deposition	87 - 113	72.2
Dumping of sewage sludge	2.9 - 16	6.8
Total input to water	**97 - 180**	**100**

374. Examples of inventories of lead releases to aquatic environments from country submissions are shown in Table 5-12. Major differences are evident among the countries. In Australia, with its extensive non-ferrous base metal industry and mining (Australia's submission, 2005), these two source categories account for the majority of the discharges. In Japan, non-ferrous industry and discharges from wastewater treatment plants are the major sources, whereas off-shore oil and gas extraction is the major industrial source in Denmark. Denmark also reports on releases of lead contained in products. Large amounts of lead metal are lost to the sea due to fishing sinkers and the lead sheathing of abandoned cables left on the sea-floor. This practice is probably not different in other countries, but not reported. In Norway, with extensive off-shore activities, these activities account for the major part of the discharges to the sea.

375. In Togo, transport at the level of the marine environment is mainly due to littoral drift (stronger East side) and the rip current (current headed out to sea). These currents transport natural and anthropogenic heavy-metal contaminated sediments over long distances along the coast and out to sea and are the cause of the spread of phosphate mining wastes that pollute the Togolese coast and that of neighbouring countries such as Benin and Nigeria (Togo's submission, 2007).

376. Additional information on the atmospheric deposition of lead to the marine environments is available (*Migon et al.*, 1991). The input of lead through rainfall and dry deposition to the Ligurian Sea, France was measured for two years (1986 and 1987). The total flux was in the range 3.3-18 kg km^{-2} $year^{-1}$ corresponding to an input of between 175 and 950 tonnes of Pb per year. The dry deposition for is within the range 8-93%. It was noted that, in this part of the Mediterranean Sea, atmospheric inputs are far higher than those from rivers. This contrasts with the Baltic Sea where about 65% of the Pb is due to waterborne species (i.e. from rivers or as direct discharges) (HELCOM, 2005).

Lead in fishing sinkers

377. In the EU, a total of 1,000 - 3,000 tonnes of lead was used for angling in inland waters in 2004, and a similar amount was used for angling in the sea (Hansen *et al.,* 2004a). Most of the lead is assumed

to be lost to the waters. Besides the use of lead sinkers for angling, some 2,000 - 9,000 tonnes of lead were used for commercial fishing. Of this, 100-1,800 tonnes were estimated to be lost to the sea through the wear of sinkers and loss of fishing tools. Consequently, the total releases of lead to waters in the EU were estimated at 2,100- 7,800 tonnes.

378. Canadian experts estimated that the volume of lead sold as fishing sinkers annually in Canada is in the range of 388 - 559 tonnes (Scheuhammer and Norris, 1995). Virtually all of this lead is, according to the authors, assumed to be deposited in the environment.

379. These releases of lead to the aquatic environments are not included in the global survey of releases to aquatic environments in Table 5-12 but may, as indicated by the estimates presented, be a significant source.

Table 5-12 Sources of lead to aquatic environments (tonnes/year) - examples

Source category	**Japan** [1] **2003** **Industry**	**Australia** [2] **2003/04**	**Denmark** [3] **2000**	**U.S.A.** [4] **2004**	**Norway** [5] **2002**
Electricity supply		0.19		17.3	
Extraction and manufacturing					
Metal ore mining		18		4.3	
Coal mining		0.2			
Off-shore oil and gas extraction			2 - 4		24.6
Non-ferrous base-metal industry	9.8	9.7		11.2	
Iron and steel industry	1.6	0.81			
Metal industry	0.2				
Chemical industry	0.1			1.9	
Ceramics, stone and clay products	1.3	0			
Paper manufacturing				11.9	
Petroleum industry				5.0	
Other industry	1.1	0.534		3.8	7.1
Waste treatment					
Sewerage treatment, drainage service and water supply	13.0	1.4	1 - 2.5		1.6
Urban run-off and bypass by heavy rainfall			1.6 - 4.3		
Scrap storage and treatment			0.03 - 0.19		
Use of products					?
Loss of fishing sinkers and lead ropes			117 - 290		
Corrosion of red lead on steel structures			1 - 3		
Sheathing of cables left on the sea floor			50 - 300		
Total	**27.1**	**30.8**	**170 - 600**	55.3	>33.4

Based on the following information sources:

1) (Japan's submission, 2005).

2) (Australia's submission, 2005).

3) Lassen *et al.*, 2004, submitted by Denmark. Note that the use of lead shot in wetlands was banned at the time of the inventory.

4) Toxics Release Inventory (TRI) database retrieval, August 2006, as suggested in (United States' submission, 2006). Included lead and lead compounds. Does not include discharges from sewage treatment plants.

5) Berg *et al.*, 2003, submitted by Norway.

5.3 Remobilisation of historic anthropogenic lead releases

380. Remobilization of historic anthropogenic lead releases denote the effect that lead formerly deposited or disposed in the environment is remobilized - moved around - in the physical environment and sometimes between environmental compartments (terrestrial, aquatic and atmospheric compartments). This issue is summarised here briefly to round up the overview of releases to and fluxes in the environment of lead; a more comprehensive description has not been possible within the frames of the devel-

opment of this review. As indicated in the introduction to Chapter 5, re-mobilization in the environment of historic anthropogenic lead releases embraces several somewhat different phenomena:

- Remobilization of lead previously deposited from the atmosphere via re-allocation of lead-bearing dust particles by wind and precipitation (lead originating from anthropogenic as well as natural sources). Quantitative data on this phenomenon are scarce.
- Remobilization of lead previously deposited with sediments in river beds, coastal areas and other aquatic environments via natural or anthropogenic physical impacts. Some examples of quantification of this phenomenon exist.
- Remobilization of lead previously deposited in general, hazardous and industrial waste landfills, and uncontrolled dumpsites, via anthropogenic or natural physical impacts (anthropogenic: urbanization, construction, excavation; natural: climatic impacts in a longer perspective). Certain aspects of involved phenomena are quantified in developed countries, but data are very scarce on this aspect for large parts of the developing regions of the world.
- Remobilization of lead historically deposited with mine tailing and waste rock under active and well controlled environmental management (waste management and rehabilitation). Most industrial scale operations involved in lead mining fall under this category, and remobilization from these operations are well quantified (though data are not always publicly available). However, some producers continue to have significant potential for improvements in both technology and environmental management.
- Remobilization of lead historically deposited with mine tailing and waste rock in episodic events of low frequency but with significant local and regional impacts (due to natural phenomena or as a result of failed engineering structures).

381. In relation to these topics, mining activities resulting in residues (for example, tailings ponds and waste rock) are a potential source of metal pollution in the event of an acid spill or release. A clear example of this situation took place on 25 April 1998, when the tailing dam at the Aznalcóllar mine (70 km north of Doñana National Park, South West Spain) collapsed and the valleys of the Agrio and Guadiamar Rivers were flooded with more than 5 million m^3 of toxic sludge, dissolved in acidic water (ca. pH 2), heavily polluting the downstream areas with heavy metals, including lead. The bulk of the sludge was removed during the four months after the collapse, but about 0.1 to 5 percent remained mixed with the uppermost layer of the soil. The source of contamination was located inland but the contaminants were transported by the rivers and accumulated in the soils and sediments (OSPAR, 2004).

382. Ecuador reports observations of mining activities in the country releasing a number of heavy metals, including lead, to nearby rivers (Ecuador's submission, 2006).

383. In a study undertaken in Cameroon, it was estimated that from 1992-2005, assuming that each motor vehicle and motorcycle imported had used only one battery in its life span, 28,962,699 kilograms of lead had accumulated during 14 years representing about 36 *percent* of secondary lead recovered in Africa annually (Tetsopgang, *et al.* 2007).

384. Countries around the world may have similar problems of different dimensions concerning the handling of historic anthropogenic lead deposition.

6 Production, use and trade patterns

6.1 Global production

385. In 2004, world mine production of lead was 3,150,000 tonnes. Lead is mined in more than 40 countries worldwide. Production and reserves by country in 2004 are shown in Table 6-1. The major producers were China and Australia, representing 30 percent and 22 percent, respectively, of global mining production. The measured lead reserves (the amount that can be economically extracted with today technology) in 2004 totalled 67,000,000 tonnes, equalling about 21 years of production at the 2004 level. The identified lead resources (including resources that cannot be economically extracted with today's technology) of the world total more than 1,500 million tonnes (USGS, 2006).

386. Lead-rich minerals most often 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).

387. After mining, the lead-rich ore (typically 3-8 percent lead) is separated from the other minerals to form ore-concentrate. The ore concentrate is converted into metallic lead with impurities by a smelting process, and the impurities are subsequently removed by pyrometallurgical or electrolytic refining. The different steps often take place in different countries, and there is extensive trade of intermediary raw products, as discussed in the next section.

Table 6-1 Mine production of lead, and reserves by country in 2004 (USGS, 2006)

Country	**Mine production 2004 1000 tonnes Pb**	**Percentage of global production**	**Reserves [1] 2004 1000 tonnes Pb**
China	950	30	11,000
Australia	678	22	15,000
United States	445	14	8,100
Peru	271	9	2,000
Mexico	139	4	1,500
Canada	77	2	2,000
Morocco	65	2	500
Ireland	65	2	NA
Kazakhstan	40	1.3	5,000
India	40	1.3	NA
South Africa	37	1.2	400
Sweden	34	1.1	500
Other countries	275	9	19,000
World total (rounded)	**3,150**	**100**	**67,000**

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.

NA: not available

388. The total global mine production of lead has decreased slightly over the last thirty years from 3.6 million tonnes in 1975 to 3.1 million tonnes in 2004 (Figure 6-1). During the same period, global refined lead production and metal consumption have increased from about 4.7 million tonnes to about 7.1 million tonnes.

389. The data in Figure 6-1 and the following tables are obtained from publications from the International Lead and Zinc Study Group (ILZSG). ILZSG is an inter-governmental organisation, formed by the United Nations in 1959, and is one of the longest-established International Commodity Organisations. ILZSG regularly brings together 28 member countries in an international forum to exchange information on lead and zinc (see list of member countries at http://www.ilzsg.org/ilzsgframe.htm). According to ILZSG, the member countries represent 90 percent of world production and over 80 percent of world consumption of both lead and zinc. ILZSG provides a unique and globally-recognised source of industry statistics and organises twice-yearly meetings between producing and consuming countries, industry and government representatives. The statistics also include data for non-member countries, though some statistics on, e.g., consumption by use category mainly include statistics from member-countries.

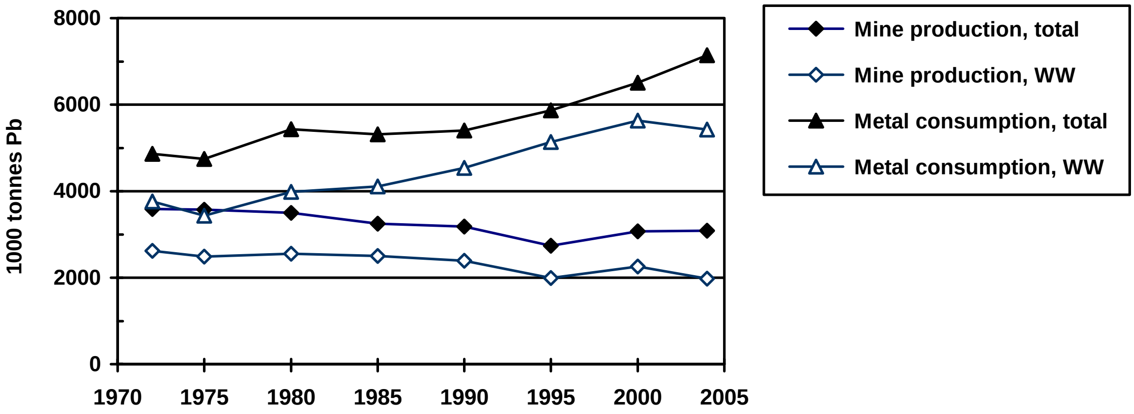


Figure 6-1 Lead mine production and metal consumption, total world and Western World (WW,) 1975-2004 (ILZSG, 2006). Note: The term "Western World" and the differentiation is today considered historic, but is used because historic information on the use of lead has mainly included this part of the world. "Western World" excludes the formerly "Eastern Countries" without market economy; first of all, countries in Eastern Europe and China.

390. The differences between mine production and consumption indicate the magnitude of the supply of recycled lead from discarded lead products and residues, drosses, wastes, etc. from fabricating/processing operations. Worldwide production, recovery and consumption of lead metal in 2004 by continent are shown in Table 6-2.

391. Secondary lead[7] accounted for 45 percent of global lead consumption. Large differences are seen among the continents, ranging from 75 percent in North America to 21 percent in Asia. These percentages do not indicate the efficiency of collection and recovery of lead scrap in these continents. The small percentage for Asia reflects, e.g., partly the steep increase in the motorisation in the region, and partly the extensive export of, e.g., cars equipped with batteries. The combining of information on mine

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[7] ILZSG definition of secondary lead: Production of refined lead and refined lead alloys from scrap materials (lead acid batteries, lead sheet, strip, pipes, cable sheathing, etc.) together with residues, drosses, wastes, etc. from fabricating/processing operations. Re-melted lead and lead alloys recovered from secondary materials without undergoing a full refining process are excluded.

production, refined lead production and recovery of secondary lead clearly indicated that Europe and Asia are net importers of raw materials for further refining, while Oceania (mainly Australia) and South America are net exporters, as discussed further in the next section. In North America and Africa the consumption is largely of the same size as the production of refined lead.

392. Most recycled lead comes from used lead batteries, with the remainder coming from other sources such as lead pipe, sheets, cable sheathing and wastes from fabricating/processing operations. In the U.S.A. in 2003, battery lead accounted for 92 percent of recycled lead, production scrap and wastes for 3.5 percent and all other discarded lead-based and copper-based products for the remaining 4.3 percent (USGS, 2003).

393. The market value of the 1998 production of lead ore is estimated at US$ 2.2 billion. It has been estimated that all mining, smelting and refining operations worldwide are worth around $15 billion per year. Worldwide employment provided by lead mining, smelting and refining is around 72,000-89,000, with a further 2,400 employed in lead oxide production (Thornton *et al.*, 2001).

Table 6-2 Worldwide production, recovery of secondary lead and consumption of lead metal in 2004 (ILZSG, 2006)

Continent [1]	**All figures in 1000 tonnes lead per year**				
	Mine Production	**Refined lead production (primary and secondary)**	**Recovery of secondary lead** [2]	**Consumption of refined lead**	**Secondary lead recovery in percent of consumption of refined lead**
Europe	219	1,557	982	1,969	50
Africa	117	100	81	116	70
North America	658	1,745	1,356	1,816	75
Central and South America	349	270	147	224	66
Asia	1,102	2,879	626	2,975	21
Oceania	642	281	46	40	115
Total	**3,087**	**6,833**	**3,239**	**7,141**	**45**

1) In the demarcation of Europe and Asia, the Russian Federation is included in Europe, whereas Turkey is included in Asia (ILZSG, 2006). North America consists of the U.S.A., Canada and Mexico. Australia and New Zealand are included in Oceania.

2) ILZSG definition of secondary lead: Production of refined lead and refined lead alloys from scrap materials (lead acid batteries, lead sheet, strip, pipes, cable sheathing, etc.) together with residues, drosses, wastes, etc. from fabricating/processing operations. Re-melted lead and lead alloys recovered from secondary materials without undergoing a full refining process are excluded.

6.2 Use and trade patterns in a global perspective

394. Lead is bought and sold by many countries on the world market, in the form of ore or ore concentrate, smelted but unrefined metal, refined metal and final products. Net export by continent is shown in Table 6-3. The data cover countries ILZSG member countries only, which explain that the net export of continents do not correspond to the net import resulting in a difference to balance. Europe and Asia are net importers of lead in concentrates and ores and lead bullion imported for further refining in the two continents. The data on trade of refined lead metal and lead alloys are more difficult to interpret as the difference to balance indicates that a significant part is exported to countries not members of ILZSG.

Table 6-3 Worldwide trade of lead ores/concentrates, refined lead and lead bullion between continents (ILZSG, 2006)

Continent [1]	**Net export from the continent to other continents (1000 tonnes Pb/ year)** [2]		
	Lead ores and concentrates	**Refined lead and lead alloys**	**Lead bullion** [3]
Europe	-51	-217	-156
Africa	67	4	0
North America	171	16	0
Central and South America	220	49	0
Asia	-733	434	-25
Oceania	264	211	150
Difference to balance	**-62**	**497**	**-31**

1) In the demarcation of Europe and Asia, the Russian Federation is included in Europe, whereas Turkey is included in Asia (ILZSG, 2006). In this table, North America consists of the U.S.A., Canada and Mexico. Australia and New Zealand are included in Oceania.

2) The data cover mainly trade with other ILZSG Member States.

3) Lead bullion is impure molten lead.

395. In order to illustrate the extensive global trade with lead raw materials, China's import and export by partner country (members of ILZSG) is shown in Table 6-4. China is the world's major producer and user of lead with a primary refined lead production in 2004 of 1,812,000 tonnes and a secondary (recycled) refined lead production of 313,000 tonnes. The major exporters of lead concentrates and ores to China were Australia, Peru and U.S.A., while the major importers of refined lead from China were the Republic of Korea, Taiwan and Thailand. Additional information on the global flow of products can be obtained by an analysis of products recalled by the U.S. Consumer Products Safety Commission (see www.cpsc.gov – United States' submission, 2007).

Table 6-4 China's trade of lead ore and concentrates, refined lead and lead bullion by partner country (ILZSG, 2006) [1)]

	Trade with other countries (1000 tonnes Pb/year)					
Country	**Lead ores and concentrates**		**Refined lead and lead alloy**		**Lead bullion**	
	Import	**Export**	**Import**	**Export**	**Import**	**Export**
Australia	84		15			
Brazil				2		
Canada	2					
Germany	12					
Hong Kong, China				40		
India	11			30		
Indonesia				42		
Italy				12		
Iran	14					
Japan				7		
Korea, Rep. of	34		8	95		
Malaysia				40		
Mexico	7					
Namibia	12					
Netherlands				6		
Peru	103					
Philippines				5		
Russia	1					
Singapore				16		
Spain	3					
Taiwan, China				77		
Thailand				57		
U.S.A.	97					
Other	73		23	19		
Total	**453**	**0**	**46**	**448**	**42**	**17**

1) The data are considered mainly to include trade with ILZSG member countries.

6.3 End Uses

396. The global consumption of lead by end-use has, during the period 1970 to 2003, increased from 4.5 million tonnes to 6.8 million tonnes (see Table 6-5).

397. Lead is used for a large number of applications. Because of its softness, pure lead is only used for a few applications. In metallic applications, lead is most often alloyed with small amounts of antimony (e.g., in batteries, flashing and cable sheathing), copper (e.g., in lead sheets and lead pipes), calcium (e.g., in batteries) or silver (e.g., in solders). In addition, lead is used as an alloying element in alloys of copper (some brass and bronze alloys) and tin (pewter, solders).

398. Its properties include: a low melting point, ease of casting, high density, low strength, ease of fabrication, acid resistance, corrosion resistance, electrochemical reaction with sulphuric acid and the ability to attenuate sound waves, ionising radiation and mechanical vibration.

399. The global consumption by end-use in 2003 is shown in Table 6-5, along with information on the consumption by end-use in the OECD countries in 1970 and 1990. The 2003 break-down by end-use is based on information from ILZSG member–countries, which in total represent about 86 percent of the total global consumption of lead. The OECD figures represent 68 percent and 60 percent of the consumption in 1970 and 1990, respectively.

400. The most significant changes in the overall use pattern are the increased consumption for batteries, and a decrease in the areas of cable sheathing and petrol additives.

401. **Batteries** – In 2003, batteries - technically termed "accumulators" - accounted for 75 percent of total lead consumption. Lead is present in batteries in both metallic and chemical form. The major application of lead batteries is starter batteries for vehicles, and the consumption for this application area will largely reflect the number of vehicles in the different countries. Other major applications are traction batteries for electric trucks, and stationary batteries for back-up power supply. Concerns regarding the use of lead with batteries are mainly related to the disposal of the used batteries, as further discussed in section 8.4.

402. **Ammunition** - Lead is used in different types of ammunition. The major application is lead shot for shotguns. Of the 52,700 tonnes of lead used in ammunition in the EU15 in 1993, 90 percent was used for lead shot, the remaining 10 percent used for bullets for rifles and pistols (Hansen *et al.*, 2004a). Of particular concern are the significant releases of lead shot to wetlands and other biotopes through hunting, as discussed in section 5.2.4.

403. **Petrol additives** - The marked decrease in the use of petrol additives is mainly the result of use-restrictions in most countries. Lead, in the form of tetraethyl-lead and tetramethyl-lead, can be used as an anti-knocking agent in petrol. Through this use, lead is released in the form of different lead compounds to the atmosphere. As shown in Table 6-5, petrol additives accounted for 10 percent of lead consumption in the OECD countries in 1970; at that time, petrol additives were by far the major source of lead releases to the atmosphere. The use of lead for manufacturing of gasoline additives, as reported to ILZSG, decreased from 31,500 tonnes in 1998 to 14,400 tonnes in 2003. Mexico and the United Kingdom were the only countries reporting the use of lead for this purpose. Today, leaded gasoline for vehicles has been phased out in most countries, but remains in use in some regions (see below).

404. The UNEP Partnership for Clean Fuels (see section 9.3.7) continuously monitors progress on the phase-out of leaded petrol globally. At the beginning of 2008, 19 countries worldwide were still using leaded gasoline. Within the year, three countries – Jordan, Lao People's Democratic Republic, and Mongolia as well as the Occupied Palestinian Territory – have ceased using leaded gasoline and an additional two countries – Afghanistan and Morocco – are expected to phase out its use at the end of 2008. Tunisia, expected to phase out such use at the end of 2008, in the Partnership national awareness raising activity, committed to phase out leaded gasoline at a date in the near future to be communicated. For information on countries still using leaded gasoline, consult the Partnership for Clean Fuels and Vehicles website (www.unep.org/pcfv)

405. Moreover, leaded gasoline (so called AVGAS) is still used for some types of propeller-driven aircraft in most countries. Global consumption figures have not been available. In Norway 2.5 tonnes lead was released to the atmosphere from aviation activities in 2002 (SFT, 2004), while in Sweden the release is estimated at about 5 tonnes (Ny Teknik, 2005).

406. **Cable sheathing** - The decrease in the use of lead for cable sheathing has partly been driven by environmental concern in some countries, and partly by development of alternative sheathing materials.

407. **Sheets** - Lead sheets are mainly used for roofing and flashing. Alternatives to lead sheets for flashing have recently been developed, as further mentioned in section 8.1.

Table 6-5 Lead consumption by end-use in OECD countries in 1970 and 1990, and globally in 2003

Category	**Lead consumption in OECD countries**				**Lead consumption, ILZSG reporting countries**	
	1970 1)		**1990 1)**		**2003 2)**	
	1,000 tonnes lead	**Percentage**	**1,000 tonnes lead**	**Percentage**	**1,000 tonnes lead**	**Percentage**
Batteries	1,190	39	2,120	63	4,590	78
Cable sheathing	370	12	170	5	71	1.2
Rolled/extruded lead (mainly sheets)	370	12	300	9	319	5
Ammunition	120	4	100	3	104	2
Alloys	210	7	130	4	115	2
Lead compounds	340	11	340	10	481	8
Petrol additives	310	10	70	2	14	0.2
Miscellaneous	150	5	130	4	192 3)	4
Total	**3,050**	**100**	**3,365**	**100**	**5,889**	**100**
Total World	**4,502**		**5,627**		**6,852 4)**	

1) Source: (OECD, 1993). Volumes are recalculated from data on percentages and total consumption.

2) Source: (ILZSG, 2005). Countries included: Australia, Austria, Belgium, Brazil, Canada, China, Czech Republic, Finland, France, Germany, India, Italy, Japan, Republic of Korea, Mexico, Netherlands, New Zealand, Scandinavia, South Africa, South East Asia, Spain, Switzerland, United Kingdom, United States of America. This represents about 86 percent of total global consumption.

3) The category "Semi-manufacturers" reported for China and Czech Republic is included in "rolled/extruded lead".

4) Source: (ILZSG, 2006).

408. The largest user of lead in 2003 was the U.S.A. (1,470,000 tonnes), followed by China (1,180,000 tonnes) and the Republic of Korea (350,000 tonnes) (ILZSG, 2005). The consumption of lead in China more than doubled from 510,000 to 1,180,000 tonnes during the period from 1998 to 2005.

409. Lead consumption by first-use in 6 countries is presented in Table 6.6 "First use" means, in practice, the use of refined (as opposed to recycled) lead for manufacturing of lead products. Thus, the differences among countries to some extent reflect the industry structure of the country as it pertains to the manufacture of lead-containing products. In the Republic of Korea, batteries account for 87 percent of lead consumption, reflecting the significant car industry in the country. A majority of the lead will be exported with the finished products. Similarly, the large consumption of lead for ammunition in Italy (6.4 percent) reflects the fact that Italy is the major producer of ammunition in Europe with a significant export (Hansen *et al.*, 2004a). In the United Kingdom, rolled/extruded lead accounts for 46 percent of consumption. This may partly reflect some regional differences in the use of lead for building purposes. Due to tradition and the style of buildings, the consumption of lead sheets for building purposes, notably lead roof flashing, is significantly higher in northern European countries than in southern European countries (Tukker *et al.*, 2001).

Table 6-6 Lead consumption by first-use in 2003 [1)]

Application area	**Percentages of total lead consumption (first use) in 2003**					
	Rep. of Korea	**China**	**Italy**	**United Kingdom**	**India**	**Mexico**
Batteries	87.2	79.5	81.1	33.3	77.0	85.6
Cable sheeting	0.7	1.9	0.6	3.3	4.2	0.2
Rolled/extruded lead (mainly sheets)	0.8	1.9	0.0	45.6	0.0	0.0
Ammunition	0.0	0.0	6.4	2.3	0.0	0.0
Alloys	0.1	0.0	0.3	4.1	6.1	1.2
Lead compounds	6.1	10.0	7.5	6.4	10.7	6.0
Petrol additives	0.0	0.0	0.0	3.3	0.0	2.4
Miscellaneous	5.2	6.8	4.2	1.8	2.0	4.6
Total	**100**	**100**	**100**	**100**	**100**	**100**
Total (1000 tonnes Pb/year)	**349**	**1,183**	**236**	**247**	**142**	**259**

1) Source: (ILZSG, 2005). Shows the percentages of lead for "First-use", i.e. mainly consumption of lead for manufacturing of lead-containing products in the country.

410. The distribution of the consumption of lead for "first-uses" in a country may be significantly different from the distribution of lead in traded end-products, in particular for smaller countries. Due to the extensive import and export of lead in traded products, it is usually difficult to obtain exact figures for the consumption of lead by end-use.

411. An example, including a detailed break-down of the consumption of lead by end-use in Denmark in 1985, 1994 and 2000, is shown in Table 6-7. For many of the major product groups, only small changes are seen over this period. The most significant changes are the decreases in the use of lead for cable sheaths, lead shot, red lead, lead pigments and petrol additives.

412. The unintentional content of lead as an impurity in coal, lime, cement, etc., amounted to less than one percent of the total lead content of end-products. Whereas the unintentional mobilisation of lead appears insignificant in this context (consumption by end use), it is of much greater significance as it concerns releases to the environment, as discussed in Chapter 5.

Table 6-7 Consumption of lead by end-use in Denmark in 1985 and 2000 (based on Lassen et al., 2004)

Product group	Consumption (tonnes Pb/year) 1)			Percentage in 2000
	1985	1994	2000	
Lead metal				
Starter batteries	}10,900 - 12,600	6,900 - 7,700	6,900 - 7,700	42
Other batteries (traction and stationary)		1.200	1,600 - 1,800	10
Building materials (mainly sheets for roofing and flashing)	3,500 - 3,700	2,850 - 4,100	3,700 - 4,100	23
Lead shot	about 870	100 - 160	20 - 39	0,2
Other ammunition	about 150	250 - 300	94 - 164	0,8
Keels	800 - 900	50 - 150	240 - 740	3.0
Cable sheaths	2,400	2,000 - 2,300	353 - 383	2.2
Lead-tin alloys	200 - 300	260 - 380	190 - 350	1.6
Other alloys (mainly copper alloys)	300 - 550	150 - 300	170 - 350	1.5
Commercial fishing (sinkers, leaded ropes)	} 400 - 600	300 - 600	430 - 740	3
Angling (sinkers, jigs, etc.)		75 - 125	97 - 170	0,8
Balancing weights (cars, windmills, etc.)	150 - 200	200 - 250	76 - 160	0,7
Radiation shielding	200 - 400	200 - 250	41 - 440	1,4
Other applications as metal	150 - 600	90 - 290	26 - 110	0,4
Chemical compounds				
Red lead (for corrosion resistance)	40 - 65	20 - 35	0.5 - 2	<0.1
Pigments	250 - 400	35 - 110	17 - 70	0.3
Cathode ray tubes	not included	550 - 900	520 - 640	3.0
Other glass (mainly crystal glass)	60 - 80	70 - 80	140 - 340	1.4
PVC (stabilizers)	200	300 - 400	440 - 570	3.0
Ceramics and enamels (glazing)	80 - 100	25 - 150	40 - 150	0.6
Petrol additives (piston engine aircraft)	250	2 - 10	1.6 - 2	<0.1
Other uses as chemical	100 - 200	12 - 40	13 - 74	0.3
As natural trace element				
Coal	250 - 300	42 - 125	40 - 67	0.3
Other products	50 - 240	40 - 115	37 - 73	0.1-0.2
Total (rounded)	**21,200 - 25,100**	**15,500 - 19,800**	**14,900 - 19,000**	**100**

1) "Consumption" is defined as the content of lead in end-products sold in the country during the year in question.

Lead compounds

413. Between 1970 and 2003, lead compounds, other than those used for petrol additives and batteries, accounted for about 10 percent of total lead consumption (Table 6-5), but some major changes within this category have taken place. A breakdown of consumption in "Western World" countries (see notes to the table for definition) is shown in Table 6-8. In 2001, the major applications of lead compounds were leaded glass used for cathode ray tubes and crystal glass, and plastic additives (mainly stabilizers for PVC). Formerly, lead pigment for paints and ceramics took up a greater share, but the consumption of pigments for these applications has decreased in recent decades.

414. **Cathode ray tubes** - The use of lead glass for radiation shielding in cathode ray tubes (CRTs) will soon be an historic application, as CRT technology is in the process of being replaced by flat-panel technology. Flat panels, and particularly plasma display panels (PDP), also contain leaded glass, but the content per panel is significantly lower than for CRTs. The purpose of leaded glass in flat panels is different from its purpose in CRTs. Of particular concern regarding lead in CRTs is the long-term fate of the large amounts of lead directed to landfills with used CRTs, as discussed in section 8.4.

Table 6-8 Lead compounds consumed by end-use in "Western World" countries, 1975 and 2001 (excluding petrol additives and lead compounds in batteries).

Application	**1000 tonnes Pb/year**		**Percentages of total**	
	1975 1)	**2001** 2)	**1975** 2)	**2001** 2)
Glass compounds:				
Cathode ray tubes	70,000	157,000	20	38
Crystal glass	63,000	62,000	18	15
Specialty glass/optical glass	42,000	16,000	12	4
Light bulbs	17,500	12,000	5	3
Other compounds:				
Plastic additives	73,500	99,000	21	24
Glazes	17,500	37,000	5	9
Paints	49,000	21,000	14	5
Ceramics	17,500	8,000	5	2
Total	**350,000**	**412,000**	**100**	**100**

1) Total volumes by application area is recalculated from the percentages (see note 2) and a total volume of 350,000 tonnes lead used for lead compounds in 1975 (Burrell, 2006).

2) Source: (ILZSG, 2004). Volumes are recalculated from data on percentages and total consumption. The term "Western World" and the differentiation is today considered historic, but is used because historic information on the use of lead has mainly included this part of the world. The term "Western World" excludes the formerly "Eastern Countries" without market economy; first of all, countries in Eastern Europe and China.

415. **Pigments** - The use of lead for pigments has decreased from 14 to 5 percent of the total consumption of lead compounds. A number of lead compounds can be used as pigments in paints, plastics and ceramics including lead oxide, lead carbonate (known also as white lead), calcium plumbate and lead chromates/molybdates (ILZSG, 2004). Four forms of lead oxide are produced: litharge (PbO) has two forms with different crystal structure - red and yellow. Lead dioxide (PbO_2) is brown. "Red lead" (Pb_3O_4) has a composition between the above. Red lead is rarely used today, although historically it was widely used as an anti-corrosive pigment in rust-inhibiting primer paint used for the protection of steelwork. It may still be used in many countries, in particular for maintenance of old steel structures. Calcium plumbate is also used as a corrosion-inhibitor on galvanised steel.

416. Lead carbonate (white lead) was historically widely used for wall paint in households and still is a significant source of lead exposure to the general public. Lead carbonate is banned in many countries, but it may still be used in some countries e.g. in artistic paints. However, a large number of older buildings, e.g. in the U.S.A., still contain lead in paint on walls, etc.

417. Lead chromates, molybdates and sulphates are still widely used. They are inorganic pigments for bright and opaque yellow, red and orange colours in plastics and paints. According to the Lead Development Association International, quoted by ILZSG (2004), lead chromates represent about 1 percent of the total lead use worldwide. The usage of lead chromate declined substantially in Europe and the U.S.A during the early 1980s, and the market has since been diminishing by an average of 4 percent annually in Europe and 7.5 percent annually in the U.S.A. (ILZSG, 2004).

418. **Enamels and ceramics -** Enamels and ceramics may contain lead and may result in significant leaching to food. Different types of lead-containing enamels and glazing exist, and the potential for lead leaching differs by type. International standards for the leaching of lead from the products to food exist, but in some countries types of glazing leading to high lead leaching rates may still be used. As an example in Morocco, certain powders (galena PbS) used for the enamelling of tagines (earthenware cooking pots) contained more than 53 percent of lead (Morocco's submission, 2005). A study conducted by the National Institute of Hygiene (INH), in 1994 showed that the quantity that the migration of lead in traditionally made tagines is very high, with an average rate of 176 mg/L and a maximum of 640 mg/L (European Method for the control of the migration of heavy metals in packages and consumer items). These lead levels widely exceed the international standards relating to the ceramic products (Morocco's submission, 2005).

419. **PVC stabilizers -** Lead compounds are widely used as heat and UV stabilizers in PVC, and stabilizers are the second most important market for lead compounds after cathode ray tubes. The applied compounds in stabilizers are mainly tri- or tetra-basic lead sulphate, di-basic lead phosphate, di-basic lead phthalate, poly-basic lead fumarate, and di-basic or normal lead stearate. Lead stabilizer systems are mainly used for cables and outdoor purposes as pipes and gutters, window and door frames, roofing, etc. In Europe (EU15, Norway, Switzerland and Turkey), a total of 112,000 tonnes of lead stabilizers were used in 2000, distributed on pipes and gutters (35,932 tonnes stabilizers), cables (17,226 tonnes) and profiles (57,147 tonnes) (ESPA, 2002). The total lead content of the 112,000 tonnes of stabilizers is estimated at approximately 50,000 tonnes (Lassen *et al.*, 2004).

420. There are regional differences apparent in the global stabilizer market. In Europe and Asia, lead-based stabilizers are widely used for rigid PVC, whereas in North America, organotin stabilizers dominate the market for rigid PVC (ILZSG, 2004). Of concern is the fate of the lead after disposal of the PVC, e.g. by incineration.

421. **Identified lead applications.** Lead is used for a wide range of applications and will be present in a significant number of traded industrial products. Identified applications, and an indication of the extent of current usage, are listed in Table 6-9. The tem "General" is used to indicate that lead is generally applied for the application and may in principle be used for the application in all countries.

Table 6-9 Identified lead applications, and indication of the extent of use

Application	**Extent of current use**
Metallic lead	
Batteries (lead is actually present in batteries in both metallic form and as lead compounds)	General - principal application of lead
Cable sheathing (mainly underground and undersea cables)	General
Sheets for roofing/flashing in building	General - regional variation
Sheets for corrosion protection in chemical industry	General
Lead cames of stained glass windows	General - regional variation
Ammunition (lead shot, rifle bullets, etc.)	General - lead shot for certain applications banned or restricted in many countries
Brass used for taps, fittings, etc. (copper alloys with typically 2-3% lead)	General
Bronzes for fittings, bearings, etc. (typically 2-25% lead)	General
Steel and aluminium alloys for drilling, boring and turning, etc. (typically <0.35%)	General
Bearings made of tin-lead alloys	General

Table 6-9 (continued)

Application	**Extent of current use**
Lead compounds	
Solders (lead-tin alloys for electronics, cans, electric light bulbs, auto radiators and plumbing)	General, in the process of being substituted in some countries
Hot dip galvanising (zinc with up to 1% lead)	General
Weights for fishing tools and anchors	General
Balancing weights for vehicles, windmills, rotors, etc.	General, restricted in a some countries for vehicles
Plating (in particular of gasoline tanks)	General
Yacht keels/ballast	General
Pipes and joints for water supply and drain	Not used in most countries for new water supply installations. May, however, be present in installations in older buildings in many countries
Radiation shielding (sheets, clothing, films, etc.)	General
Tin-lead alloys (pewter) for organ pipes, lead soldiers, figures, ornaments, tableware, etc.	General
Tank linings, pumps, valves, pipes, and heating and cooling coils in chemical operations using sulphuric acid or sulphate solutions	General
Printing type	More or less phased out by technology changes
Candle wicks	Candle wicks containing lead have been banned in Australia, U.S.A., Canada and Denmark and are also restricted for indoor use in Finland. They are in reality also removed from the market in the EU due to a voluntary agreement between European manufacturers (Hansen *et al.,* 2004a).
Capsules or foil wrap for wine bottles	Not used in most countries - banned or restricted in many countries
Weights for scuba diving	General
Other marginal applications: Curtain weight, security seals, fuses, lead powder for some corrosion protective paints, lead hammers, truncheons, battery cable clamps, anodes for zinc and manganese electroplating)	General
Dental amalgams	Reported in Burkina Faso's submission, 2005 but in general lead is not used for amalgams
Jewellery	Reported from the U.S.A. (Maas *et al*. 2005)
Gasoline additives (tetraethyl lead and tetramethyl lead)	Phased out in most countries, but still in use in about 26 countries (by June 2006)
PVC stabilisers (many compounds)	General
Pigments for paints and artistic paints (lead chromates and molybdates, calcium plumbate, white lead)	White lead banned or restricted in several countries. Other lead pigments only restricted in a few countries.
Pigments for plastics (lead chromates and molybdates)	General
Rust-inhibitive primers (red lead)	General
Drying agent in varnish and paint (lead naphthanate)	General for some paint types - phased out for many applications in some countries
Hardening agent in polysulphide rubber	?
Glass of cathode ray tubes of TV-sets and monitors	General - until recently the main application of lead compounds - is being phased out by technology changes
Other uses as glass (optical glass, filter glass, crystal glass, plasma display panels, fluorescent lamps, light bulbs, etc.)	General

Table 6-9 (continued)

Application	**Extent of current use**
Lead compounds	
Glassing and enamel (porcelain, tile, ceramics, enamelled iron, etc.)	General, different types are applied
Ceramic elements in electronics (piezo-electric devices, capacitors, etc.)	General
Automotive brake linings (lead sulphite)	General - banned or restricted in some countries
Explosives (lead styphnate, lead azide)	General
Fireworks	General - banned or restricted in some countries
Laboratory chemicals	General
Antiseptics	Mentioned by Japan’s submission (2005)
Makeup (such as the eyeliners or shades for the eyelids)	Mentioned by Mexico’s submission (2005)
Remedies used as treatment for diarrhea	Mentioned by Mexico’s submission (2005)
Other marginal applications: Lubricants for demanding industrial applications, components of specialty lamps, pyrotechnical initiators for airbags, superconductors	General

7 Long-range transport in the environment

422. Environmental transport pathways explored in this review include atmospheric transport, ocean transport, river transport and transport in large, transboundary lakes. These are considered the most important pathways for environmental transport of lead beyond the local scale. Some long-range transport of lead may also take place with migrating fauna.

423. Long-range transport in the environment here refers to transport in air or water of substances (e.g. lead) whose physical origin is situated in one country and which are transported and deposited to another country at such a distance that it may not generally be possible to distinguish the contribution of individual emission sources. Regional transport here refers to such transport within a geographical region such as for example Africa or North America, whereas intercontinental transport refer to such transport from one continent to another, for example between Asia and North America.

7.1 Atmospheric transport

424. The definition in article 1 of the Convention on Long-range Transboundary Air Pollution of long range transport is useful for illustrating the scope of this chapter: *"Long-range transboundary air pollution" means air pollution whose physical origin is situated wholly or in part within the area under the national jurisdiction of one State and which has adverse effects in the area under the jurisdiction of another State at such a distance that it is not generally possible to distinguish the contribution of individual emission sources or groups of sources."* (UN ECE, 1979). Similar In some cases the term "regional transport" is used in this section, meaning transport within the same geographical region (e.g. Europe, North America, or other regions).

425. Atmospheric transport contributes to lead dispersion in the environment. Once emitted to the atmosphere, lead disperses through the atmosphere and ultimately deposits to land or water bodies. The deposition can occur locally (close to sources), regionally, or in locations far from emission sources. Some lead emissions can be transported by airflows over hundreds or even thousands of kilometres and may contribute to the impact on human health and ecosystems far away from the emissions source location as further discussed in this chapter. The range of atmospheric dispersion (and distances of deposition) depends on various factors including, *inter alia,* particle size, stack height, and meteorology. The main principles of lead atmospheric transport are discussed in greater detail below.

7.1.1 Environmental levels of lead and transport patterns

426. As described in chapter 5, human activities (such as mining, metal production and combustion of fossil fuels), can result in elevated lead concentrations in the environment. Measurements of lead concentration in ice cores, fresh water sediments and peat bogs demonstrate a significant increase in lead airborne depositions compared to the pre-industrial period (e.g. Candelone and Hong, 1995; Farmer *et al.*, 1997; Coggins *et al.*, 2006). Due to anthropogenic emissions of lead to the atmosphere lead mass concentrations measured in atmospheric aerosol in various locations were much higher (up to 1000 times) than its natural content in soil and soil derived aerosols. This level of enrichment was observed even in such remote locations as Greenland, the Bolivian Andes, New Zealand and Antarctica (Candelone and Hong, 1995; Correia *et al.*, 2003; Halstead *et al.*, 2000; Ikegawa *et al.*, 1999).

427. Cores of ice extracted from the Greenland Summit glacier contain a well preserved record of atmospheric metal deposition dating back several hundred years. When comparing pre- and post-industrial (i.e. before and since 1800) depositional fluxes of lead the record demonstrates a 12-fold increase that peaked in the 1970s. Lead was however, used quite extensively before 1800 at which time deposition rates were already elevated. It is estimated that the peak in the 1970s represented a 200-fold increase over natural back-

ground deposition rates. Rates of lead deposition had declined by 6.5-fold by the early 1990s reflecting the introduction of unleaded gasoline (AMAP, 2005).

428. Table 7-1 illustrates levels of lead concentrations in the ambient air observed in different parts of the globe. It should be noted that the concentrations presented should not be directly compared due to different measurement periods and sampling and analysis procedures, detection limits, etc. but rather give a general idea of airborne lead levels in the regions covered. Note also that data from the Southern hemisphere are under-represented in the table, because most available data are from the Northern hemisphere. Lead concentrations in the urban environment are commonly considerably higher (up to an order of magnitude) than those in rural areas. The highest concentrations relate to 1970s and reflect high atmospheric emissions due to usage of leaded gasoline. For example, the St. Louis levels in Table 7-1 relate to data collected in 1975-1977. The lowest concentrations were observed in such remote regions as the Arctic, the Antarctic and the middle parts of the Atlantic and Pacific Oceans.

Table 7-1 Concentration of lead in ambient air measured at various sites in the Northern Hemisphere and Antarctica (Adapted from U.S. EPA, 2005a and supplemented with some European data)

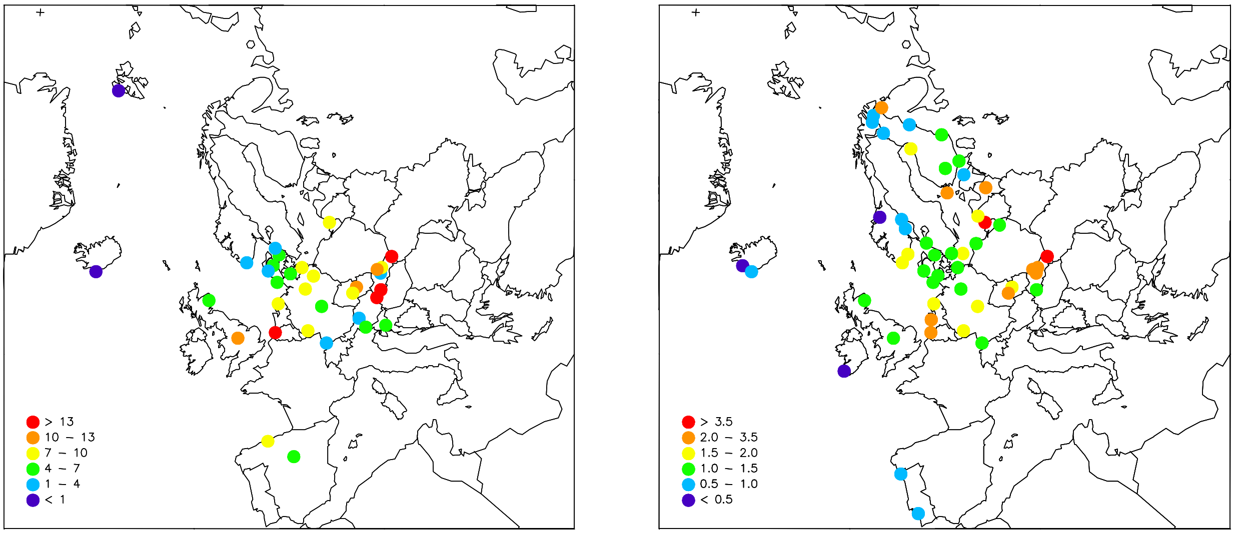
Location	**Concentration, ng/m^3**	**Reference**
Urban		
Boston, U.S.A.	326±15.6 in fine mode	Thurston and Spengler, 1985
Boston, U.S.A.	75.6±5.95 in coarse mode	Thurston and Spengler, 1985
Clemson, U.S.A.	330	Del Delumyea and Kalivretenos, 1987
Akron, U.S.A.	52	Del Delumyea and Kalivretenos, 1987
Norfolk, U.S.A.	31	Del Delumyea and Kalivretenos, 1987
Chicago, U.S.A.	64	Del Delumyea and Kalivretenos, 1987
Range reported in U.S.A. in literature	30-96,270	Schroeder *et al.,* 1987
Cadiz, Spain	12 ± 6	Torfs and Van Grieken, 1997
Bari, Italy	10 ± 8	Torfs and Van Grieken, 1997
Malta, Malta	64 ± 47	Torfs and Van Grieken, 1997
Eleusis, Greece	110 ± 65	Torfs and Van Grieken, 1997
Caesarea, Israel	4-444	Erel *et al.,* 1997
Geneva, Switzerland	45 ± 16	Chiaradia and Cupelin, 2000
Vancouver, Canada	49 ± 43	Brewer and Belzer, 2001
Riverside, U.S.A.	13.1	Hui, 2002
Los Angeles, U.S.A.	15.4-18.9	Hui, 2002
San Francisco, U.S.A.	6.9	Hui, 2002
Jerusalem, Israel	22 ± 17	Erel *et al.,* 2002
Yerevan, Armenia	<40	Kurkjian *et al.,* 2002
St. Louis, U.S.A.	230-650	Kim *et al.,* 2005
Rural		
Packwood, U.S.A.	16	Davidson *et al.,* 1985
Range reported in U.S.A. in literature	2-1700	Schroeder *et al.*, 1987
Whiteface Mountain, U.S.A.	9	Miller and Friedland, 1994
IMPROVE network	2.5	Eldred and Cahill, 1994
IMPROVE network	0.54-6.34	Malm and Sisler, 2000

Location	**Concentration, ng/m^3**	**Reference**
Lake Balaton, Hungary	28.6	Hlavay *et al.,* 2001
Austria	4.6-14.8	Aas and Breivik, 2005
Czech Republic	9.6-10.6	Aas and Breivik, 2005
Germany	2.84-9.6	Aas and Breivik, 2005
Denmark	3-6.9	Aas and Breivik, 2005
Spain	4-8.9	Aas and Breivik, 2005
United Kingdom	4-10.3	Aas and Breivik, 2005
Slovakia	3.2-17.6	Aas and Breivik, 2005
Remote		
Olympic National Park, U.S.A.	2.2	Davidson *et al.,* 1985
Glacier National Park, U.S.A.	4.6	Davidson *et al.,* 1985
Great Smoky Mt. National Park, U.S.A.	15	Davidson *et al.,* 1985
Alert, Canadian Arctic	1.8-1.9	Gong and Barrie, 2005
Range reported in literature	0.007-64	Schroeder *et al.*, 1987
Storhofdi, Iceland	0.5	Aas and Breivik, 2005
Zeppelin, Spitsbergen, Arctic	0.7	Aas and Breivik, 2005
Bermuda	0.04-3.2	Huang *et al.,* 1996
Antarctica	<0.032	Arimoto *et al.,* 2004

429. In Europe, long-term measurements of lead background air concentration and deposition are performed at stations of the EMEP monitoring network (EMEP/CCC, 2006). In 1990, measurement data on background atmospheric concentrations of lead were available from 30 stations in Europe, located in 9 countries. In 2003, measurement data were carried out at 63 stations in Europe, situated in 20 countries. However, there are still large areas where measurement data are not available, e.g. southern, southeastern and eastern parts of Europe.

430. Annual averages of lead concentrations in air and in precipitation in 2003 in Europe are presented in Figure 7-1 (a and b). In general, an increasing gradient can be seen moving southeast, but the concentration levels are not evenly distributed - there are some areas with elevated concentration. The lowest air concentrations were found at high Arctic and Icelandic stations (lower than 1 ng/m^3). The highest lead concentrations in air were observed in Slovakia, as well as in Austria (higher than 13 ng/m^3). Also, for lead in precipitation, the lowest concentrations in precipitation were measured in Scandinavia, Iceland and Ireland (below 1 µg/L), whereas the highest concentrations were found in Slovakia and, besides, elevated levels were also seen at some sites in northern Scandinavia, Lithuania and the Benelux countries.

431. In the U.S.A., there were a total of 454 monitoring stations for lead in 1990, and 196 stations in 2003. Each year, the U.S. EPA evaluates lead in ambient air. Trend analyses of lead air concentrations are based on actual measurements of lead in the ambient air at monitoring sites across the country. Trends are derived from measurements from these monitoring stations, which use the Federal Reference Monitoring method on a yearly basis. Because the National Ambient Air Quality standard (NAAQS) for lead is based on a maximum quarterly (90 day) average of lead in Total Suspended Particulate (TSP), assessed each year, these trend data are typically summarized using this measure (HM Protocol review, 2006, submitted by EMEP).



(a) (b)

Figure 7-1 Lead concentration in aerosols (a) and in precipitation (b) measured at the EMEP monitoring stations in 2003 (Units: ng/m^3 *for aerosol concentration; μg/L for concentration in precipitation; Ilyin et al., 2005).*

432. The U.S.A. also has the Interagency Monitoring of Protected Visual Environments or IMPROVE program, which is an effort to track visibility changes in rural and remote locations, including national parks and wilderness areas. This effort, which was initiated in 1985, uses monitors that measure particulate matter smaller than 2.5 µm (designated PM2.5) and lead. Because these lead measurements are based on PM2.5, they are likely to represent lead transported over longer distances. The network currently comprises 170 sites. According to the IMPROVE data (Figure 7-2), the concentrations of lead in air averaged from 1995-1998 are 5–10 ng/m^3 in the northeast, 3–5 ng/m^3 in the east of the U.S.A., and about 2–3 ng/m^3 in the central regions of the country (Malm and Sisler, 2000).

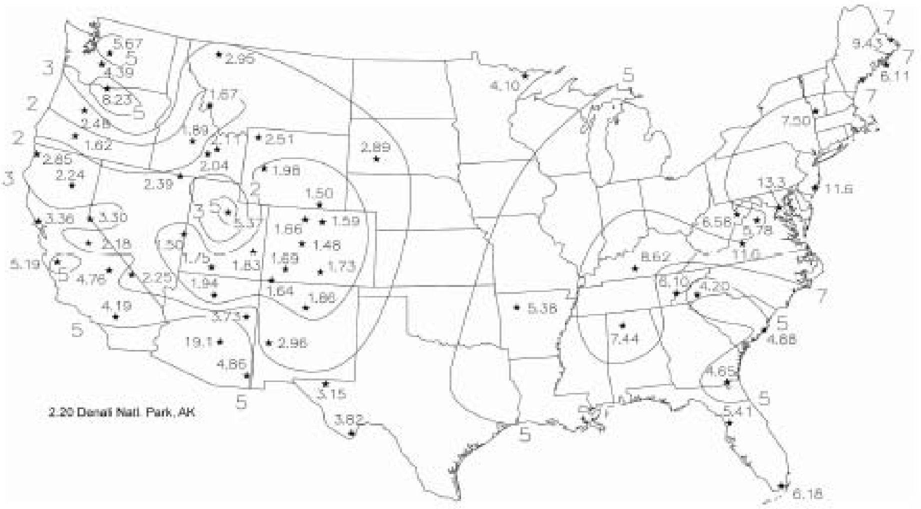


Figure 7-2 Concentrations of lead measured in 1995-1998, as recorded by the IMPROVE network. Data are given in ng/m^3 (Reprinted from Malm and Sisler, 2000)

433. Measurements of lead concentrations in rain and snow were performed by Takeda *et al.* (2000) in western Japan for a period of three years (1995-1997). The measured concentrations were within the range of 0.02-25.15 µg/L, with a mean value of 1.24 µg/L, which is comparable to concentrations measured in Europe (see Figure 7-1). No systematic seasonal variation was observed. Lead concentrations in snow collected across the island demonstrated an increasing trend from the Seto Inland Sea to the Sea of Japan. This was associated with the pollutant-enriched aerosols transported from the Asian continent by strong northwest monsoons.

434. Long-term measurements of wet and dry depositions of lead were also performed by Sakata *et al.* (2006) in 2003-2004 at 10 sites in Japan located in different parts of the country. In general, wet depositions of lead exceeded dry depositions at most sites. Measured annual wet deposition flux varied within the range of 1-13 mg/m^2/year, whereas dry depositions were from 1 to 8 mg/m^2/year. Elevated wet deposition fluxes were also observed at the coast of the Sea of Japan, indicating a large contribution of long-range transport from the Asian continent.

435. Total atmospheric depositions of lead were measured at urban, suburban and rural locations in the Pearl River Delta of southern China in the summer and winter seasons of 2001-2002 (Wong *et al.*, 2003). Measured levels of lead depositions (12.7 ± 6.72 mg/m^2/year) were significantly elevated in comparison with depositions in North America and Europe, reflecting strong anthropogenic inputs as a consequence of rapid industrial and urban development in the region.

436. Concentrations of lead in rainwater and wet depositions were measured at the remote site of Paradise in Fiordland, New Zealand during 1993-1995 (Halstead *et al.*, 2000). Measured lead concentrations in precipitation varied within the range of 2-69 ng/L, with a mean value of 20 ng/L. These concentrations are among the lowest in the world in remote precipitation, with the lower values being similar to those for modern Antarctic ice. Air-mass trajectories showed prevailing Australian and Southern Ocean influence on lead pollution levels in this remote area.

Spatial patterns

437. The overall patterns of lead air concentrations and deposition can be illustrated by results of lead atmospheric transport modelling.

438. Figure 7-3 (a, b) presents levels of lead concentration in the ambient air and atmospheric depositions in the Northern Hemisphere simulated with the MSC-E-HM-Hem model for 1990 (for more de-

tails on atmospheric modelling and its accuracy, see Section 7.1.3). The spatial patterns of lead air concentration and deposition reflects its atmospheric transport from major anthropogenic source areas. Highest lead concentrations in the surface air (more than 30 ng/m^3) and deposition fluxes (up to 10 kg Pb/km^2/year) are characteristic of such industrialized regions as Europe, Southeast Asia, and the eastern and southern parts of North America. Tracks of lead deposition from anthropogenic sources of these regions can be seen in the northern Atlantic and Pacific (up to 0.8 kg Pb/km^2/year). Even in the high Arctic, background concentrations of lead can exceed 1 ng/m^3 because of the long-range atmospheric transport from industrial areas.

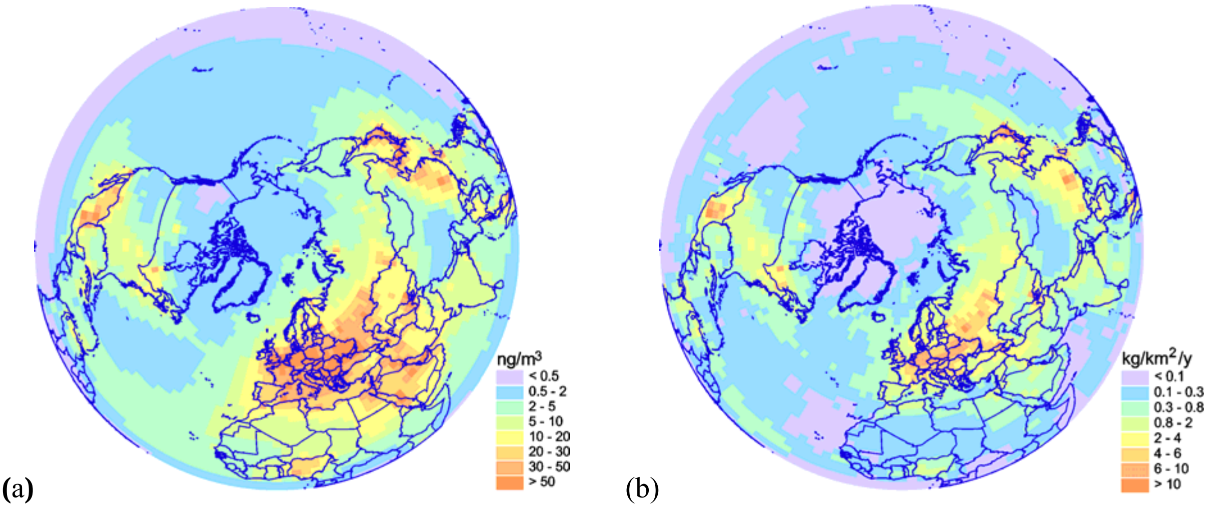


Figure 7-3 Spatial distribution of mean annual lead concentration in the ambient air (a) and total deposition (b) in the Northern Hemisphere in 1990 (calculated with the MSCE-HM-Hem model).

439. The spatial pattern of modelled lead air concentrations and deposition levels in Europe in 2003 is shown in Figure 7-4 (a, b) (Ilyin *et al.*, 2005). The areas with elevated lead concentrations and depositions are located in some countries of Western, Central and Eastern Europe (United Kingdom, Germany, Belgium, Poland, Ukraine, Russia), and also in the southeast of Europe. Ambient air concentrations of lead in these regions are 5-20 ng/m^3, and deposition fluxes exceed 2 kg Pb/km^2/year. In the northern part of Europe, lead levels are significantly lower – concentrations and depositions are below 3 ng/m^3 and 0.5 kg Pb/km^2/year, respectively.

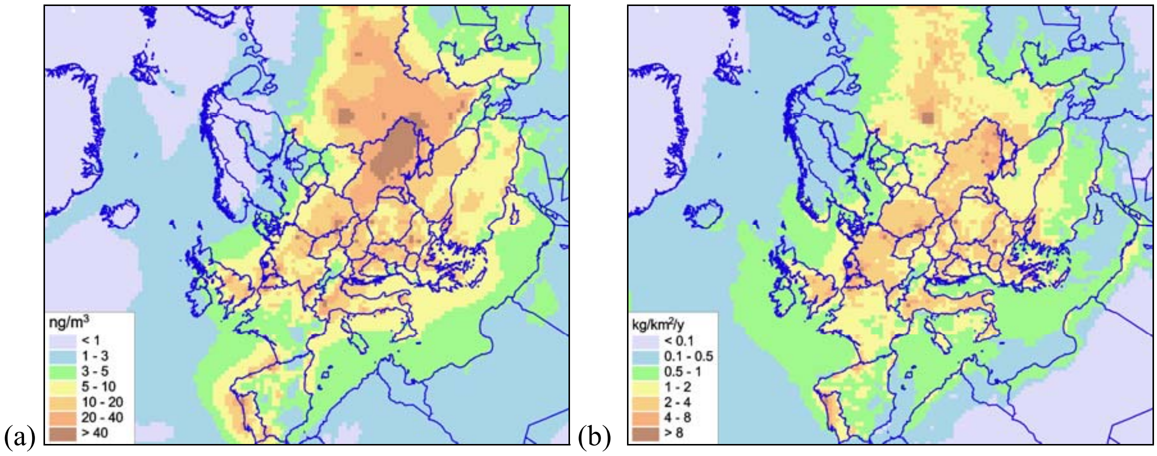


Figure 7-4 Spatial distribution of lead air concentration (a) and deposition (b) in Europe in 2003, simulated with the MSC-HM model (Ilyin et al., 2005).

440. Additional information on spatial distribution of lead environmental levels can be obtained from measurements of its concentration in mosses. Elevated concentrations of lead in mosses can be associated either with local contamination from various industrial and mining activities, or with atmospheric long-range transport from large-scale point or widespread area sources. Figure 7-5 shows the mean measured concentration of lead in European mosses from a survey by *Working Group on Effects* (2004). Elevated concentrations observed in Central European countries (Poland, Czech Republic, Slovakia) are associated with high industrial activity in this region. The higher concentrations in Southern Europe (Bulgaria) are related to mining activity and geochemically enriched areas. Relatively high concentrations are also characteristic of urbanized areas of France, the United Kingdom and Portugal. North-south increasing gradient is typical for moss concentrations in Scandinavia.

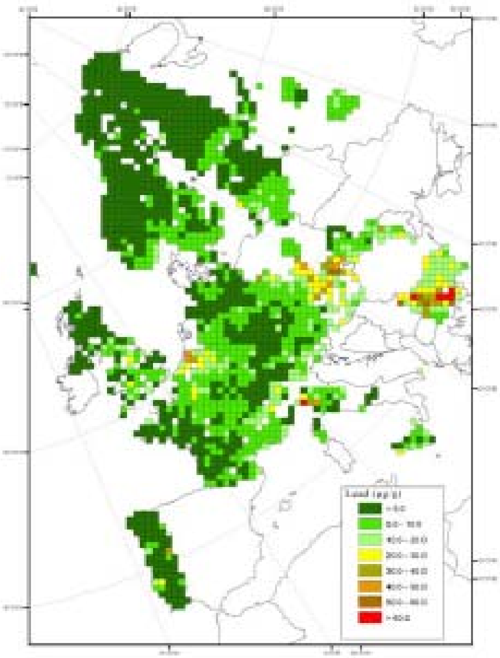


Figure 7-5 The mean lead concentration in mosses within the EMEP 50 km x 50 km grid cell. Units: μg/g dry weight (Reprinted from Working Group on Effects, 2004)

441. In the U.S.A., the National-Scale Air Toxics Assessment (NATA) has been conducted by the U.S. EPA to assess air quality for a range of chemicals. NATA includes modelling ambient air concen-

trations of lead. The U.S. EPA used the ASPEN air dispersion model to first model air concentrations for individual census tracts (i.e., geographical units smaller than counties). The available NATA results for lead based on 1999 emissions data are shown in Figure 7-6. The median tract-level annual average lead concentration was then selected to represent each county. As shown in Figure 7-6, the modelled concentrations for 1999 were generally between about 0.05 ng/m^3 (or lower) to 4 ng/m^3, with maximum concentrations up to 140 ng/m^3 (U.S. EPA, 2002; as cited in HM Protocol review, 2006, submitted by EMEP).

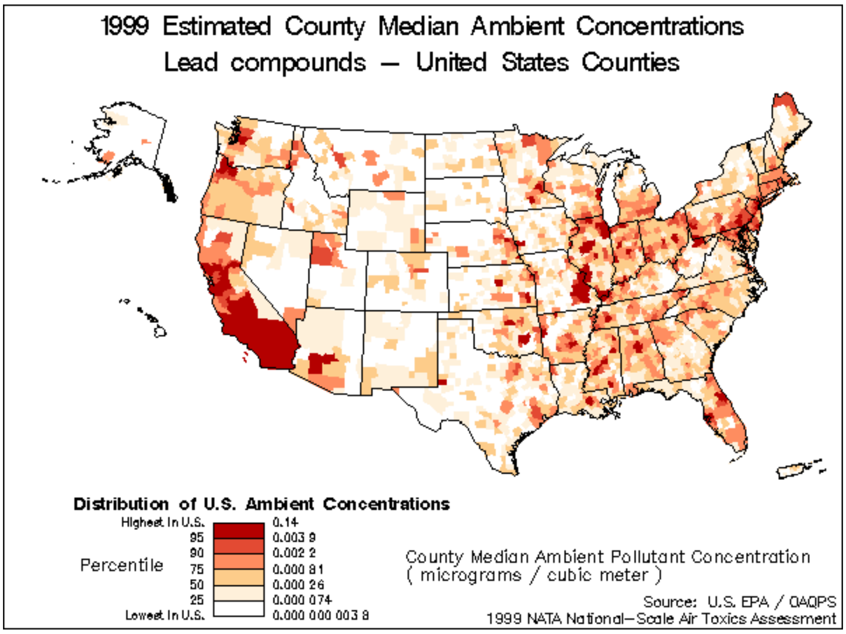


Figure 7-6 Modelled median county-level (annual-averaged) ambient air concentrations for lead in the U.S.A. for 1999 (U.S. EPA, 2006b).

Temporal trends

442. Most available long-term measurements of lead background concentrations and depositions demonstrate significant reduction (up to several times) of lead pollution levels in the environment after the phase-out of leaded gasoline in many countries (EMEP/CCC, 2006). Figure 7-7 shows long-term trends of measured lead concentrations in air and precipitation averaged over different European countries. As seen in the figure, long-term changes of lead levels in air and precipitation vary considerably across Europe. Based on these data, the decrease of lead concentration in air of central and north-western Europe was about 2–3 times from 1990 to 2003. Concentration in precipitation also demonstrated considerable decrease during this period. It varied from 1.5 times decrease in Finland to 3 times decrease in the United Kingdom and Norway.

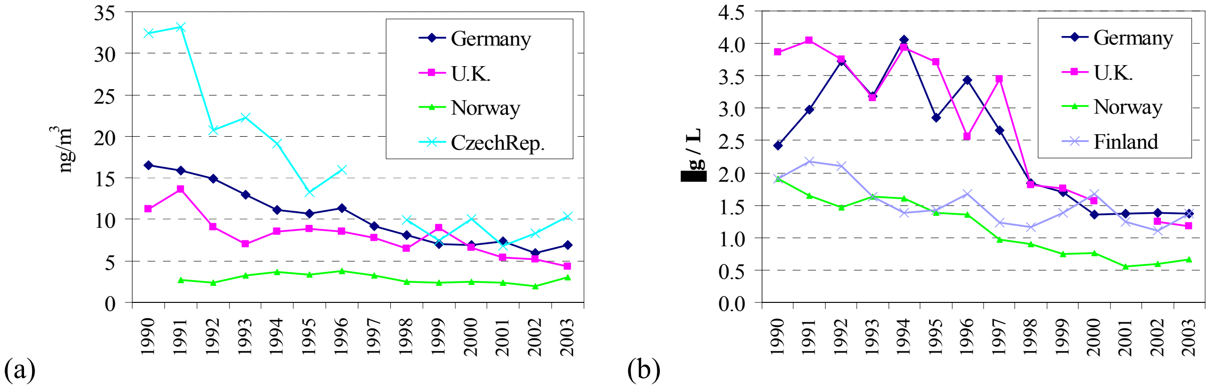


Figure 7-7 Long-term changes of lead concentrations in air (a) and in precipitation (b) in different parts of Europe, based on EMEP monitoring data (EMEP/CCC, 2006).

443. European marine environment studies show that at nine coastal locations, increasing trends in lead concentration in mussels are observed, and in most cases these are different from the observed hot spots. A total of 266 temporal trends were analysed on a station-by-station basis, of which only 39 were significant, 30 down and 9 up (Green *et al*., 2003 in Finland's submission, 2007).The decrease of lead levels in the environment can also be illustrated by changes in its concentration in mosses. Figure 7-8 shows changes in the lead concentration in mosses in Finland during 1985–2000 (Poikolainen *et al.*, 2004). Lead concentrations in moss in Finland were relatively low, being highest in southern Finland, where most of the population lives, and where industry and traffic are also more obvious emission sources. A statistically significant decrease in concentrations has been detected over the whole territory of Finland since 1985. The reduction in lead concentrations between 1985 and 2000 was, on average, 78 percent. In addition, the reduction of lead concentrations increased from north to south. The concentrations of lead in mosses did not highlight any major single industrial emission source of lead in Finland.

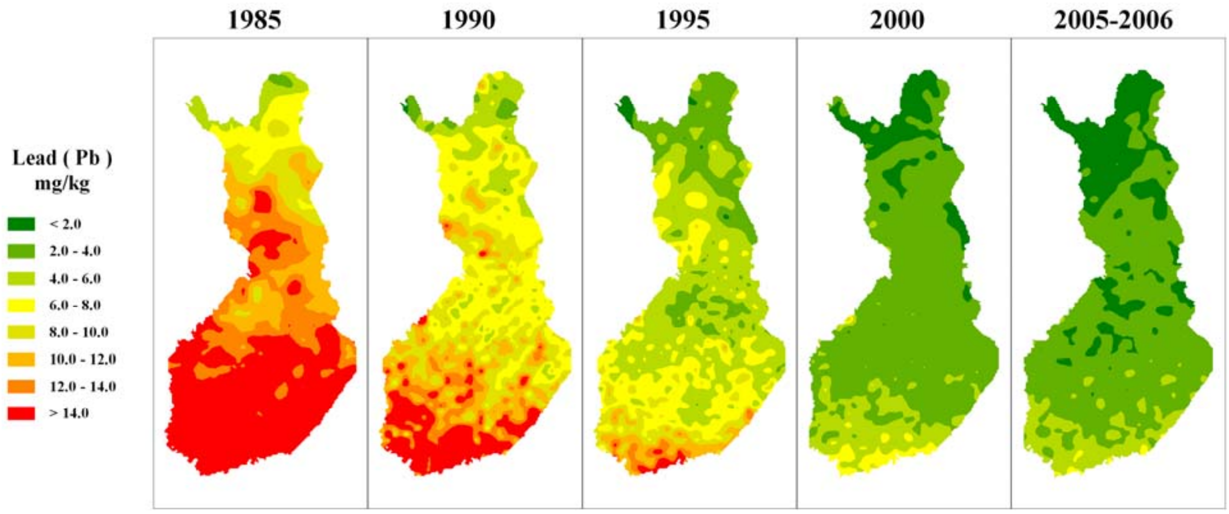


Figure 7-8 Changes in the lead concentration in mosses in Finland during 1985–2000 (reprinted from Poikolainen et al., 2004) and Piispanen, J (2007).

444. Long-term changes of European emissions of lead are likely to be reflected in measured trends. In order to evaluate consistency between national official European emissions and monitoring data, emission and measurement trends were compared (Ilyin and Travnikov, 2005). These trends differ significantly between individual countries. In some countries, the reduction of emissions for 1990 – 2003 was more than 10 times, but the decline of observed lead levels in air and in precipitation was much lower (2-3 times). This fact is confirmed by examples of the United Kingdom and Norway, shown in Figure 7-9. Lead pollution levels in the United Kingdom are mainly conditioned by national emission

sources. Lead pollution in Norway is considerably influenced by long-range transport. That is why the trend of official emissions in Norway is accompanied by official emission trends of France and the United Kingdom (Figure 7-9b). These countries are the main contributors to lead transboundary pollution in Norway.

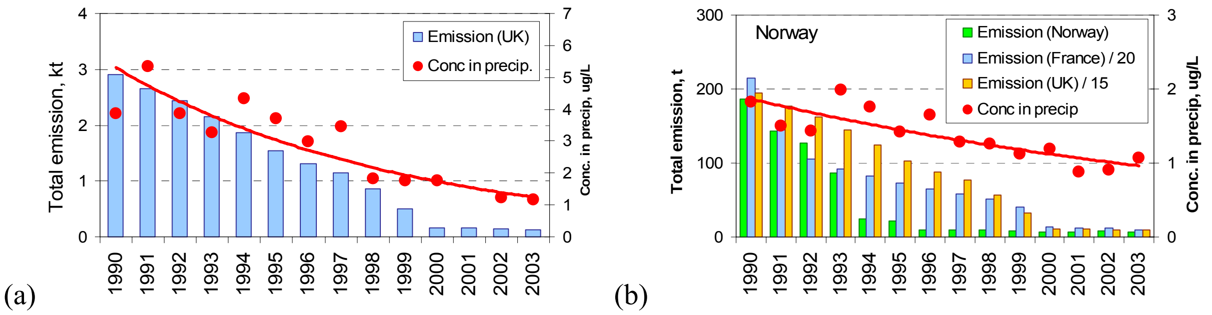


Figure 7-9 Long-term trends of total anthropogenic emissions of lead in some countries, and mean concentration in precipitation in the United Kingdom (a) and Norway (b). Red circles show annual measurements, red line shows exponential approximation.

445. An inconsistency between measured levels of lead and the emissions estimates is evident not only for individual countries, but also for Europe as a whole. Taking into account the relatively short residence time of lead in the atmosphere (see Section 7.1.3), it is unlikely that significant input of this metal to the atmosphere of Europe would come from sources located outside this region. That is why it is possible to analyse the atmospheric balance for Europe as a whole through comparing total values of emission and deposition. Comparison of total officially-reported anthropogenic emissions of lead in Europe with total wet deposition to European countries based on measurement data indicated that observed wet depositions of lead are higher than the reported emissions in 1995 – 2003 (Figure 7-10) (Ilyin and Travnikov, 2005). The exception is 1990, when measured depositions were available only from Scandinavian stations, and, hence, were probably too low compared to European-mean depositions. However, one should keep in mind that a significant mass of lead is also deposited to the surface through so-called dry deposition (see Section 7.1.2), deposited over marginal seas and transported beyond European boundaries. Dry deposition of this particle-bound heavy metal is generally comparable in magnitude to wet deposition. Hence, one could expect total (dry and wet) annual lead depositions to be approximately twice the official anthropogenic emissions.

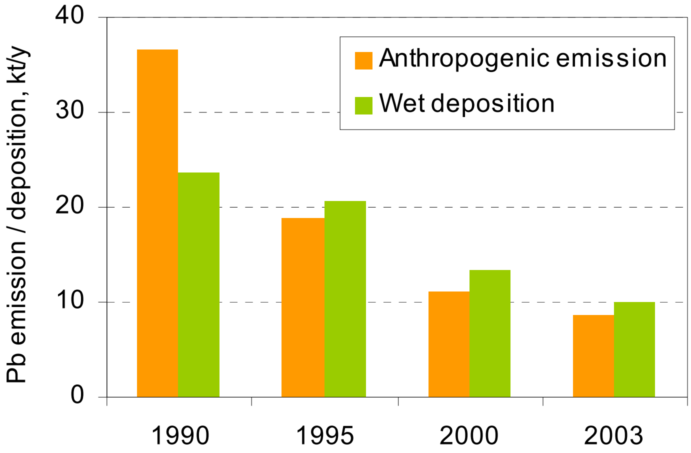


Figure 7-10 Comparison of total anthropogenic lead emissions with total wet deposition in European countries based on measurement data (Ilyin and Travnikov, 2005).

446. These inconsistencies between officially reported emissions and observed lead concentrations and depositions could be explained by one or more of the following factors: underestimation of anthropogenic emissions, significant unaccounted influence of natural emissions and/or lack of adequate consideration of re-emissions of historic depositions. In order to better understand the uncertainties and reasons for these inconsistencies, these topics would need further investigation.

447. Figure 7-11 presents trend data for ambient lead concentrations for rural, suburban and urban sites in the U.S.A. for the years 1982 to 2001. These estimates are based on 38 monitoring stations, which are not point-source-oriented. These stations measure total suspended particles (TSP) and therefore likely reflect lead from local sources (bound to larger coarse particles) and lead transported over longer distances on fine particulate matter (PM2.5). Figure 7-11 shows that urban and suburban sites have had the greatest decrease in ambient lead concentrations. However, the figure also shows that rural sites have also experienced significant reductions. Overall, lead air concentrations across the U.S.A. have decreased more than 94 percent since 1983, based on these data. Furthermore, this trend has continued, although at a reduced rate throughout the 1990s, with lead concentrations decreasing 57 percent between 1993 and 2002 (U.S. EPA, 2003; as cited in HM Protocol review, 2006, submitted by EMEP).

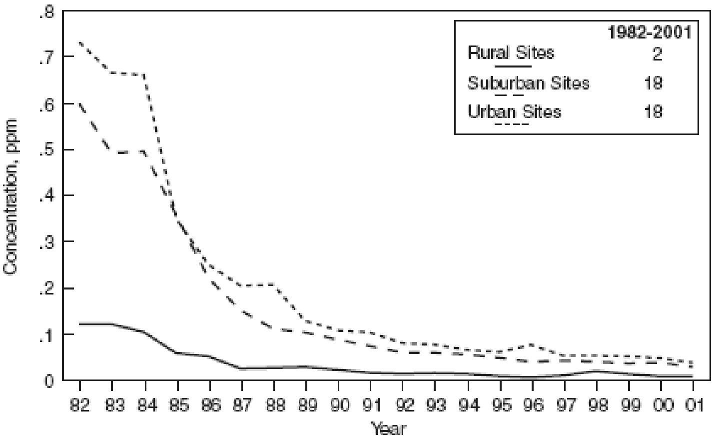


Figure 7-11 Maximum quarterly mean lead concentration trends in the U.S.A. by location (excluding sites designated as point-source oriented) 1982-2001(U.S. EPA, 2003).

448. Long-term changes of lead levels in the Arctic can be characterized by measurements available from stations at Alert (Canada) and Zeppelin (Spitsbergen, Norway). Observations at Alert (Figure 7-12a) reveal some decline of lead concentrations in air - of about 1.5 – 2 times - for the considered pe-

riod (Sirois and Barrie, 1999; Gong and Barrie, 2005). The Zeppelin data do not exhibit any noticeable trend (EMEP/CCC, 2006). However, seasonal variability of concentrations at the Arctic stations is significant (Figure 7-12b). Minimum concentrations are observed in summer, and maximum in winter (Heidam *et al.*, 1999; Gong and Barrie, 2005). This seasonal characteristic of high Arctic levels of lead is connected with intensive atmospheric transport of contaminants from Eurasian sources in winter, known as the phenomenon of arctic haze (Macdonald *et al.*, 2005).

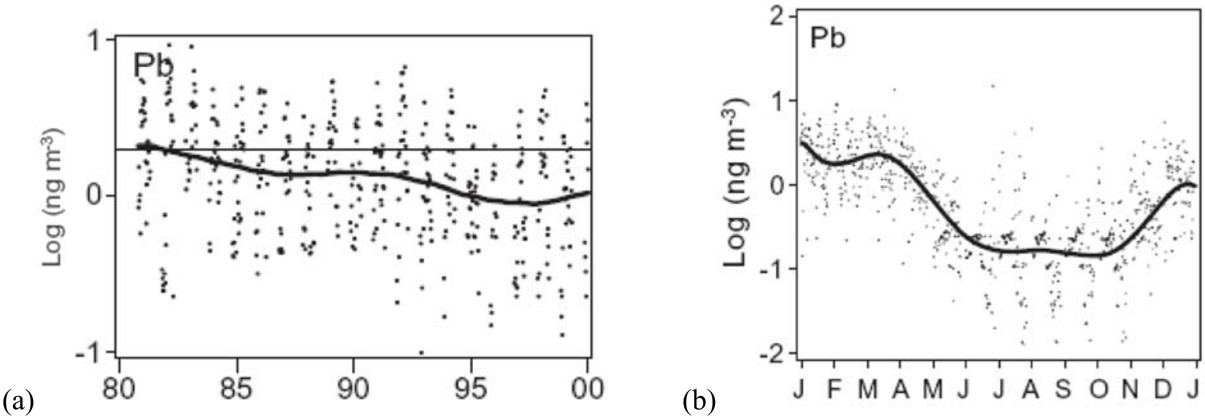
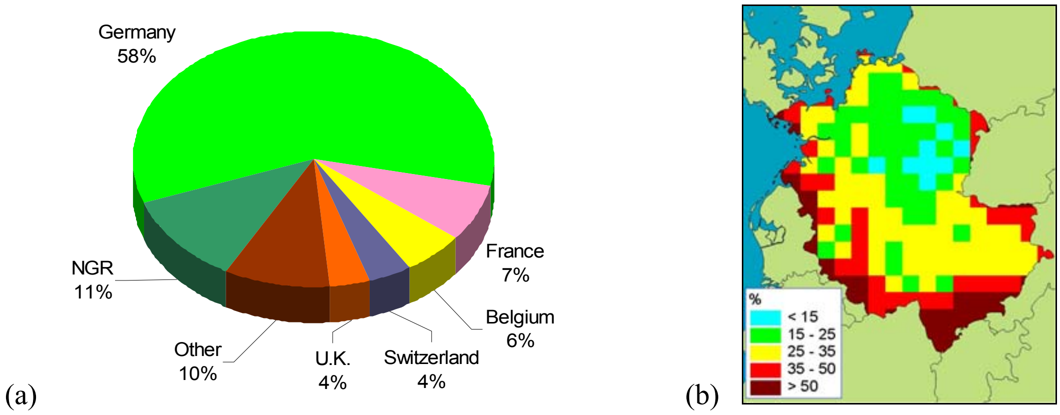


Figure 7-12 Long-term trends in aerosol lead concentration at Alert, Ellesmere Island for the winter half of the year (November to April, year 1980 to 2000) (a) and its seasonal variation (b) (Reprinted from Gong and Barrie, 2005).

Regional scale transboundary pollution

449. Operational calculations of lead transboundary pollution within the European region are performed by Meteorological Synthesizing Centre East of EMEP (EMEP/MSC-E) (Travnikov and Ilyin, 2005). Concentration levels of this heavy metal in the ambient air, and deposition fields for each Party to the LRTAP convention within the EMEP area are evaluated annually, along with the transboundary transport between countries (e.g. Ilyin *et al.*, 2004; 2005). Figure 7-13 illustrates an example of the assessment of lead transboundary pollution based on modelling in one European country – Germany. About 30 percent of total lead depositions in this country are defined by the atmospheric transport from anthropogenic sources located in other nearby countries (such as France and Belgium), about 60 percent from sources within Germany and 10 percent from natural sources and re-emission. The contribution of external sources to these depositions is distributed non-homogeneously over the territory: In regions close to national borders, this contribution can exceed 50 percent, whereas in the central part of the country, it can be less than 15 percent.



(a) (b)

Figure 7-13 Main contributors to deposition of lead in Germany (a) (NGR - natural, global sources and re-emission); Spatial distribution of contribution of external anthropogenic sources to lead depositions in Germany (b) (calculated with the MSCE-HM model, Ilyin et al., 2005).

450. The contribution of lead depositions to a country's territory caused by transboundary transport varies significantly (10 – 90 percent) between European countries (Figure 7-14) (Ilyin *et al.*, 2005). The highest contribution took place for the Republic of Moldova, Luxemburg, Monaco and Belarus (more than 80 percent), the lowest for Italy, the United Kingdom and Portugal (below 20 percent). In one-third of European countries, the contribution of transboundary transport from external anthropogenic sources exceeds 60 percent of total deposition, and in two–thirds, 40 percent (Figure 7-14).

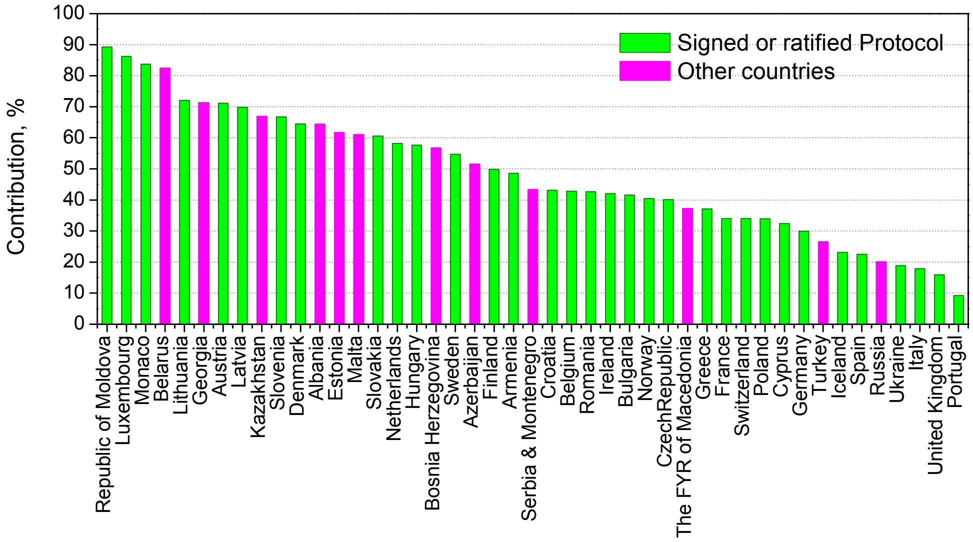


Figure 7-14 Contribution of external European anthropogenic sources to depositions of lead in European countries in 2003 (calculated with the MSCE-HM model, Ilyin et al., 2005).

Intercontinental transport

451. The evidence for intercontinental atmospheric transport of lead is limited. Due to the relatively short residence time of lead in the atmosphere (days or weeks; Alcamo *et al.*, 1992), the airborne dispersion of this pollutant has a pronounced local or regional character. However, data from ice core measurements in Greenland and the Antarctic indicate that lead can be transported over distances of up to thousands of kilometres (Boutron, 1995; Vallalonga *et al.*, 2002). Analysis of lead in aerosols in a number of regions further illustrates long-range transport. Some small portion of anthropogenic lead from North America has been noted in the Russian Arctic (Shevchenko *et al.*, 2003). Further, measure-

ments at the Canadian Alert station show that a portion of airborne lead reaching the Canadian Arctic comes from industrial sources in Europe (Mercier *et al.*, 1999).

452. Some evidence of the intercontinental transport of lead is obtained from measurements of stable isotope signatures of the airborne dust in combination with air-mass back trajectories (Véron and Church, 1997; Mercier *et al*., 1999; Bollhöfer and Rosman, 2001; Grousset and Biscaye, 2005). These measurements indicate the origin of dust particles transported by air masses, and thereby provide evidence that aerosols carrying lead are transported intercontinentally and from industrialized regions to remote regions with few local emission sources such as the Arctic. Soil in Kauai, Hawaii, was found to contain lead from diverse distant sources, including lead from anthropogenic sources in Asia and North America (Monastra *et al*., 2004). Another study, in Japan, shows long-range transport of air pollution (including lead) from continental Asia (Bellis *et al.*, 2004).

453. Available modelling data show that intercontinental transport makes only minor contributions to regional environmental levels of lead in industrially developed regions on a long-term basis. According to the modelling results obtained for this study with the MSCE-HM-Hem model (Figure 7-15), annual contribution of external emission sources to the total lead deposition in Europe is less than 5 percent, and it is even lower in North America. The calculations were based on 1990 emission data, the latest global emission data set available. Taking into account that the global emission pattern has changed since 1990, the presented results can qualitatively characterize intercontinental atmospheric transport, which takes place. While a hemispheric model and aggregated emission estimates exist for the northern hemisphere, these are associated with uncertainty, as described in chapter 10. In addition, emission data from several regions is very limited and modelling of hemispheric transport has not been done for the southern hemisphere (see Chapter 10).

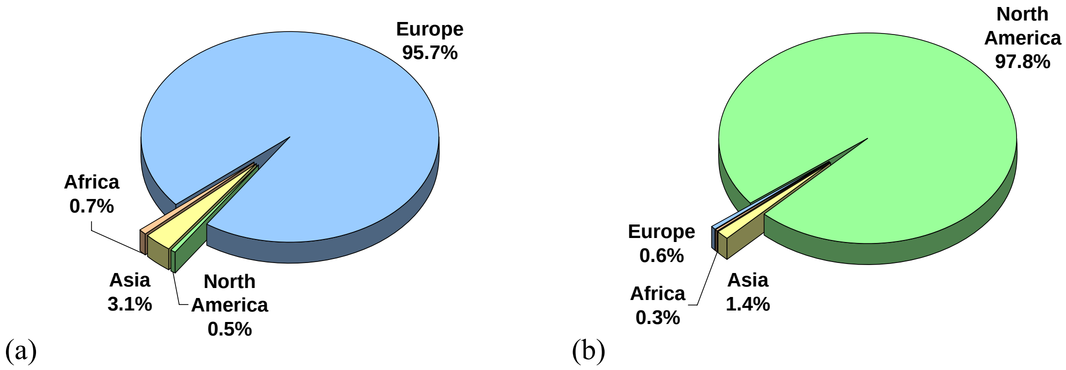


Figure 7-15 Relative contribution of different continents of the Northern Hemisphere to annual lead deposition in Europe (a) and North America (b)(calculated for this study with the MSCE-HM-Hem model).

454. However, based on the model calculations, episodically, the contribution of intercontinental transport can be significantly higher at certain locations on these continents. Figure 7-16 and 7-17 illustrate the modelled daily mean contribution of intercontinental transport from different continents of the Northern Hemisphere to Norway, in Europe, and British Columbia (Canada), in North America. Based on the model calculations, the daily contribution to these areas is calculated to exceed 35 percent of total deposition during these episodes. The long-range transport episodes corresponding to the highest values of the contribution are illustrated in the diagrams to the right of Figure 7-16 and 7-17.

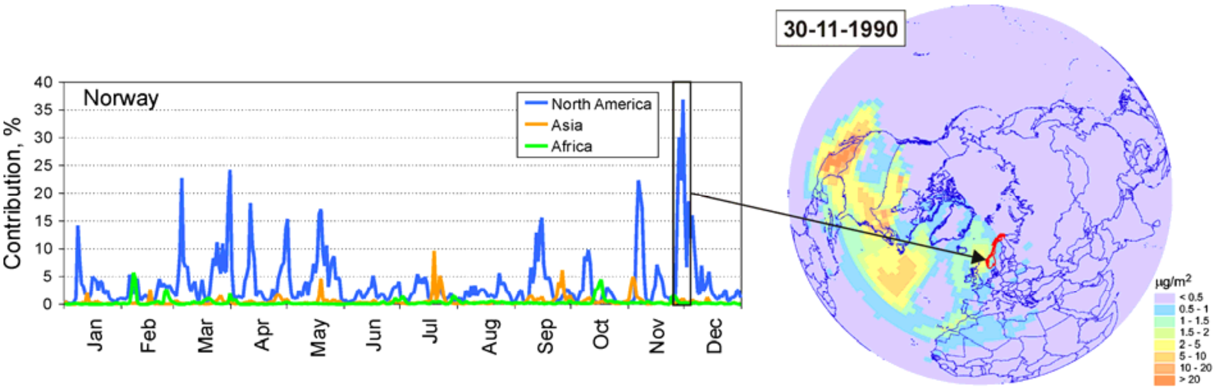


Figure 7-16 Daily mean contribution of different continents of the Northern Hemisphere to lead deposition in Norway (a); Spatial distribution of the integral mass of lead from North American sources in the air column during a long-term transport episode (November 30, 1990) (b) (calculated for this study with the MSCE-HM-Hem model).

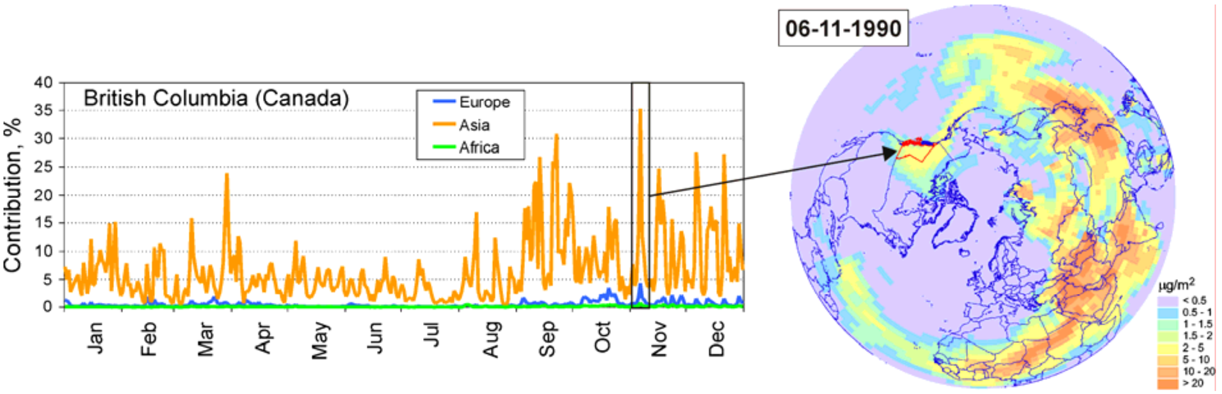


Figure 7-17 Daily mean contribution of different continents of the Northern Hemisphere to lead deposition in British Columbia (Canada)(a); Spatial distribution of the integral mass of lead from Asian sources in the air column during a long-term transport episode (November 6, 1990) (b) (calculated for this study with the MSCE-HM-Hem model).

455. Compared to pollutants with longer atmospheric residence time which cycle globally, like mercury and some POPs, the intercontinental transport of lead has an episodic character due to its significantly smaller residence time in the atmosphere (characteristics of the long-range transport of lead are discussed in Section 7.1.2). However, as shown above, the intercontinental contribution of lead to regional pollution can be significantly higher during short-term episodes. On the other hand, long-term chronic exposure has more of an effect on human health than the episodic peaks, meaning that intercontinental contributions to exposure are low.

Arctic pollution

456. Europe and the Asian part of Russia contribute all but a few percent of the airborne lead reaching the Arctic (AMAP, 2002). Models show (Figure 7-18a) that the main atmospheric pathways are across the North Atlantic, from Europe and from Siberia. The transport of lead follows seasonal patterns. Lead levels in airborne particles are lowest in early fall, and at that time of the year lead reaching the Canadian Arctic comes mostly from natural sources in the Canadian Arctic Archipelago and western Greenland. In late fall and winter, airborne lead comes primarily from industrial sources in Europe. By late spring and into summer, lead from Asian industrial sources can be detected (Mercier *et al.*, 1999; as cited in AMAP, 2005).

457. The spatially extensive snow sampling program (Koerner *et al.*, 2002) spanning the Canadian and Russian Arctic islands and the Arctic Ocean during the period 1993-1998 (Figure 7-18(b)) found

concentrations increase from the eastern-most sites (Academii Nauk, Leningradskii) to the western islands (Ushakova, Greem Bell, Aleksandry). The relationship between surface and subsurface snow concentrations probably reflects a seasonal dynamic in which the Severnaya Zemlya sites receive local dust inputs or very small contributions from Norilsk during the summer and/or autumn, while concentrations at the western islands are generally near background levels. In the late winter and spring, however, Severnaya Zemlya appears to receive a smaller contribution from polluted southern air masses than the western islands (AMAP, 2005).

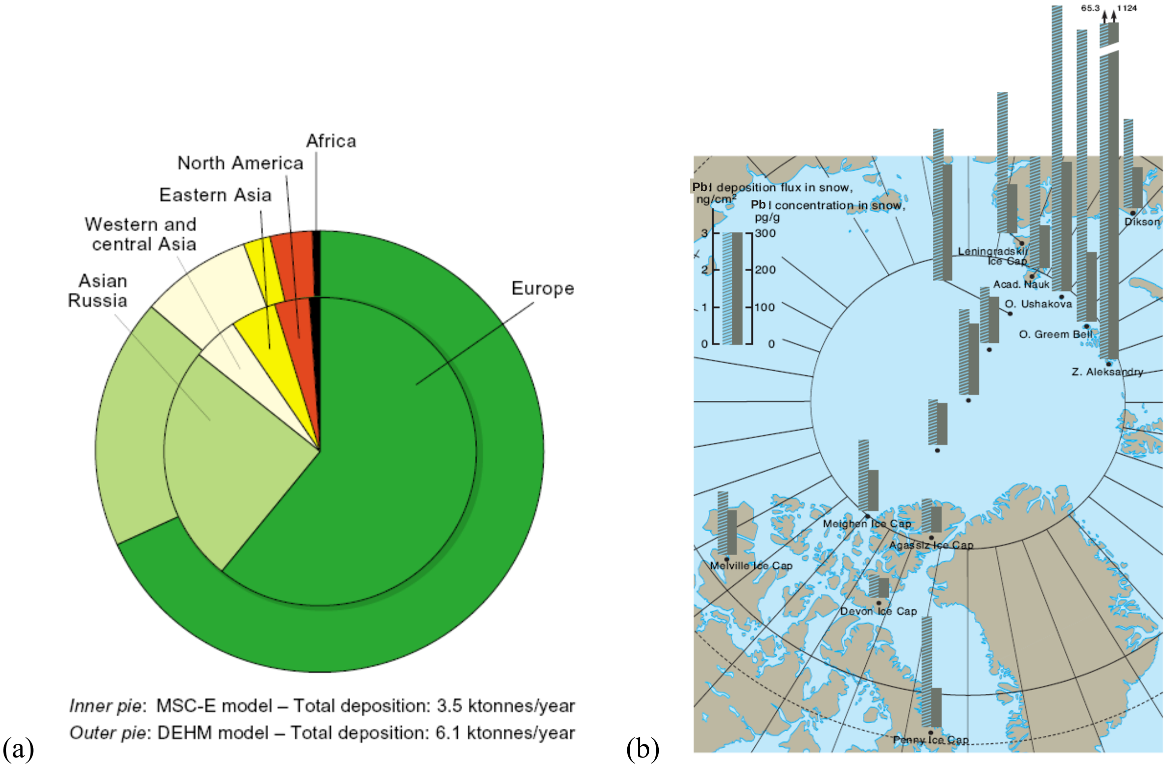


Figure 7-18 Relative contribution of different source regions to lead depositions in the Arctic in 1990 (a) and lead concentrations in snow and deposition across the Arctic Ocean (b) (Reprinted from AMAP, 2002; AMAP, 2005)

7.1.2 Factors affecting the long-range atmospheric transport of lead

458. Factors affecting the behaviour, fate and deposition of lead from the atmosphere during its long-range atmospheric transport include:

- Characteristics of emission sources;
- Physical and chemical forms of lead in the atmosphere, especially particle size;
- Atmospheric stability and wind speed influencing vertical mixing and dispersion;
- Removal properties determine washout of lead with precipitation (wet deposition) and uptake by the Earth's surface (dry deposition).

In addition to these factors, according to Qureshi *et al.* (2009) the physical resuspension of soil and marine aerosols constitutes a mechanism for the mobilization of non-volatile pollutants like lead from the surface of the earth either from naturally occurring sources or from anthropogenic activities like mining. Although the rates of these processes are slow, models should consider them as they could enhance long-range transport potential of lead (Switzerland submission, 2010).

459. Lead is emitted to the atmosphere from different mobile and stationary sources (see Chapter 5). The height of an emission source can significantly affect atmospheric dispersion and transport range. Greater release height generally results in increased dilution of the emission plume, larger dispersion

and greater transport distance. Higher temperature of the release can also increase the height of the emission plume in the atmosphere and leads to longer transport.

460. Besides the height of the emission source, the stability of the atmospheric boundary layer significantly affects the rise of the pollution plume and its subsequent dispersion in the atmosphere. For example, in stable conditions, which are often during the night, weak vertical mixing can result in stagnation of air masses near the ground and elevated pollutant concentrations. On the other hand, unstable conditions commonly occurring on sunny days lead to a rise of the pollution plume higher in the atmosphere, where the winds are generally stronger and the pollutant can be transported for a longer distance.

461. Because of its low volatility (see Chapter 2), lead is emitted to the atmosphere as a component of aerosol particles with a wide range of particle sizes. Lead on larger particles (from a few to tens of microns) is deposited closer to the emission source and has more local impact. On the contrary, finer particles (less than a few microns) can be transported for large distances - up to a thousand kilometres. Therefore, size distribution of the emitted lead-containing particles can significantly affect the range and properties of long-range transport.

462. During its trajectory in the atmosphere, the size distribution of particulate lead changes dynamically because of interaction between particles of different sizes, and due to the condensation of water vapour and other gases. These processes result in an increase of the particle size and the number of larger particles. On the other hand, larger particles are more effectively removed from the atmosphere by gravitational settling and scavenging with precipitation.

463. According to measurement data, lead mostly occurs in the atmosphere as aerosol particles of sub-micron size. The mass median diameter of airborne lead was estimated by Milford and Davidson (1985) to 0.55 µm, based on the literature survey. A bimodal distribution for lead particles with the larger peak in the fine fraction was measured by Lin *et al.* (1993). The mass median diameter for lead samples in the fine fraction was 0.38±0.06 µm, and 8.3±0.6 µm in the coarse fraction. Allen *et al.* (2001) have obtained similar results: Most of the lead particulate mass was contained within a fraction at about 0.5 µm and an additional, minor, coarse fraction.

464. Lead is removed from the atmosphere by two major mechanisms: through uptake by the ground surface (so called dry deposition) and as washout with precipitation (wet deposition). The surface uptake efficiency depends both on properties of lead-containing particles, and on characteristics of the underlying surface. Dry deposition is the most effective for coarse particles (several micrometers and larger) because of gravitational settling. Ultrafine particles (< 0.1 µm) are also easily removed through the surface uptake because of their high mobility in so-called Brownian and turbulent diffusion. Thus, the surface uptake efficiency (or dry deposition velocity) has a minimum for particles at a size between 0.1 and 1 µm (e.g. Slinn *et al.*, 1978; Sehmel, 1980). It also is highly dependent on the type - or roughness - of the ground surface. The highest dry depositions take place over rough terrain, such as areas of significant vegetation (forest, shrubs etc.) and urban areas; the lowest dry depositions occur over smooth terrain (desert, snow cover) and water bodies.

465. Wet deposition of lead takes place during precipitation events (rain, snow). The scavenging of lead-containing particles depends on precipitation intensity and on some aerosol properties such as particle size, hydrophoby, etc. Precipitation scavenging is very efficient for coarse and ultrafine particles, and less efficient for so-called "accumulation mode" particle sizes 0.1–2 µm (Volken and Schumann, 1993; Laakso *et al.*, 2003). Relative contribution of dry and wet depositions to overall lead removal varies from one location to another and depends on local climatic conditions and the type of terrain.

7.1.3 Atmospheric transport models for lead

466. Measurements of lead concentration in ambient air and in precipitation performed sporadically or routinely at certain locations cannot supply thorough information on the environmental pollution levels of this metal. First, there is relatively scarce spatial coverage of the territory with measurement sites. Second, they have very restricted abilities to characterize transboundary and intercontinental transport.

Finally, current observations cannot easily be used for long-term predictions of future lead levels. For the solution of these problems, various numerical models of lead atmospheric transport are employed.

467. Models used for the simulation of lead atmospheric dispersion vary in their formulation and scope of coverage depending on the investigated problems. Local-scale models are employed for evaluation of pollution levels in the vicinity of large emission sources or in the urban environment. Regional or continent-scale models consider the atmospheric dispersion and transboundary transport within the ranges of a continent or certain region (e.g. the Baltic Sea, the Arctic). Intercontinental transport is simulated by hemispheric or global models. Moreover, according to their formulation, the models are distinguished between the so-called Gaussian, Lagrangian and Eulerian types.

468. The airborne concentration of a species emitted from a point source is frequently described with a Gaussian distribution (U.S. EPA, 2005a). This simple description holds true only when turbulence is stationary and homogeneous. However, the Gaussian model can be modified to account for more complex atmospheric conditions (Seinfeld and Pandis, 1998). Gaussian models are in general reasonably accurate for small-scale work – within approximately 100 km of the source.

469. For long-range transport modelling, Lagrangian trajectory models or Eulerian models are commonly employed. Lagrangian models follow parcels of air moving though space along the wind direction. The pollutant emissions enter the parcel at different locations and times. In contrast, Eulerian models operate in a fixed coordinate system considering air motion between different points or cells of a fixed grid. Characteristics of a number of specific transport models employed for evaluation of the atmospheric transport of lead are summarized in Table 7-2.

Table 7-2 Chemical transport models employed for evaluation of the long-range atmospheric transport of lead.

Model	**Type**	**Coverage**	**Reference**
EMITEA-AIR	Gaussian	Local	Baldasano *et al.*, 1997
TRACE	Climatological	Europe	Alcamo *et al.*, 1992
HMET	Eulerian	Europe	Bartnicki, 1996
GKSS	Lagrangian	Europe	Krüger, 1996
ASIMD	Eulerian	Europe	Pekar, 1996
LPMOD	Lagrangian	Europe	Pekar, 1996
DEHM	Eulerian	Northern Hemisphere	Christensen, 1997
TREND	Lagrangian, statistical	Europe	Nijenhuis *et al.*, 2001
ADOM	Eulerian	Europe	Sofiev *et al.*, 2001
HILATAR	Eulerian	Baltic Sea	Sofiev *et al.*, 2001
MSCE-HM-Hem	Eulerian	Northern Hemisphere	Travnikov, 2001
RAMS-TDM	Lagrangian	Middle East	Erel *et al.*, 2002
ASPEN	-	U.S.A.	U.S. EPA, 2002
MSCE-HM	Eulerian	Europe	Travnikov and Ilyin, 2005

470. A Gaussian dispersion model (EMITEA-AIR) was applied to estimate air pollution from primary and secondary lead smelters at two sites in Europe – Copenhagen, Denmark and Catalunya, Spain (Baldasano *et al.*, 1997). The modelling results showed that airborne concentrations of lead were both lower and more symmetrical surrounding the Copenhagen site than surrounding the Catalunya one. The prevalence of calm winds and the complex terrain were the most important factors contributing to high lead concentrations surrounding the Catalunya smelter.

471. The climatological TRACE model was used for evaluation of air concentration and deposition of some heavy metals (including lead) in Europe (Alcamo *et al.*, 1992). The atmospheric residence time

of lead was estimated at 2.7 days. The dominating role of wet depositions over dry ones was demonstrated for most of the European territory.

472. Transboundary exchange of airborne heavy metal pollution between European countries was evaluated for 1985 with the Eulerian transport model HMET (Bartnicki, 1996). It was demonstrated that between 30 percent and 90 percent of lead and other heavy metals emitted from European countries undergoes transboundary transport and deposits outside the territory of the country of the sources.

473. The contribution of the atmosphere to the input of heavy metals to marine environments of northern Europe was determined by applying the Lagrangian GKSS model (Krüger, 1996). The modelling results demonstrated that the atmospheric input of lead to the North Sea is higher then for the Baltic Sea, and the highest deposition fluxes took place mainly over the coastal regions.

474. The Lagrangian model (EU) TREND was applied to calculate the transport and deposition of lead and other heavy metals to the OSPAR Convention waters (Nijenhuis *et al.*, 2001). Results were obtained for the regions: greater North Sea, Celtic Sea, Bay of Biscay, Iberian coast, and parts of the following regions: Arctic waters and wider Atlantic regions. The contribution of five major source categories was calculated, as well as deposition from different countries.

475. Two nested Eulerian atmospheric transport models ADOM and HILATAR were used for the evaluation of heavy metal pollution of the Baltic Sea (Sofiev *et al.*, 2001). The European-wide calculations were made with the ADOM model, and the Baltic regional calculations were performed with the HILATAR model using one-way 3-D nesting. The total annual atmospheric load of lead to the Baltic Sea in 1997/98 was estimated at about 300-350 tonnes, which is approximately half of the measurements-based value (Schneider *et al.*, 2000)

476. A numerical model that consisted of a regional weather prediction modelling system (RAMS) and three-dimensional Lagrangian transport and diffusion model (TDM) was used to determine the foreign contributions of lead to airborne concentrations in Israel (Erel *et al.*, 2002). These predictions, in conjunction with isotopic measurements, indicated that Israel received significant amounts of lead from Egypt, North Africa, the United Arab Emirates, Jordan, Turkey and Eastern Europe.

477. To develop nationwide estimates of annual average ambient concentrations of air toxins (including lead) over the territorial U.S.A, the U.S. EPA is using the Assessment System for Population Exposure Nationwide (ASPEN) model developed in U.S. EPA's Cumulative Exposure Project (U.S. EPA, 2002). The output of this air dispersion model is an estimate of the annual average ambient concentration of each toxic air pollutant at the centroid of each census tract (land areas that vary in size but typically contain about 4,000 residents each) within the geographic scope of the assessment.

478. The European-scale atmospheric transport model MSCE-HM (Travnikov and Ilyin, 2005) is actively used for operational calculations of lead transboundary pollution within the European region, in connection with the EMEP programme and other activities relating to the LTRAP Convention. The model formulation is based on the experience of preceding transport models for heavy metals developed in EMEP/MSC-E – ASIMD and LPMOD (Pekar, 1996). Concentration levels of lead in the ambient air and deposition fields for each party to the LRTAP Convention within the EMEP area are evaluated annually, along with transboundary transport between countries (e.g. Ilyin *et al.*, 2004; 2005). In addition to regional modelling, the hemispheric model MSCE-HM-Hem is used for the assessment of heavy metal pollution levels in the Northern Hemisphere and evaluation of intercontinental transport (Travnikov, 2001; 2005).

Model inter-comparisons

479. Some of the models mentioned above were included in the models inter-comparison study for lead under the EMEP/MSC-E study (Sofiev *et al.*, 1996). The aim of the study was evaluation of the modelling results obtained by different transport models via comparison between the model results and measured values. Seven atmospheric transport models with various numerical approaches and diverse representations of atmospheric processes were involved. The comparison has shown that the discrep-

ancy of modelling results did not exceed a factor of two for all the models, and less than 50 percent for models of similar approaches (Eulerian or Lagrangian). Figure 7-19a illustrates the comparison of modelled wet depositions of lead with observations at different monitoring sites located mostly along the North Sea coast. The locations of the observation sites are shown in Figure 7-19b).

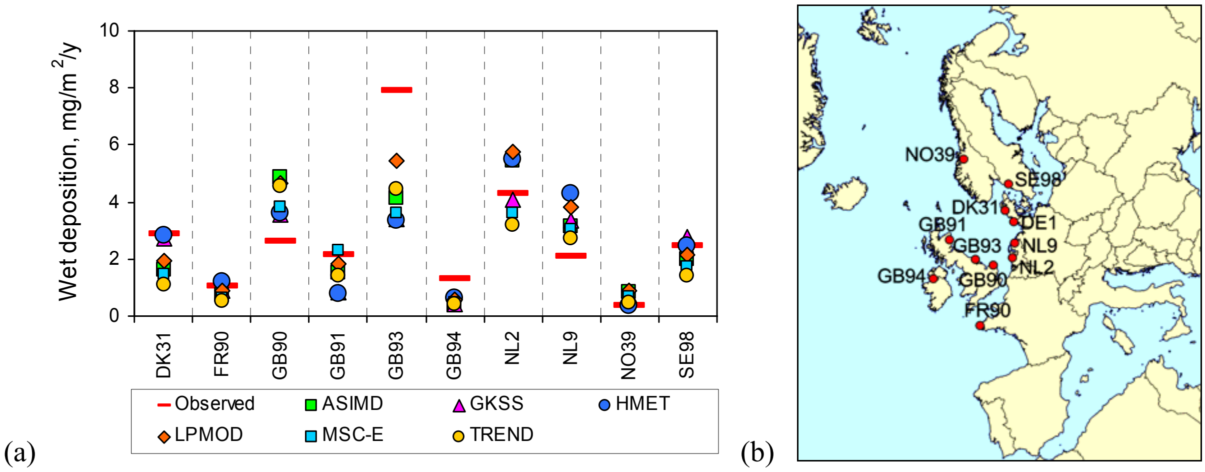


Figure 7-19 Comparison of modelled wet depositions of lead with observations at different monitoring sites (a) and location of monitoring sites involved into the intercomparison study (b) (Adapted from Sofiev et al., 1996).

480. In the other part of the study, the models' ability to simulate transboundary transport was examined. In particular, budgets of lead atmospheric deposition to three different European countries (Italy, Poland and United Kingdom) were compared. Figure 7-20 shows comparison of modelled total lead deposition to Poland from its national anthropogenic sources. Variation of total deposition values obtained by different models does not exceed 20 percent.

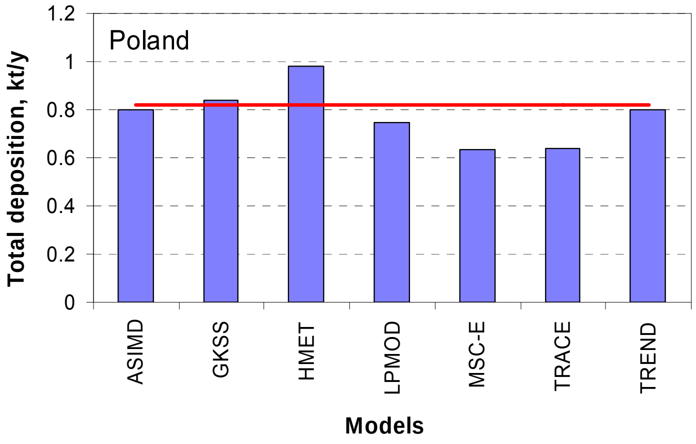


Figure 7-20 Comparison of modelled total lead deposition in Poland from its national anthropogenic sources. Red line shows mean value for all models (Adapted from Sofiev et al., 1996).

481. Another intercomparison of different transport models for lead was performed within the framework of the AMAP - Assessment of Arctic pollution by heavy metals (AMAP, 2005). Three hemispheric-scale models participated in the study: the Norwegian Meteorological Institute model (DNMI), the Danish Eulerian Hemispheric Model (DEHM) and the EMEP/MSC-E hemispheric model (MSCE-HM-Hem). Modelled lead depositions to the Arctic were compared between the models and with available measurements. An example of the comparison is shown in Figure 7-21 for monitoring sites located within or near the Arctic. Two of the models showed close results for all the stations, and the third one predicted somewhat lower concentrations. All the models under-predicted lead concentrations at stations located in Alaska.

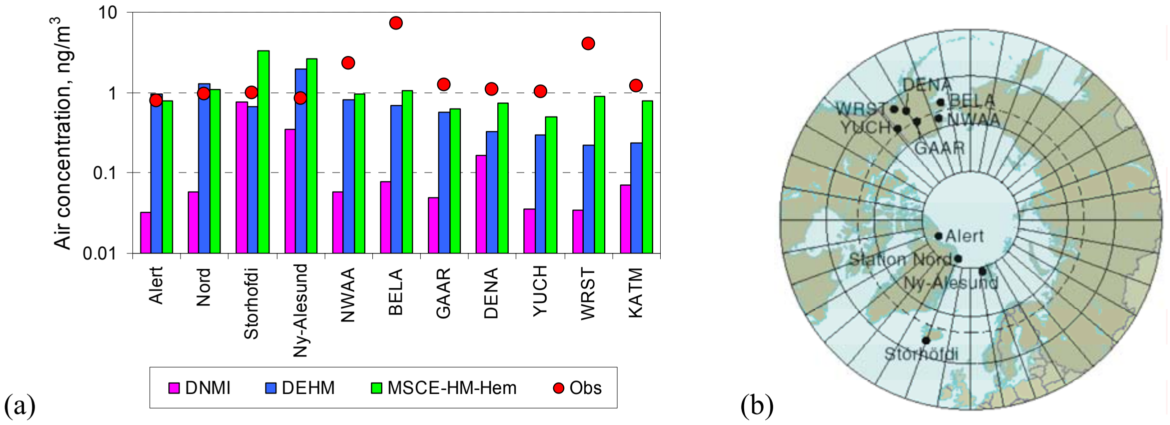


Figure 7-21 Comparison of the modelled annual mean surface air lead concentrations against data from air monitoring sites within or near the Arctic (a); Location of stations is shown in (b) (Adapted from AMAP, 2005).

482. With the exception of some differences (particularly different meteorological data inputs to the models), the broad features of surface air concentration and deposition patterns obtained from the models were consistent (AMAP, 2005). The DEHM and MSCE-HM-Hem models both confirm that the major sources of lead transported to the Arctic are from Europe and the Asian part of Russia. The associated estimates (DEHM: 68 percent from Europe and 18 percent from Asian Russia, and MSC-E: 61 percent from Europe and 25 percent from Asian Russia) are comparable. However, in terms of total lead deposition flux to the Arctic, the models yield distinctly different results. The total lead deposition north of the Arctic Circle as estimated by the DEHM model (6,790 tonnes/year) is approximately twice that estimated by the MSCE-HM-Hem model (3,280 tonnes/year) (Table 7-3).

Table 7-3 Total lead deposition estimates for emissions and model results for 1990 (Adapted from AMAP, 2005).

	DEHM	DNMI	MSCE-HM-Hem
In model domain (tonnes/year)	139,835	ca. 150,134	151,178
North of 50ºN (tonnes/year)	50,793	50,482	47,196
North of 60ºN (tonnes/year)	16,188	13,371	12,282
North of Arctic Circle (tonnes/year)	6,788	4,791	3,278

Model evaluation against measurements

483. An essential part of the model evaluation involves the comparison of modelling results with observations. One should take into account that this kind of comparison is inevitably affected by - often unknown - uncertainties associated with both modelling results and measured data. In addition, modelled pollution levels are significantly affected by some input information used in the modelling process (particularly emissions data). A high sensitivity of modelling results to emissions data results in direct transfer of emissions uncertainties to the model output. That is why the quality of emissions data is critical for model estimates. As mentioned in Section 7.1.1, reported emission estimates for lead are not consistent with measured pollution levels. In this case, introducing some independent expert estimates of lead emissions can significantly improve the quality of the modelling results.

484. The models TRACE, GKSS and HMET, which were applied for evaluation of lead pollution levels in Europe in the early- and mid-1990s, demonstrated satisfactory agreement between modelled and observed values (Alcamo *et al.*, 1992; Bartnicki, 1996; Krüger, 1996). The average of modelling results and measurements were close, and most data showed agreement within a factor of two. These

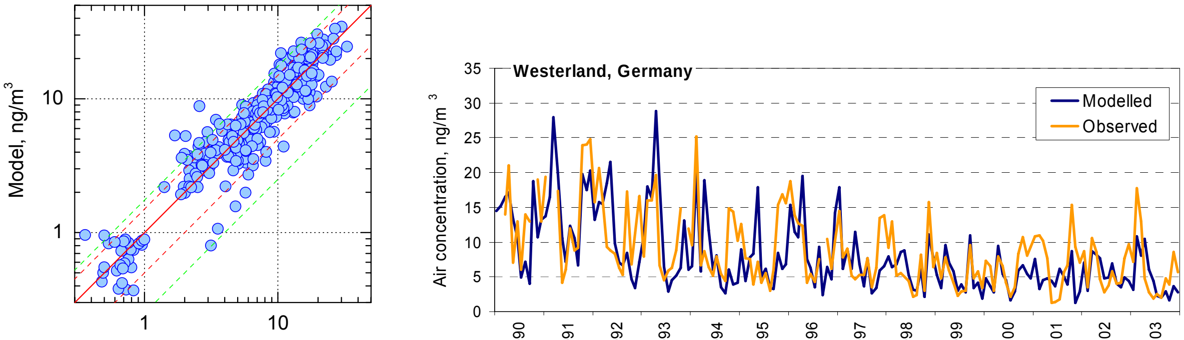
models used expert estimates of lead emissions to the atmosphere (Pacyna, 1988; Axenfeld *et al.*, 1992), since official emissions data were not available at that time.

485. Modelling results obtained by the TREND model (Nijenhuis *et al.*, 2001) were based on UBA/TNO expert estimates of lead anthropogenic emissions for 1990 (Berdowski *et al.*, 1997). The emission figures referred, where possible, to data officially submitted by the countries. The comparison of modelled results with measurements has shown satisfactory agreement for lead concentrations in air. However, about 30 percent underestimation of observed values was detected.

486. The same set of emission expert estimates for 1990 (Berdowski *et al.*, 1997) was used for lead airborne pollution modelling with the models ADOM and HILATAR. Calculations of lead depositions to the Baltic Sea in 1997/98 demonstrated some overestimation when compared with lead measurements in this region. However, it was noted that a significant reduction of lead emissions in Europe between 1990 and 1997 (2-3 times) that was not reflected in the emissions data used for the modelling was responsible for this overestimation.

487. The U.S. EPA compared modelled ambient concentrations from NATA with available ambient monitoring data (from 242 sites for 1996, and 181 sites for 1999) to evaluate the modelling results. This evaluation indicated that NATA underpredicted ambient concentrations of lead for 1996 by about 4-8 times, and an average of about 3 times for 1999. A combination of several factors may be responsible for these discrepancies, including: missing emissions from the inventory (e.g., especially re-emissions of historic lead emissions and natural emissions); spatial uncertainty in locations for sources and high coarse particle deposition velocities. However, the primary factor is likely that "re-entrainment" (i.e., re-emissions of historic lead emissions) is not included in the modelling (U.S. EPA, 2002 and U.S. EPA, 2006b; as cited in HM Protocol review, 2006, submitted by EMEP). The results of a similar evaluation for the 1999 NATA results are about the same as found in the 1996 NATA comparison, which is that for most pollutants the ASPEN model tended to underestimate the monitored values at the location of the monitors, especially for metals (U.S. EPA, 2006b).

488. Comparison of MSCE-HM modelling results based on reported emission data against measurements resulted in substantial (2-3 times) under-prediction of observed values by the model. Discrepancies between model output and measurements could be mainly connected with uncertainties concerning emission data, natural emissions and re-emission of historic depositions of lead. Modelling results, based on independent emission expert estimates, for 1990 - 2003 (Ilyin and Travnikov, 2005) demonstrated that the modelled concentrations of lead in air and in precipitation agreed well with the measurements (Figure 7-22 a, b). The correlation coefficient for annual lead concentrations in air was almost 0.9, and for concentrations in precipitation – 0.7. About 90 percent of modelled lead concentrations in air and 70 percent of concentrations in precipitation agreed with measurements, with accuracy better than ±50 percent of measured value.



(a) (b)

Figure 7-22 Comparison of annual mean modelled (with MSCE-HM) and measured air concentrations of lead in Europe for 1990–2003 (a); Monthly-mean concentrations at station Westerland, Germany (b) (Reprinted from Ilyin and Travnikov, 2005).

489. In summary, as it follows from the preceding discussion the accuracy and availability of emission estimate inputs are of key importance to the models' ability to predict transport outputs. Most assessed models exhibit a good prediction of actually measured values, when reported emission input data are supplemented with additional expert estimates. The uncertainty of emission estimates, and lack of inclusion of natural emissions and re-emission of former lead depositions in the model inputs, are considered the major possible causes for the under-predictions.

7.2 Ocean transport

7.2.1 Examples of ocean transport of lead in the Arctic

490. In the Arctic Ocean, a region which has been investigated in considerable detail over the last decades, the importance of ocean transport of heavy metals has been indicated by AMAP (2004).

491. Recent work on lead suggests that the ocean may provide a central role for lead transport and distribution along the Eurasian Basin boundaries of the Arctic Ocean (AMAP, 2004).

492. Macdonald *et al.* (2005) state that the focus on the atmosphere as a contaminant metal pathway to the Arctic has to some degree diverted attention from the ocean. Sediment cores collected along the margins of the Eurasian and Canadian Basins suggest that a major route for contaminant lead to the Arctic Ocean has been the same ocean current that transports radionuclides northward from the European reprocessing plants (Gobeil *et al.*, 2001, as cited by Macdonald *et al.*, 2005). The residence time of lead in surface water, which is relatively short (<5 years), is still long enough to permit transfer of contaminant lead from the North Atlantic and Nordic Seas into the Arctic (Gobeil *et al.*, 2001, as cited by Macdonald *et al.*, 2005).

493. Lead comprises four stable isotopes, ^{204}Pb (1.48%), ^{206}Pb (23.6%), ^{207}Pb (22.6%) and ^{208}Pb (52.3%) with the composition varying among the world's geological reservoirs (Sangster *et al.*, 2000). That variation has provided an incisive way to determine the sources of contaminant lead in global environmental media including arctic aerosols and ice (Rosman *et al.*, 1993; Sturges and Barrie, 1989; Sturges *et al.*, 1993). Accordingly, Gobeil *et al.* (2001a) were able to relate the contaminant lead accumulating in sediments along the Barents Sea margin to a western European source (206Pb/207Pb~1.14) with ocean currents acting as the major transporting mechanism. In contrast, the contaminant lead in sediments near the North Pole had a distinctly eastern Europe or Russian composition (^{206}Pb/^{207}Pb~1.18) (see Figure 7-23). Based on the composition of contaminant lead in North Pole sediments, these authors proposed a second transport route wherein contaminant lead enters the Arctic Ocean via the Laptev Sea, either in ice or, perhaps more likely, in water of the TPD (Gobeil *et al.*, 2001, as cited by Macdonald *et al.*, 2005). Climate changes may alter the ocean currents and thereby alter the observed ocean transport pathways (Macdonald *et al.*, 2005).

494.

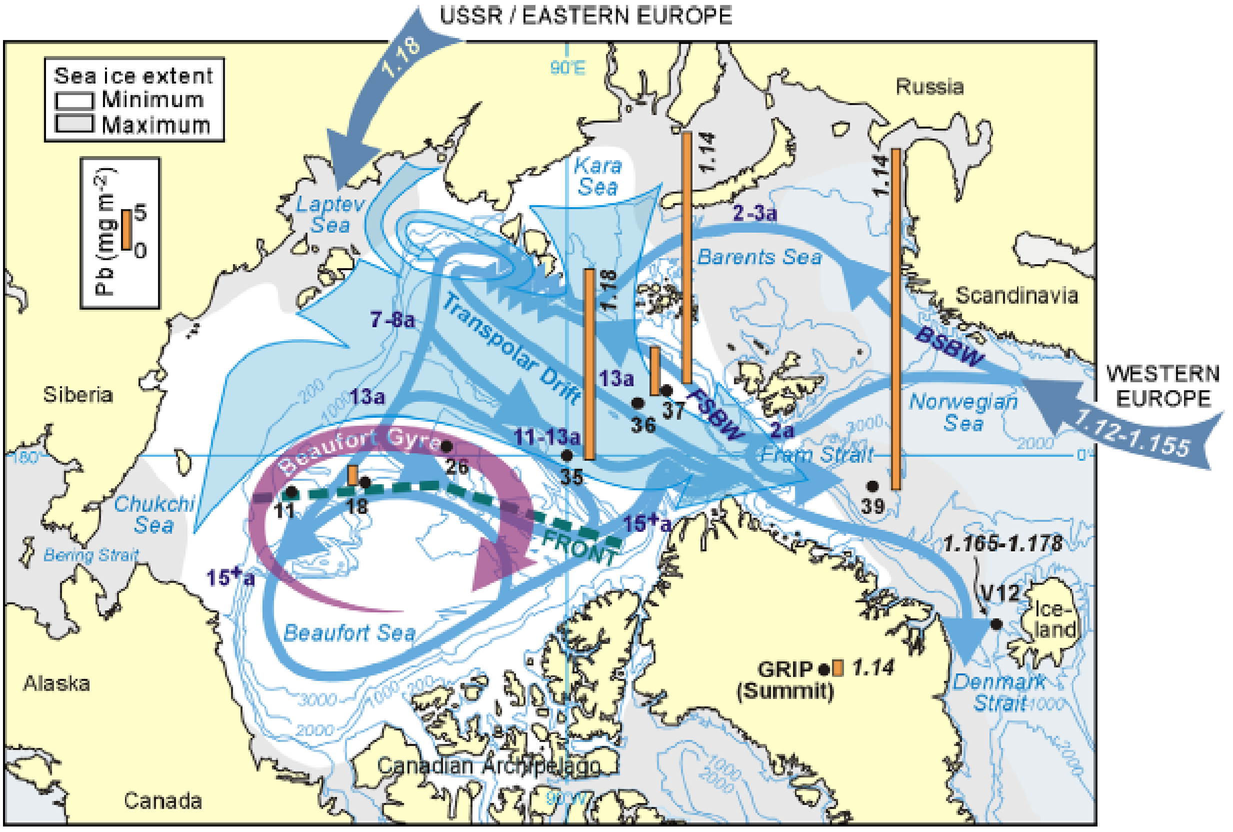


Figure 7-23 The transport of lead into the Arctic Ocean following boundary currents shown by the contaminant lead inventory in sediment cores. Sources of the lead (western Europe and Eurasia) is shown by the stale lead isotope composition (from Macdonald et al., 2005 as adapted from Gobeil et al., 2001).

495. Due to the scarcity of examples of mapping the flow of heavy metals with ocean currents it may be relevant to refer to similar findings for cadmium, which however have longer residence time in the water column than lead. Reference is made to UNEP's (2006) sister review on cadmium for a description of cadmiums flow with water currents in the Arctic region.

Long-range environmental transport in the oceans

496. **Transport in solution and suspension -** A study in Toulon Bay, Southern France (Rossi and Jamet, 2008) highlighted the difference between Cd and Pb in terms of the importance of transport in association with suspended particulate matter. Lead concentrations in SPM samples collected twice per month from March 2006 to March 2007 showed marked temporal variation (from 0.02 µg L^{-1} to 0.29 µg L^{-1} in a single month at one sampling site) whilst Cd was rarely above detection limits, with highest recorded concentration in SPM of only 3.92 x 10^{-3} µg L^{-1}. The same study found that both bacteria and phytoplankton had large capacities to bioaccumulate metals but, importantly, that zooplankton biodiminished these levels, and hence constitute an important break in Cd and Pb accumulation in aquatic food webs.

497. **Bioaccumulation and transport via Bio -** Concentrations of Cd and Pb in various species of fish have been reported (Table 7.4) though often with the aim of assessing potential contamination in food rather than potential for bioaccumulation and contribution to the long-range transport of potentially toxic elements (PTE). It is clear that large predator species such as swordfish and bluefin tuna at the top of the foodchain can accumulate large amounts of metals (Storelli *et al.*, 2005). Concentrations vary between fish species, geographical locations, and tissue types (Pb and, especially, Cd concentrations are generally considerably higher in the liver than in muscle); liver concentrations increase with age of the specimen (Szefer *et al.*, 2003) and may be subject to seasonal variation. A study in Norway

(Berg *et al.*, 2000) compared trace metal contents in fish caught in the Nordfjord with fish caught off the coast and proposed that the higher levels found in livers of flord fish (8.5 x higher than oceanic fish for Cd and 4.4 x higher than oceanic fish for Pb) were due to atmospheric transport and accumulation of atmospheric contaminants in the fjord ecosystem, there being no local sources of PTE.

498. Mussels are recognised as pollution bioindicators because they can accumulate pollutants from the surrounding waters. As sedentary organisms, they do not directly transport Pb and Cd around the globe. However, the presence of elevated concentrations in their tissue (Table 7.5) – sometimes at levels that render them unfit for human consumption (Julshamn *et al.*, 2008) – provides clear evidence of the bioaccumulation for these metals in coastal ecosystems..

499. There is also recent research on levels of Cd and Pb in large migrating mammals such as dolphins (Lahaye, 2006) and whales (see Table 7.6). Skin samples taken by dart gun from over 300 sperm whales, ranging from polar areas to equatorial waters, contained measurable concentrations of several PTE (Ocean Alliance, 2010). Other workers found marked accumulation of Cd in the liver and, especially, kidney of a specimen of Cuvier's Beaked Whale stranded in Corsica (Frodello *et al.*, 2002). A relationship between metal concentrations and age (but not sex or sampling season) of bowhead whale has been reported (Rosa *et al.*, 2008). These studies support the hypothesis that large migrating mammals may contribute to the long-range environmental transport of Cd and Pb in the ocean around the world. However, there do not appear to be any quantitative estimates in literature of the overall amounts of metals transported by this route.

Table 7-4 Concentrations of cadmium and lead in fish

Organisms	**Locations**	**Tissue**	**[Cd] mg kg^{-1}**	**[Pb] mg kg^{-1}**	**References**
Rainbow Trout *(Oncorhyncus mykiss)*	Mediterranean Sea	Gils	0.005 ± 0.001 w	0.021 ± 0.004 w	(Ciardullo et al., 2008)
		Kidney	0.114 ± 0.024 w	0.018 ± 0.001 w	
		Liver	0.023 ± 0.006 w	0.012 ± 0.004 w	
		Muscle	0.004 ± 0.001 w	0.005 ± 0.001 w	
		Skin	0.003 ± 0.001 w	0.022 ± 0.006 w	
Flat-head sole *(Hippoglossoides elassodon)*	Alaska	Gill	na	na	(Meador et al., 2005)
		Liver	1.9-3.9 d	<0.25 d	
		Muscle	0.02-0.3 d	nd	
		Stomach content	0.5-1.3 d	0.9-11.2 d	
White croaker *(genyonemus lineatus)* and English sole *(Pleuronectes vetulus)*	California	Gill	0.02-0.18 d	0.6-1.9 d	
		Liver	1.5-9.8 d	0.23-5.2 d	
		Muscle	< 0.01 d	<0.15 d	
		Stomach content	0.3-4.1 d	1.5-37 d	
Swordfish *(Xiphias gladius)*	Mediterranean Sea	Liver	0.10-0.29 w	0.06-0.11 w	(Storelli et al., 2005)
		Muscle	0.002-0.01 w	0.04-0.08 w	
Bluefin tuna *(Thunnus thynnus)*		Liver	0.06-2.72 w	0.11-0.39 w	
		Muscle	0.01-0.04 w	0.07-0.18 w	
Perch *(Perca fluviatilis)*	Baltic Sea	Liver	0.021-0.057 w	0.013-0.069 w	(Szefer et al., 2003)
		Muscle	0.003-0.043 w	0.009-0.033	
Red mullet *(Mullus barbatus)*	Adriatic Sea	Liver	0.011-0.18 w	0.099-0.97 w	(Gaspic et al., 2002)
		Muscle	0.008-0.029 w	0.057-0.16 w	
Hake *(Merluccius merluccius)*		Liver	0.007-0.15 w	0.039-0.30 w	
		Muscle	0.004-0.14 w	0.049-0.14 w	
Tusk *(Brosme brosme)*	Norwegian fjord	Liver	0.06-0.90 w	0.02-0.09 w	(Berg et al., 2000)
	North Sea	Liver	0.013-0.15 w	<0.01-0.03 w	

Values presented are either a range or a mean value ± standard deviation; w = value expressed on wet weight basis d = value expressed on a dry weight basis; na = not analysed; nd = not detected

Table 7.5 Concentrations of cadmium and lead in shellfish

Organisms	**Locations**	**[Cd] mg kg^{-1}**	**[Pb] mg kg^{-1}**	**References**
Great scallops *(Pecten maximus* L.*)*	Norwegian Waters	0.07-68 w	<0.01-12.4 w	(Julshamn et al., 2008)
Horse mussel *(Modiolus modiolus* L.*)*		0.2-12 w	0.04-85 w	
Mussel *(Elliptio buckleyi* Lea*)*	Marmara Sea	0.04-1.4	0.08-0.96	(Yarsan et al., 2007)
Blue mussel *(Mytilus edulis)*	Bergen Harbour, Western Norway	0.08-0.2 w	0.4-1.7 w	(Airas et al., 2004)
Mussel *(Mytilus galloprovincialis)*	Aegean Sea	0.02-0.25	0.16-0.68	(Zachariadis et al., 2001)

Table 7.6 Concentrations of cadmium and lead in whales

Species	**Locations**	**Tissues**	**[Cd] mg/kg**	**[Pb] mg/kg**	**References**
Bowhead Whale *(Balaena mysticetus)*	Northern Alaska	kidney	0.01-64 w	na	(Rosa et al., 2008)
		liver	0.003-51 w	na	
Sperm whale	Atlantic Ocean	Skin	0.09 ± 0.01	1.2 ± 0.34	(Ocean Alliance, 2010)
	Indian Ocean		0.32 ± 0.09	0.94 ± 0.11	
	Pacific Ocean		0.29 ± 0.02	2.7 ± 1.0	
Cuvier's Beaked whale *(Ziphius cavirostris)*	Mediterranean Coast, Corsica	bone	0.04 ± 0.01 d	4.2 ± 0.1	(Frodello et al., 2002)
		kidney	46 ± 0.5 d	3.6 ± 0.02 d	
		liver	11 ± 0.8 d	1.3 ± 0.07 d	
		lung	3 ± 0.1 d	3.1 ± 0.03 d	
		muscle	0.8 ± 0.3 d	2.5 ± 0.04 d	
		skin	0.29 ± 0.01 d	2.7 ± 0.05 d	
Pigmy Bryde's Whale *(Balaenoptera edeni)*	South China	kidney	3.18 d 0.79 w	15.9 d 3.97 w	(Parsons et al., 1999)

Values presented are either a range or a mean value ± standard deviation; w = value expressed on wet weight basis d = value expressed on a dry weight basis; na = not analysed.

7.2.2 Potential of ocean currents for transport of heavy metals

The "global conveyer belt"

500. The nature of ocean currents indicates their potential for the global-scale transport of pollutants. The global, deep-sea ocean currents are (with varying strength) connected to one big, dynamic system, the so-called thermohaline circulation or "global conveyer belt", which transports enormous water masses through the Atlantic Ocean, the Southern Ocean around Antarctica, and the Pacific Ocean. The main driving force of the thermohaline circulation is the sinking of cold water in the Arctic and the Antarctic, and upwelling of deep-sea waters in eastern parts of the Atlantic and Pacific Oceans (Toggweiler and Key, 2001).

501. Figure 7-24 shows a simplified presentation of the thermohaline circulation, or "global conveyor belt" (based on Broecker, 1991, as cited by Zenk, 2001). Recent research indicates that the transport of deep-sea water masses formed in the Atlantic Ocean may reach the Pacific Ocean to a somewhat lesser degree than indicated in the figure (Toggweiler and Key, 2001). Note that large water masses are

transported to the Polar Regions from oceans in regions with significant anthropogenic sources (e.g. North America and Europe).

502. The circulation time of the thermohaline circulation - i.e. the time from when a water molecule leaves a specific deep-sea location until it reaches the same location along the path of the thermohaline circulation - is estimated at around 600 years (Toggweiler and Key, 2001). This indicates that ocean transport time and large-scale response time to anthropogenic pollution is much longer than the transport time of pollutants in the atmosphere (days to weeks in the hemispherical scale). This means that anthropogenic releases of pollutants may take a long time on the way from one continent to another.

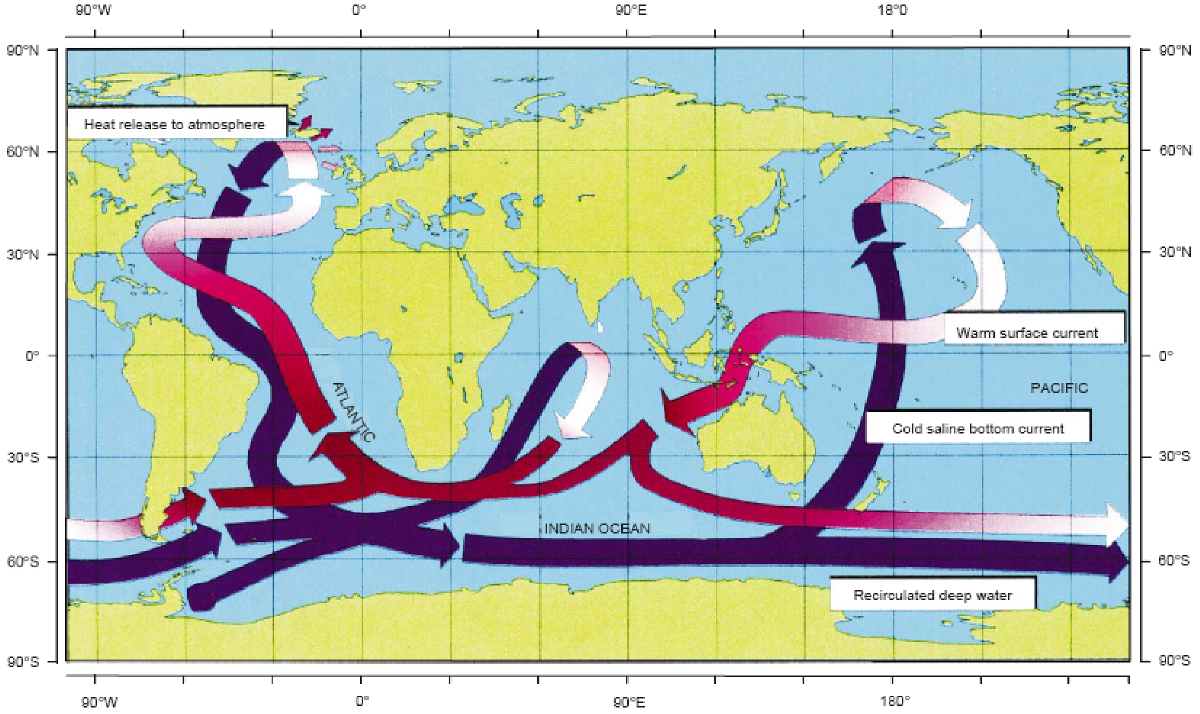


Figure 7-24 The Atlantic thermocline circulation as a key element of the global oceanic circulation. (reprinted from Zenk, 2001).

Residence time of lead in the water column

503. Research over the last decades has shown that trace metals such as lead and cadmium behave quite differently in the water column according to their inherent characteristics and their role in the biological mechanisms of the upper water layers. Researchers characterise trace elements according to their vertical distribution in the water column. One group of elements associate quickly with particles which sink towards the bottom sediments. This sinking is termed "scavenging", and these elements are referred to as "scavenge-type" elements. Another group of elements are assimilated in phytoplankton near the surface and are recycled many times in the upper water layers before they eventually sink to the depths (for example cadmium belongs to this group; Bruland and Lohan, 2004).

504. Lead entering the ocean by atmospheric transport, by direct discharges or via river transport will normally be in the particulate state, and will quickly be bound to other particulate material in the ocean, which will sink to the ocean sediment relatively quickly. The general oceanic residence time of scavenge-type metals like lead is characterised as short; in the range of 100-1000 years, which is less or equal to the overall mixing time of the deep sea ocean waters (around 600 years; Toggweiler and Key, 2001). The concentration distribution of dissolved lead in the water column is accordingly called the "scavenge-type distribution". The concentrations of scavenged-type trace metals typically decrease with distance from the sources, and in general, the concentrations of the scavenged metals tend to decrease along the flow path of deep water due to continual particle scavenging (Bruland and Lohan, 2004).

505. As mentioned above, according to Gobeil *et al.* (2001, as cited by Macdonald *et al.*, 2005), the specific residence time of lead in *surface* water is relatively short (<5 years), yet still long enough to permit transfer of contaminant lead from for example the North Atlantic and Nordic Seas into the Arctic.

506. For comparison, cadmium's behaviour, by way of example, follows a rather different pattern, called the "nutrient-type distribution". This is due to the fact that cadmium (as an exception to the general case for this metal) plays a biological role in the offshore waters poor in nutrient and essential elements, and thereby is kept high in the water column for much longer time than scavenged type elements like for example lead (for details see UNEP, 2006). For this reason, the ocean transport of cadmium may be more significant than for lead.

Modelling of ocean transport of anthropogenic pollutants

507. The possible relevance of modelling ocean transport of heavy metals like lead and cadmium is indicated by the fact that some other priority pollutants - such as POPs (persistent organic pollutants) - are now included in pollution transport models.

508. Examples of factors of relevance to include could be:

- Exchange between the ocean surface and the atmosphere;
- Advective (horizontal) transport by sea currents and turbulent diffusion (including vertical mixing in the upper mixed layer);
- Partitioning between the dissolved and particulate phase;
- Sedimentation;
- Degradation.

7.2.3 Trace metal inputs to oceans

509. The sources of "new" inputs of heavy metals to the oceans are atmospheric deposition, river inputs, hydrothermal vents - sub-seafloor hot water vents - (Bruland and Lohan, 2004), and direct anthropogenic discharges. Besides these new inputs, recycling via re-suspension of heavy metals in sediments and upwelling to surface waters may perhaps play a role.

510. In the case of lead, a number of researchers have been able to observe enhanced lead concentrations in the ocean water column during the peak use of leaded petrol, from around the 1950s until this use was regulated in the U.S.A. and Europe in the 1970s and 1980s. Since then, reductions in oceanic concentrations of lead in water and corals have been demonstrated (Boyle, 2001).

511. In the case of cadmium, which has a longer residence time in the water column than lead, the oceanic reservoir is believed to be large compared to anthropogenic contributions of cadmium in surface waters (Boyle, 2001).

7.3 Fresh water transports

512. Rivers are important transport pathways for heavy metals on a national and regional scale. Heavy metal input to rivers includes direct anthropogenic discharges from industry and municipal sewage systems, as well as runoff from atmospheric deposition (natural and anthropogenic sources) and weathering of the earth's crust in the catchment areas of rivers (natural source). No specific examples for lead have been sought for this review. By way of example, rivers were determined to contribute about 23 metric tonnes of the total input of about 500 metric tonnes of cadmium to the Arctic Ocean, most of which was transported by ocean currents (Macdonald *et al.*, 2000, as cited by AMAP, 2004).

513. Big lakes can be transport pathways for heavy metals on a national and sometimes regional scale. The Great Lakes on the border between Canada and the U.S.A. in North America are examples of lakes where heavy metal pollution has become a common problem.

514. The significance of rivers as transport pathway for lead can be illustrated by data for the Greater North Sea. The total annual riverine and direct input of waterborne lead the in the UK, Sweden, Norway, the Netherlands, Germany, France, Denmark and Belgium is shown in Figure 7-25. In 1996 these inputs totalled about 798 tonnes, of these the riverine inputs accounted for 740 tonnes or more than 90 percent (both estimates based on the lower estimates for riverine inputs). According to OSPAR (2000) the waterborne inputs to the marine environment in these countries were in 1996 larger than the airborne inputs. The atmospheric deposition was at that time responsible only for 1/3 of the total inputs to the marine environment. Taking into account that these countries have extensive waste treatment, the proportion of the input to the marine environment from developing countries may be even more significant.

515. More recently OSPAR concludes that "*For the main body of the North Sea, the atmospheric deposition of cadmium and lead is estimated to be roughly of the same magnitude as the total of riverine inputs and direct discharges* " (OSPAR, 2006).

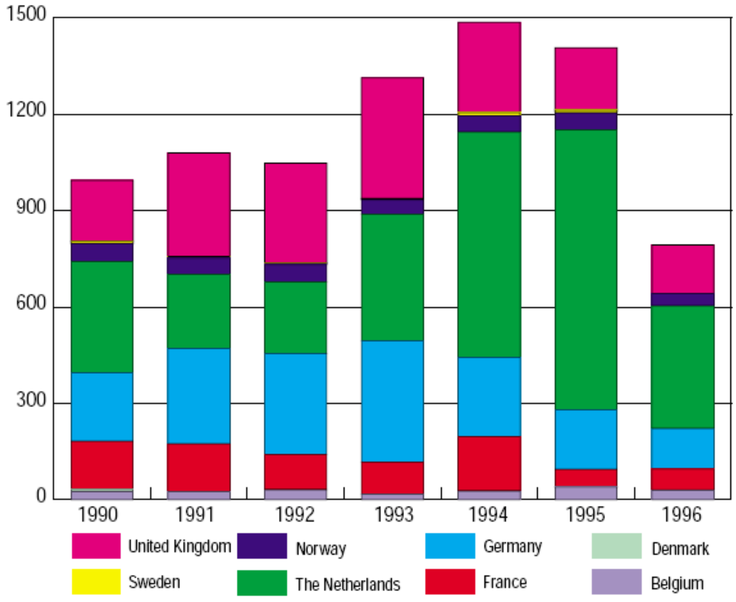


Figure 7-25 Total waterborne lead input to the Greater North Sea from eight European countries in tonnes per year using lower estimate for riverine inputs (OSPAR, 2000)

516. A study carried out by the Industrial Toxicology Research Centre, Lucknow, India of the Ganga river system including the main channel and its 7 tributaries in India to assess levels of 10 metals including lead and cadmium during a period of six years is an example (Seth, 2006). In the main Ganga channel lead was monitored at 20 different locations over a streach of 800 km. As per the study, lead levels ranged from "not detectable" to 1.28 mg/L. The average annual water runoff in the Ganga river is 150,000 million m^3 .

517. In Trinidad, the concentration of lead in rivers has been measured at concentration levels from 1.0 up to 300 µg/L (TCPD, 2000; IMA, 1997/8 & 2002).

518. Groundwater movement is not expected to be an important pathway for lead as concerns long-range transport. Infiltration of rainwater into groundwater and entry into aquifers normally involve passage through soil. As lead binds to soil minerals and humus, groundwater normally contains very low concentrations of lead, typically below 10 µg/L (OECD, 1993).

519. **Migrating fauna** - Transport of heavy metals released to the environment may be taken up in migrating fauna, however, this issue have not been covered by this review.

7.4 Transport by world rivers to the marine environment

520. Research conducted over several decades has demonstrated the importance of major river systems as sources of material, including potentially toxic elements (PTE), to the coastal marine environment. However, perhaps the most comprehensive (and frequently cited) work in the area is now over 30-years old (Martin and Meybeck, 1979). More recent information on global variability of daily total suspended solids and their fluxes in rivers is available (Meybeck *et al.*, 2003) and studies on specific river and estuarine systems continue to appear. For example, research on a small brackish coastal lake in Greece showed that pH and salinity have a strong influence on the lability of Cd and Pb, with biological processes possibly playing a secondary role (Scoullos and Pavlidou, 2003). Work on the Marabasco river in Mexico (Figure 7.26) confirmed the importance of transport in association with suspended particulate matter (SPM) as a mechanism for introducing PTE to coastal systems and, hence, the oceans (Shumilin *et al.*, 2005). Cadmium concentrations in SPM ranged from 0.4 to 5.8 mg kg^{-1} in the river but were considerably enriched (1.0-59 mg kg^{-1}) in the receiving body, the Barra de Navidad Lagoon. In contrast, SPM Pb concentrations were similar in river (2.3-29 mg kg^{-1}) and lagoon (2.7-23 mg kg^{-1}) systems, apart from a single site frequented by tourist boats (118 mg kg^{-1}).

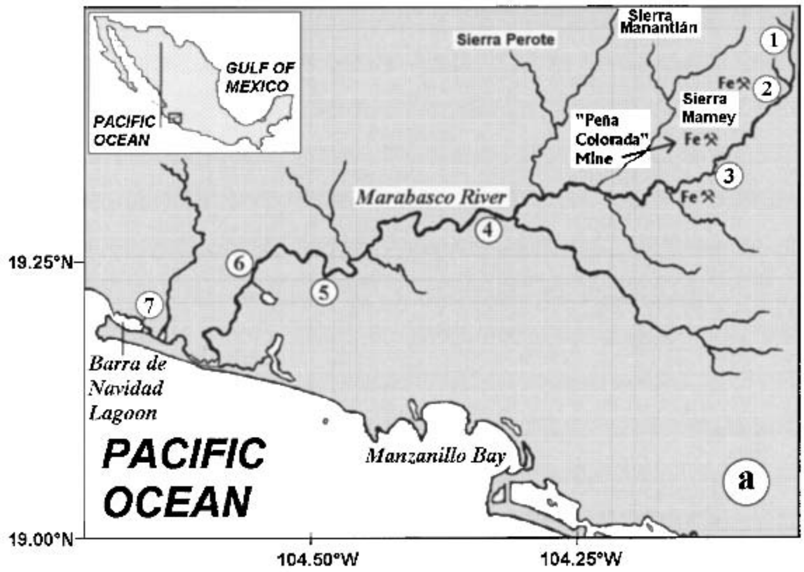


Figure 7.26 *Marabasco River study area (Shumilin et al., 2005).*

521. HELCOM (HELCOM, 2005) have reported that just a few major rivers account for the major part of the total riverine heavy metal loads to the Baltic Sea. In 2003, the reported riverine (including coastal areas) Pb load entering the sea amounted to 285.8 tonnes and the Cd load was 8.1 tonnes. A detailed metal budget for the Seine River basin has been developed (Thevenot *et al.*, 2007). The authors highlighted the large uncertainties, sometimes > 100%, associated with the values of some of the metal fluxes used to create the model e.g. industrial metal demand.

8 Prevention and control technologies and practices

522. This chapter summarizes information about prevention and control technologies and practices, and their associated costs and effectiveness, which could reduce and/or eliminate releases of lead, including the use of suitable substitutes where applicable.

Guidelines and methods for the reduction and prevention of release to the marine environment

523. Guidelines for the prevention of release of Cd and Pb to the marine environment have been discussed in the "Draft final review of scientific information on cadmium and lead" (UNEP a and b, 2008). Usual methods for reduction have been compiled in the "Guidelines for treatment of effluents prior to discharge into the Mediterranean Sea (UNEP, 1996)". Methods for the reduction of cadmium and lead specifically targeted at drinking water supplies are also available (Water Quality Association a and b, 2005). There is increasing research interest in the use of bio-sorption as a waste water treatment process. Biosorption is reported to be an economical feasible alternative to conventional technologies for metal removal and effective at low metal concentrations where approaches such as ion-exchange or precipitation are not useful (Lodeiro *et al.*, 2006). Some recent examples are provided in Table 8.a.

Table 8.a *Biosorption of metals in water treatment processes*

Contaminant metals in water	Organisms	References
Cd, Pb, Hg	Marine bacteria highly resistant to mercury (BHRM) *Alcaligenes faecalis, Bacillus pumilus, Bacillus sp., Pseudomonas aeruginosa, and Brevibacterium iodinium.*	(Jaysankar De *et al.*, 2008)
Cd, Pb	Lactic acid bacteria *Bifidobacterium longum 46* *Lactobacillus fermentum ME3* *Bifidobacterium lactis Bb12*	(Halttunen *et al.*, 2007)
Cd, Pb	*Cystoseira baccata*	(Lodeiro *et al.*, 2006).
Cd, Pb, Cu, Ni	Anaerobicgranules (microbial aggregates)	(Hawari and Mulligan, 2006)
Cd, Pb	Halophilic bacteria	(Massadeh *et al.*, 2005)
Cd, Pb, Cu, Ni, Zn	Marine algae *Sargassum sp.* *Padina sp.* *Ulva sp* *Gracillaria sp*	(Sheng *et al.*, 2004)
Cd, Pb, Ni, Zn	*Lyngbya taylorii*	(Klimmek *et al.*, 2001)

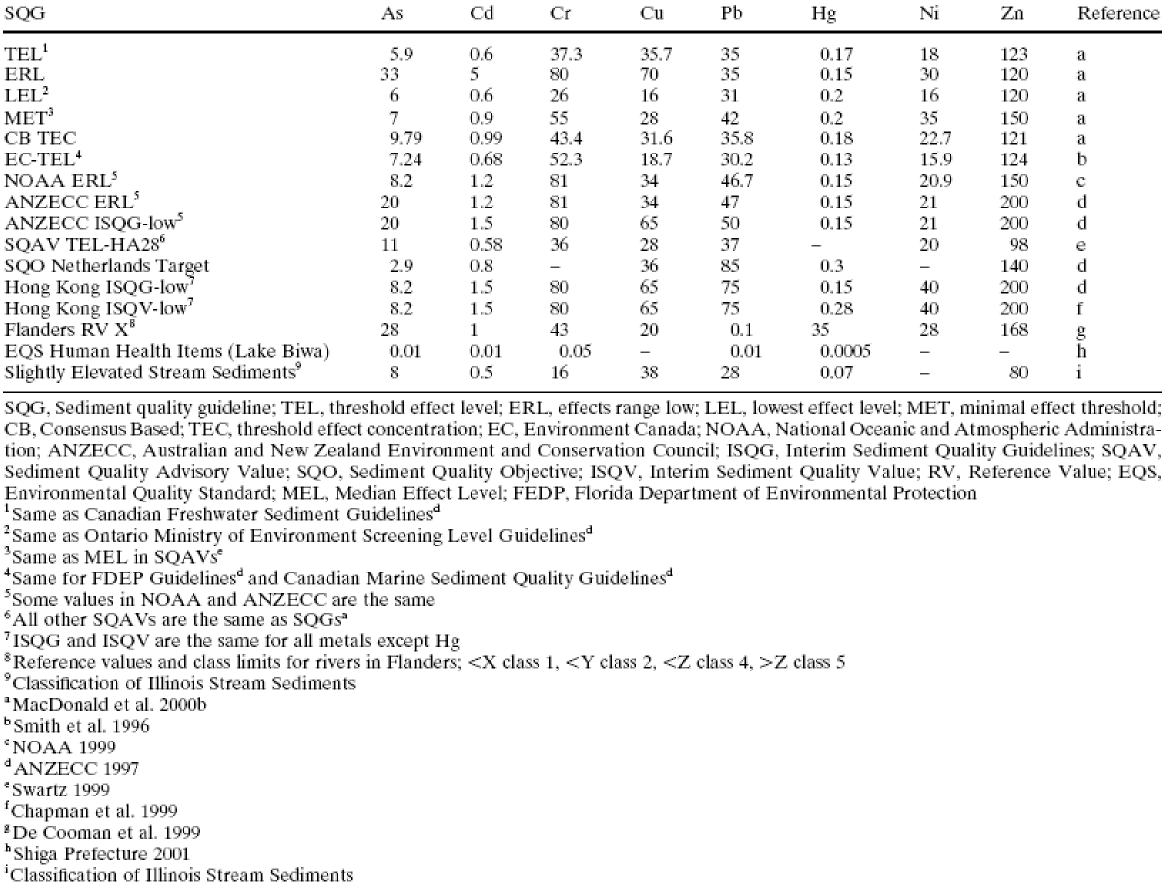
524. New, non-biological methods for the remediation Cd- and Pb-contaminated water, and sediment, are also being developed. The microbially-produced surfactant, rhamnolipid has been shown to remove 80% of Cd and 36% of Pb from contaminated sediment under optimised condition (4 successive batch washings at pH 10) (Shi *et al.*, 2004). The addition of nano-hydroxyapatite particles to contaminated sediment reduced concentrations of Cd and Pb present in forms most likely to be re-released (porewater and exchangeable species) and thus effectively immobilised the contaminant metals (Zhang

et al., 2010). The possibility of using electrokinetic remediation (more usually applied to soils) for *in-situ* removal of Cd, Pb and Zn from contaminated river sediments has been demonstrated on a laboratory scale (Shrestha *et al.*, 2003).

Guidelines for monitoring the marine environment

525. No guidelines appear to exist specifically designed for the monitoring of Cd and Pb in marine systems. However, in common with any monitoring campaign, due consideration must always be given to the monitoring strategy, monitoring objectives, monitoring design, selection of core and supplemental water indicators, quality assurance, data management, data analysis and assessment, reporting, programme evaluation and general support and infrastructure planning (USEPA, 2003). Baseline monitoring programme seek to gain knowledge and understanding of the biogeochemical processes within a particular study area, and their inter-relationships, so as to understand ecosystem functioning (Taljaard *et al.*, 2006; Kusek and Rist, 2004). It is important to make the correct decision between probability based sampling, where sampling units are selected at random, and authoritative (also called 'judgemental') sampling (USEPA, 2002a; UNEP-GEF, 2009); to have the correct number, type and location (spatial and/or temporal) of sampling units to ensure that data are sufficient to draw the conclusion needed (UNEP/MAP, 2005), and to ensure that the entire analytical protocol – including sample storage and pre-treatment steps (UNEP/ROPME, 2006) – is fully fit-for-purpose (USEPA, 2006d). In the absence of monitoring strategies Environmental Quality Standards are often used for environmental protection. There are many flaws in this parochial approach as the values are then derived from different ecological tests and do not account for differing parameters such as temperature or salinity. The links have mostly been collated on the GESAMP website http://www.gesamp.org. Sediment Quality Criteria values from around the world have been collated by Burton (2002) and Table 8.b reproduced below shows the threshold effect sediment guidelines for metals (mg/kg)

Table 8.b Threshold effect sediment guideline for metals (mg/kg)



SQG	As	Cd	Cr	Cu	Pb	Hg	Ni	Zn	Reference
TEL[1]	5.9	0.6	37.3	35.7	35	0.17	18	123	a
ERL	33	5	80	70	35	0.15	30	120	a
LEL[2]	6	0.6	26	16	31	0.2	16	120	a
MET[3]	7	0.9	55	28	42	0.2	35	150	a
CB TEC	9.79	0.99	43.4	31.6	35.8	0.18	22.7	121	a
EC-TEL[4]	7.24	0.68	52.3	18.7	30.2	0.13	15.9	124	b
NOAA ERL[5]	8.2	1.2	81	34	46.7	0.15	20.9	150	c
ANZECC ERL[5]	20	1.2	81	34	47	0.15	21	200	d
ANZECC ISQG-low[5]	20	1.5	80	65	50	0.15	21	200	d
SQAV TEL-HA28[6]	11	0.58	36	28	37	–	20	98	e
SQO Netherlands Target	2.9	0.8	–	36	85	0.3	–	140	d
Hong Kong ISQG-low[7]	8.2	1.5	80	65	75	0.15	40	200	d
Hong Kong ISQV-low[7]	8.2	1.5	80	65	75	0.28	40	200	f
Flanders RV X[8]	28	1	43	20	0.1	35	28	168	g
EQS Human Health Items (Lake Biwa)	0.01	0.01	0.05	–	0.01	0.0005	–	–	h
Slightly Elevated Stream Sediments[9]	8	0.5	16	38	28	0.07	–	80	i

SQG, Sediment quality guideline; TEL, threshold effect level; ERL, effects range low; LEL, lowest effect level; MET, minimal effect threshold; CB, Consensus Based; TEC, threshold effect concentration; EC, Environment Canada; NOAA, National Oceanic and Atmospheric Administration; ANZECC, Australian and New Zealand Environment and Conservation Council; ISQG, Interim Sediment Quality Guidelines; SQAV, Sediment Quality Advisory Value; SQO, Sediment Quality Objective; ISQV, Interim Sediment Quality Value; RV, Reference Value; EQS, Environmental Quality Standard; MEL, Median Effect Level; FEDP, Florida Department of Environmental Protection

[1] Same as Canadian Freshwater Sediment Guidelines[d]

[2] Same as Ontario Ministry of Environment Screening Level Guidelines[d]

[3] Same as MEL in SQAVs[e]

[4] Same for FDEP Guidelines[d] and Canadian Marine Sediment Quality Guidelines[d]

[5] Some values in NOAA and ANZECC are the same

[6] All other SQAVs are the same as SQGs[a]

[7] ISQG and ISQV are the same for all metals except Hg

[8] Reference values and class limits for rivers in Flanders; <X class 1, <Y class 2, <Z class 4, >Z class 5

[9] Classification of Illinois Stream Sediments

[a] MacDonald et al. 2000b

[b] Smith et al. 1996

[c] NOAA 1999

[d] ANZECC 1997

[e] Swartz 1999

[f] Chapman et al. 1999

[g] De Cooman et al. 1999

[h] Shiga Prefecture 2001

[i] Classification of Illinois Stream Sediments

526. Some limit values for Cd and Pb contamination in sea water are presented in Table 8.c. Although many countries have either EQS or SQC values, many developed countries do not have this type of environmental protection and will either use any values found or use inappropriately derived standards (e.g. from a different temperate region)

Table 8.c Limit values of cadmium and lead according to TSE, WHO, and EPA (Suren et al., 2007)

	Limit values of cadmium and lead		
Metals	TSE 266 (mg l^{-1})	WHO (mg l^{-1})	US-EPA (mg l^{-1})
Cd	0.010	0.010	0.010
Pb	0.050	0.050	0.050

TSE: Turkish Standards Institute

WHO: World Health Organization

US-EPA: United States Environmental Protection Agency

527. The specific methods for controlling lead releases from these sources fall generally under the following four groups described below:

- Reducing consumption of raw materials and products that include lead as an impurity;
- Substitution (or elimination) of products, processes and practices containing or using lead with lead-free alternatives;
- Controlling lead releases through low-emission process technologies and cleaning of off-gases and wastewater;
- Management of lead-containing waste.

8.1 Reducing consumption of raw materials and products that include lead as an impurity

528. Reducing the consumption of raw materials and products that include lead as an impurity is a preventive measure for reducing lead releases. This group of measures might potentially include the choice of an alternative raw material, such as using natural gas for power generation instead of coal, but the reduction of lead emissions would most probably not be the main driver for such a shift. No measures specifically addressing substitution of lead-containing raw materials have been identified.

8.2 Substitution

529. In order to prevent lead releases from lead extraction and production, use and disposal of lead-containing products, lead may be replaced by less harmful substances.

530. The present status regarding development and marketing of substitutes for lead is indicated in the Table 8-1. The table indicates to what extent substitutes are available today. It should be noted that the table only lists one or a few of the most promising substitutes and that additional substitutes may be available or are being developed. Furthermore, the table indicates the cost level of the substitute solution as compared to the lead application. For applications where no alternative exists or research is ongoing, it is not possible to state precisely when alternatives would be available and ready for market, as this depends heavily on the demand for these alternatives, as well as regulations or other restrictions on the lead application. It should be noted, that some alternatives to lead may themselves have undesired environmental and health properties.

531. A similar table in Hansen *et al.* (2002) has been used as a starting point, but the table has been expanded and updated, as necessary. One of the main drivers for development of alternatives to lead in Europe has been the introduction of the ban of certain applications of lead in vehicles and electrical and electronic equipment by the End-of-Vehicles Directive and the RoHS Directive (see section 9.1). In relation to the implementation of these directives, a number of studies of the application of the targeted substance in the products and possible alternatives have been undertaken. Among these studies, Goodman and Strudwick (2002), Goodman *et al.* (2004), Hansen *et al.* (2005) and Lohse *et al.* (2001) have been used for collection of updated information.

Table 8-1 Options for substitution of lead with initial indication of level of expenses relative to lead-technology

Application	**Alternatives**	**Price relative to lead technology** [1)]	**Extension of alternatives**
Metallic lead			
Batteries	Lithium-ion-polymer batteries or other types.	"+" - Compared to the lead-acid battery, the lithium-ion-polymer battery costs 6 times more, but lasts 2-3 times longer (Hansen and Lassen, 2003).	At 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, 1997).	"=" – Production costs, lifetime and quality of PE/XLPE-cables deemed equal to traditional lead cables for low-voltage ground applications (Gudum, 2002).	In Denmark, PE/XLPE is replacing lead in 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.)	Other Alternatives may be organised as (Maag *et al.*, 2001): 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 is estimated at 10% of total costs installed (Gudum, 2002).	Aluminium solutions and some rigid profiles are already available on the market (Meier, 2002) Training in pure zinc solutions has been initiated at Danish training centres for plumbers.
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 historical 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	Different alloy systems based on SnAgCu, SnCu, SnAgBi, SnZn, SnAg, SnAgIn among others. SnAgCu seems to be the main alternative (Hansen *et al.*, 2005)	"+" - Metal price 1.5- 2.5 times conventional SnPb.	Electrical glue can replace solders for some applications, but not all. Lead-free solders are needed (Christensen *et al.*, 2000). Alternatives are readily available and frequently used. New machinery and design may be needed (Hansen *et al.*, 2005).
Plating for printed circuit boards	Pure Sn and different systems based on SnCu, SnBi, Ni/Au, Ni/Pd/Au, SnCuNi, organic solderable protectants (OSP) (Hansen *et al.*, 2005).	"=/++" – Metal price ranges from approximately the same for OSP to significantly higher. Furthermore, there may by costs of new machinery and changes in techniques	Alternatives are readily available for most products and are frequently applied. New machinery and design may be needed (Hansen *et al.*, 2005).

Table 8-1 continued

Application	Alternatives	Price relative to lead technology [1)]	Extension of alternatives
Solderable plating of electronic components	Pure Sn and different systems based on NiPdAu, NiPd, NiAu, matte Sn with Ni or Ag underplate, reflowed Sn, hot dipped SnAgCu or SnAg, hot dipped Sn among others (Hansen *et al*,, 2005).	”=/+ ” Metal price ranges from approximately the same to higher. Furthermore, there may by costs of new machinery and changes in techniques and design.	Alternatives are readily available for most applications - concerns for fine-pitch applications. New machinery may be needed (Hansen *et al*., 2005).
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.A. since December 1990 (U.S. EPA, 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. 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: + 20% Tin shot: + 50-150% Bismuth shot: + 200-400% (Hansen *et al.,* 2004a).	Lead shot for use in wetlands are prohibited in a number of European countries. 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 (Hansen *et al.,* 2004a).
Bearings 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 0,1-1% lead)	Lead-free galvanization by use of antimony (Hansen *et al.*, 2005)	"="	Lead-free coatings with antimony are available.
Steel alloys	Machinability enhancers based on tin, calcium, bismuth, selenium and tellurium (Hansen *et al.,* 2005).	“=/+” Material price ranging from about the same to more expensive. Costs of manufacturing may increase	Steels with non-lead machinability enhancers are in use for different steel grades.
Aluminium alloys	Alloys with tin, zinc and bismuth (Hansen *et al.,* 2005).	?	Alternatives are under development.
Copper alloys	Brass: Alloys with selenium, silicon, bismuth in connection with other alloying elements. No identified alternatives for lead in bronzes of bearing shells for particular applications (Hansen *et al.,* 2005).	“+”	Lead-free brass alloys developed for waterworks are readily available.

Table 8-1 continued

Application	**Alternatives**	**Price relative to lead technology** [1)]	**Extension of alternatives**
Weights for fishing tools and anchors	Depends on the application: Anglers' equipment: Lead can be substituted by iron, tin, 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 ropes 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) Weights for trawls: ~ 0% (iron) (Ponsaing and Hansen, 1995). Robes and lines: 20 – 100% (Gudum, 2002).	Regarding anglers' equipment and trawls, substitutes are available on the market. Lead-free ropes are being developed. In Canadian national parks, only lead-free equipment is allowed (Environment Canada, 2002).
Thermal elements/fuses	InSb and BiSn alloys. However, substitutions may not be available for all purposes (Goodman and Strudwick, 2002). In some cases, the use of components may be avoided by improved cooling.	"x/xx" - Indium is very expensive.	Alloys based on cadmium or lead dominate the market (Goodman and Strudwick, 2002).
Balance weights for vehicles	Alternative materials for weights evaluated so far are tin, steel, zinc, tungsten, plastic (thermoplastic PP) and ZAMA, which is an alloy of ZnAl4Cu1 (Lohse *et al.*, 2001).	"+"	Weights made of ZAMA and PP are already in use (Lohse *et al.*, 2001).
Plating of gasoline tanks	Several lead-free alternatives are available and widely-used by car producers: Galvannealed steel sheets with an additional organic coating, galvanized steel with a nickel flash plating, tin-zinc alloy coated steel sheet, aluminium-plated steel, zinc-nickel alloy with a chromium oxide film, zinc plate coated with epoxy resin, plastics (Lohse *et al.*, 2001).	"-/="	Most European companies changed to lead-free steel tanks. Other companies only use plastic tanks or a mixture of plastic and steel tanks (Lohse *et al.*, 2001).
Yacht keels	Iron is used as an 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 share the market.
Lead tubes and joints for drain and water pipes	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.	"?"	Lead solders and miniatures phased out in many countries.
Lead compounds			
Gasoline additives for vehicles	Refinery operating changes, high-octane gasoline components and/or additives (including oxygenates and others)	"?"	In most countries, lead additives have been completely substituted for several years.

Table 8-1 continued

Application	**Alternatives**	**Price relative to lead technology** [1)]	**Extension of alternatives**
Gasoline additives for propeller driven aircraft	Today no alternatives are available for the AVGAS 100/130 octane. Today only lead-free AVGAS 91/96 UL is supplied	"+"	Used in Sweden and probably other countries (Lassen *et al.,* 2005)
Brake linings	One alternative in use is graphite. However, in most cases a 1:1 replacement of lead by one alternative material is not possible; it will be necessary to develop fully new recipes as properties of brake linings are determined by a complex interaction of different materials (Lohse *et al*., 2001).	"?"	Lead-free friction materials are in use, and the majority of new cars from different manufacturers are already equipped with lead-free brake linings (Lohse *et al.*, 2001).
PVC stabiliser	Substitutes are generally: Calcium/zinc stabilisers, which already dominate indoor applications, and have proven useful also with respect to electrical cables and wires. Calcium/zinc stabilisers seem to be the primary choice also for outdoor purposes. However, research/development based on organic compounds is ongoing (Gudum, 2002). 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, 2002).	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, 2002).
Heat stabilizers in elastomers	Organotin stabilizers (Kang *et al*., 2006)	"?"	
Pigments	Many alternatives are available on the market. Ultimately, the choice is a matter of cost and the colour and other characteristics preferred, like weather fastness, torsion stability and brilliance. Persistent inorganic colours for yellow to orange are, e.g., based on tin-zinc-titanate or bismuth-vanadate. (Hansen *et al.,* 2004a).	"-/++" - Other pigments providing other colours can easily be found at lower costs. Trying to develop the perfect substitute may be rather costly (Ponsaing and 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 requires heavy occupational safety protection, the use of lead primers may be far more costly than other primers.	Lead-based primers are almost completely replaced in Denmark.
Siccatives in paint	Several zirconium- or calcium-based siccatives are available. However, for special applications, alternatives may be few or missing.	"=/+" - Compared to price of final product, cost increase for siccatives must be assumed small.	Lead-based siccatives are replaced by zirconium or calcium-based siccatives in the U.S.A (Hoffman, 1992).
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.

Table 8-1 continued

Application	**Alternatives**	**Price relative to lead technology [1)]**	**Extension of alternatives**
Glass in plasma display panels (PDP)	Alternatives may be bismuth, zinc borate or tin phosphate glasses, but all alternatives have significant drawbacks. (Hansen *et al.*, 2005)	?	Alternatives are under development.
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. A large number of glasses, among others glasses based on borosilicate, tinfluorophosphate, zinc-borate, barium, titanium and bismuth are available. The alternatives generally cannot match all properties of the lead-based optical glasses (Hansen *et al.*, 2005). For semi-crystal glass, barium, potassium and zinc are alternatives. For whole crystal glass, research is ongoing but no introduction of alternatives is 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 (Hansen *et al.*, 2005).	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 (Campbell, 1998). For some applications of decorated faience no substitutes exist to lead silicate (Hansen and Havelund, 2006).	"?"	In the United Kingdom, 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).
Marginal applications	Information on alternatives for a number of marginal lead applications can be found in Hansen *et al.* (2005), such as: Printing inks for borosilicate glass, Garnet crystal of optical isolators, adhesives of optical transceivers, radiant agent of HID lamps, fluorescent powder of certain lamps, lead in amalgams of very compact fluorescent lamps, magnetic heads and lead glass in sheath heater.	Not assessed.	Not assessed.

1) Indication of the overall current user/consumer price levels for lead-free alternatives as compared to lead-based 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.
"–": indicates lower price level (i.e. the alternative is cheaper);
"=": indicates approximately the same price level;
"+": indicates higher price level;
"++": indicates much higher price levels;
"?": indicates that the price difference is not known.

532. In the report "Lead in Articles" prepared by the Swedish Chemicals Agency and the Swedish Environmental Protection Agency, a review is undertaken of selected products groups and describes the exposure, some alternatives and the justification for further measures. The relevant section of the report covers fishing tackle for angling, fishing gear for commercial and subsistence fishing, other consumer products, lead in aviation gasoline, batteries and iron sand (Sweden's submission, 2007).

8.3 Emission control

533. Processing of minerals at high temperatures, such as combustion of fossil fuels, roasting and smelting of ores, kiln operations in the cement industry, as well as incineration of wastes results in the release of lead and a number of other volatile trace elements into the atmosphere.

534. There are several possibilities for controlling or preventing lead emissions. Emission reduction measures focus on add-on technologies and process modifications (including maintenance and operating control).

535. Lead can be emitted from processes by fugitive emissions or through flue gas systems. Fugitive emissions are uncontrolled emissions associated with the discharging, handling, and stockpiling of raw materials or by-products. The emissions can be reduced by moving these activities to completely enclosed buildings, which may be equipped with ventilation systems with suitable controls.

536. The overall efficiency of flue gas and fugitive emission reductions depends to a great extent on the evacuation performance of the gas and dust collectors (e.g. suction hoods). Capture/collection efficiencies of over 99 percent have been demonstrated (European Commission, 2001).

537. During high-temperature processes, a number of chemical transformations of the lead present in the feed materials take place and the distribution of lead between different release routes will depend on a number of parameters, among others the temperature of the process, the chemical environment within the process, and the applied emission-control technology.

538. The species of lead emitted from the processes depends on feed material and process conditions. As an example, in coal, lead is mainly present in trace amounts in the form of PbS (galena), but can also be present as pyrite and PbSe. In pulverised coal combustion at 1,527°C (1,800K), the lead species found in the gas phase were elemental Pb, PbO, PbCl and $PbCl_2$. The solid phase comprised of elemental Pb, PbO, PbO_2 and $PbO{\cdot}SiO_2$. As the flue gas cools, the composition of lead changes. $PbCl_2$ increases and is the main constituent of the gas phase before condensation occurs at 627°C (900K) (Furimsky, 2000, as cited in U.S. EPA, 2005a).

539. At the temperatures at which flue gases usually pass dust-emission controls, nearly 100 percent of the lead in the flue gas will be bound to particles, and the emission of lead will depend on the particle size and the efficiency of the dust-cleaning devices. Because of the high efficiency of dust-emission controls in detaining the dust, lead-specific controls are in general not applied. However, for some processes involving lead, such as lead crystal glass production or lead base metal production, reduction of lead emission may be the main driver for the design of the emission control

540. Typical dust concentrations after gas cleaning with selected techniques are given in Table 8-2, derived from the UNECE Heavy Metals Protocol (UNECE, 1999). Most of these measures have generally been applied across sectors. The most efficient devices are fabric filters of the membrane type which can clean the flue gas to below 1 mg dust/m^3.

Table 8-2 Performance of dust-cleaning devices expressed as hourly average dust concentrations (UNECE, 1999)

Dust-cleaning device	Dust concentrations after cleaning (mg/m^3)
Fabric filters (FF)	< 10
Fabric filters, membrane type	< 1
Dry electrostatic precipitators (dry ESP)	< 50
Wet electrostatic precipitators (wet ESP)	< 50
High-efficiency scrubbers	< 50

541. The lead concentration of flue gas can be further reduced if the flue gas after the dust reduction is guided through a system for acid gas reduction as applied in power plants and waste incinerators, for example.

Applied emission control systems in the metallurgical industry

542. The non-ferrous industry, especially primary and secondary lead smelters, has the potential for particularly high emissions of lead, both as fugitive and stack emission. Fugitive emissions can be a very significant source of occupational exposure and releases of lead to the local environment. Fugitive emissions to air arise from the storage, handling, pre-treatment, pyro-metallurgical and hydrometallurgical stages. The largest sources of process fugitive emissions in lead smelters are furnace charging, slag tapping, and agglomerating furnace operation (U.S. EPA, 1998a). Lesser sources are lead tapping and kettle refining. In secondary lead production, battery breaking may be a significant source of fugitive emissions.

543. According to the EU Reference Document on BAT in the Non-Ferrous Metals Industries (European Commission, 2001), data provided have confirmed that the significance of fugitive emissions in many processes is very high, and that fugitive emissions can be much greater than those that are captured and abated. In these cases, it is possible to reduce environmental impact by following the hierarchy of gas collection techniques from material storage and handling, reactors or furnaces and from material transfer points. Potential fugitive emissions must be considered at all stages of process design and development. The hierarchy of gas collection techniques from all of the process stages is (with first priority measures mentioned first):

- Process optimisation and minimisation of emissions;
- Sealed reactors and furnaces;
- Targeted flue gas collection;
- Roofline collection of exhaust gases (very energy consuming measure and should be a last resort).

544. For cleaning of the collected gas, very high dust-collection efficiency can be reached by use of fabric filters or ceramic filters. Due to their tendency to blind in certain circumstances, and because of their sensitivity to fire, fabric filters are, however, not suitable for all applications. Examples of current emissions from some dust-abatement applications and their costs in the metallurgical industry are shown in Table 8-3. Some of the techniques may be used in combination.

Costs of controls

545. As mentioned above, lead is efficiently captured by multi-pollutant emission control technologies and lead-specific controls are in general not applied. In the following the relevant multi-pollutant abatement technologies and their costs are briefly described on the basis on a review provided by Germany for the UNECE Heavy Metals Task Force (Rentz *et al.*, 2004). The findings of the report have not been adopted within the Protocol on Heavy Metals, and in particular the indication of abatement costs should be used with care. Attention is also drawn to the third report from Netherlands a "Study to the effectiveness of the UNECE Heavy Metals (HM) protocol and cost of additional measures". The report is available at: http://www.tno.nl/downloads%5C2006-A-R0087-B_rapport_AV_hdg_V04_1-8.pdf (Germany's submission, 2007).

546. For the preparation of the revision of the annex on BAT in the UNECE Heavy Metals protocol, data on costs for abatement measures has been collected where available (Rentz *et al.*, 2004). In order to prevent misunderstandings, the authors of the report note that the new cost data may not be comparable with the existing information for several reasons (Rentz *et al.*, 2004):

- At large, cost data is available only for some emission reduction technologies of a sector, so a general lack of data can be stated;

- Cost data was available partly in US$, partly in Euro (€). The exchange rate varied over the last two years from 1 € = 0.88 to 1.14 US$, so no unequivocal exchange rate can be defined. As a consequence, new cost information is given in the currency indicated in the reference, so that US Dollar and Euro might appear together in the same table;

- Often there is no definite reference year indicated to which the costs refer, and the date of publication might be the only indication about the approximate point in time of cost assessment. Accordingly, it is generally impossible to take into account effects of inflation or purchasing power;
- Not always a reference is made to the size of the process or the production capacity, respectively, so the correct interpretation of data might be difficult;
- Some sources reported financing and operating costs for a particular installation. These may not be applicable to other sites because the costs of individual operations would include a substantial percentage of site and corporate specific cost components;
- Investments and operating costs may be highly influenced by site-specific factors like local prices (for transport, energy etc.), climatic (affecting e.g. energy demand) or financial conditions (taxes, interest rate etc.), just to name a few. Thus, reported financing and operating costs may not be generalized if they include a substantial percentage of site and corporate specific cost components;
- The level of detail for cost information varies widely. While in some cases a detailed cost analysis is given, in others just a rough cost range is indicated;
- Often the basis for calculation is not indicated, e.g. there is no information available if and which amortization period or interest and discount rate, respectively, was employed.

547. In conclusion, an accurate comparison of cost data is, in general, not possible. The costs indicated below thus give an order of magnitude of the cost range for a technology and allow only a limited comparison of costs between techniques.

548. Emission sources, control measures, dust reduction efficiencies and costs for the metallurgical industry are shown in Table 8-3 .

Table 8-3 Emission sources, control measures, dust reduction efficiencies and costs for the metallurgical industry (based on Rentz et al., 2004)

Emission source	**Control measure(s)**	**Dust reduction efficiency, Percentage of input to controls**	**Reported dust emissions mg/Nm^3**	**Abatement costs (total costs)**	
				Investments	Operating costs
Primary iron and steel production					
Sinter plants	Emission optimized sintering	ca. 50	-	-	-
	FF	> 99	<20	5-15 € /(Nm^3/h)	0.25-1.5 € /1000Nm^3 treated
	Scrubbers	> 90	-	-	-
	Conventional ESP		100 – 150	-	-
	Advanced ESP 3)	95-99	< 50	5-7.5 € /(Nm^3/h)	0.05-0.08 € /1000Nm^3 treated
	ESP + FF		< 10 – 20		
	Cyclone	60-80	300 – 600	0.5-0.75 € /(Nm^3/h)	0.007-0.015 €/1000Nm^3 treated (0.02 to 0.04 €/t sinter)
	Pre-dedusting (e.g. ESP or cyclones) + high performance wet scrubbing system	95 Cd, Pb: >90	< 50 Cd: 0.003 Pb: 0.05	-	
				Investments	Operating costs
Primary iron and steel production					
Pellet plants	ESP + lime reactor + fabric filters	> 99			
	Scrubbers	> 95			
	ESP at the grinding mills		<50	2 m€ (300,000 Nm^3/h)	0.03 -0.05 €/t pellet (4 Mt/a)
	Mechanical collector / multi-cyclone / et scrubber / FF / ESP at the drying and indura-tion zone	95 ->99	<20		
	Gas Suspension Absorber	99.9	2		

Table 8-3 continued

Emission source	**Control measure(s)**	**Dust reduction efficiency, Percentage of input to controls**	**Reported dust emissions mg/Nm³**	**Abatement costs (total costs)**	
Blast furnaces	FF / ESP	> 99		ESP: 0.24-1 US$/t pig iron	
	Wet scrubbers	> 99			
	Wet ESP	> 99			
	2-stage blast furnace gas cleaning systems		1 – 10 Pb: 0.01-0.05		
	Dedusting of tap holes and runners (e.g. bag filter)	99	(<10 g/t pig iron)	1 – 2.3 m€ (690,000 Nm3/h)	0.5 – 2.8 €/t pig iron (3 Mt pig iron/a)
	Fume suppression during casting		(12 g/t pig iron)		
Basic Oxygen Furnace (BOF)	Primary dedusting: wet separator/ESP/FF	> 99		Dry ESP: 2.25 US$ / tonne steel	
	Secondary dedusting: dry ESP/FF	90 – >97	FF: 5 – 15 ESP: 20 – 30	12 – 20 Mio. €	0.8-4 € /tonne liquid steel
	Primary dedusting: Suppressed combustion + venturi scrubber or dry ESP;Full combustion + venturi scrubber	-	5 – 50 (1 g/t LS)	24 – 40 Mio € (1 Mtonne steel/year)	2 – 4 € /t liquid steel
	Pig iron pre-treatment (FF)	-	<10 (1 g/t LS)	10 Mio. €	
Fugitive emission	Closed conveyor belts, enclosure, wetting stored feedstock, cleaning of reads	80 – 99	-	-	-
				-	-
Secondary iron and steel industry	ESP	> 99		-	-
	FF	> 99.5	Dust: <5	24/tonne steel	
Iron foundries				-	-
Induction furnace	FF/dry absorption + FF	> 99	<< 10	-	-
Cold blast cupola	FF (AC/UC)	> 98	< 20	-	-
	Above-the-door take-off: FF + pre-dedusting	> 97		8-12/Mg iron	
	FF + chemisorption	> 99		45/Mg iron	

Table 8-3 continued

Emission source	**Control measure(s)**	**Dust reduction efficiency, Percentage of input to controls**	**Reported dust emissions mg/Nm³**	**Abatement costs (total costs)**	
				Investments	Operating costs
Hot blast cupola	FF + pre-dedusting	> 99		23/Mg iron	
	Venturi (UC)		36 – 41	-	-
	Disintegrator (UC)		5	-	-
	FF (AC/UC)		1.1 – 20	-	-
Rotary furnace	Afterburner (normal operation)		< 30	-	-
	Afterburner (solid phase of melt)		150 – 250	-	-
	FF		< 15	-	-
Primary non-ferrous metal industry					
Fugitive emissions	Furnace sealing, suction hoods, enclosure etc. off-gas cleaning by FF	Dust: >99		-	-
Roasting/sintering	Updraught sintering: ESP + scrub-bers (prior to double contact sul-phuric acid plant) + FF for tail gases	-		7 - 10 US$ / tonne H_2SO_4	
	FF	Dust: > 99.5		24 US$ / tonne steel	
Secondary non ferrous industry					
Lead production	Short rotary furnace: suction hoods for tap holes + FF; tube condenser, oxy-fuel burner	Dust. 99.9		45/tonne Pb	-
Zinc production	Imperial smelting	Dust: > 95		14/tonne Zn	-

ESP: Electrostatic precipitator; FF: Fabric filter

Applied dust emission control systems in other industries

549. Applied dust-emission control systems are generally the same applied across sectors. Control measures and reduction efficiency for waste incineration, coal combustion and cement production are shown in Table 8-5. The data on efficiency are derived from operating experience and are considered to reflect the capabilities of current installations. The reduction efficiency for lead is in general above 90 percent, and through the use of efficient fabric filters efficiencies of 99 percent can be reached.

550. The distribution of lead between the various releases of coal-fired power plants with different flue gas desulphurisation (FGD) systems is illustrated in Table 8-4. In all three types, more than 97 percent of the lead ends up in the bottom ash and fly ash, whereas the FGD system focussing on the few percentages of lead that have passed the dust-cleaning devices.

Table 8-4 Mass balances for Danish coal-fired power plant with different flue gas desulphurisation (FGD) systems (Lassen et al., 2004)

FGD system	**Bottom ash/slag**	**Fly ash**	**Desulphurisation product**	**Emission gas**
Semi-dry	4.6%	92.9%	2.1%	0.4%
Wet	5.7%	93.7%	0.4%	0.2%
No desulphurisation	3.8%	95.4%	0.0%	0.8%

551. The distribution of lead between the bottom ash and the fly ash is, among other parameters, dependent on the temperature of the process. In waste incinerators in general, a higher proportion of the lead ends up in the slag, as illustrated by the behaviour of lead in an Austrian municipal solid waste incinerator (MSWI) in Figure 8-1. About 72 percent of the lead ended in the slag, and less than 1 percent passed the electrostatic precipitator.

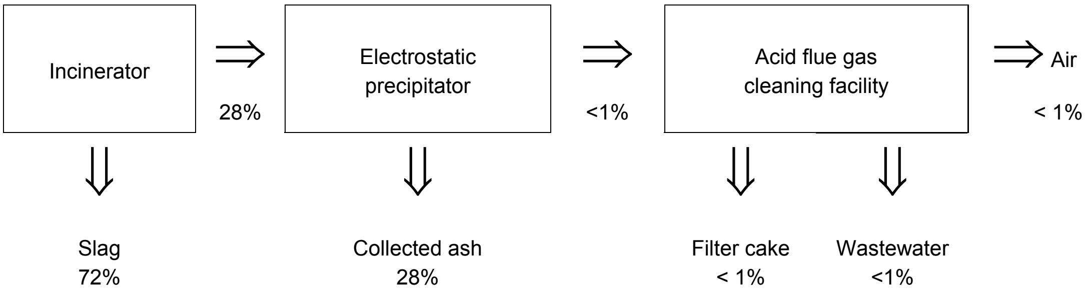


Figure 8-1 Behaviour of lead in the Austrian MSWI plant at Spittelau, incinerating clean household waste (Schachermayer et al., 1995)

552. Emission sources, control measures, dust reduction efficiencies and costs for fossil fuel combustion, cement industry, glass industry and waste incineration are shown in Table 8-5.

Table 8-5 Emission sources, control measures, dust reduction efficiencies and costs for fossil fuel combustion, cement industry, glass industry and waste incineration (based on Rentz et al., 2004)

Emission source	**Control measure(s) 1)**	**Reduction efficiency, Percentage of input to controls**	**Abatement costs (total costs) 2)**		**Comment**
			Investments	**Operating costs**	
Fossil fuel combustion					
Combustion of fuel oil	Switch fuel oil to gas	Pb, Cd: 100	Highly case-specific		
Combustion of coal	Switch from coal to fuels with lower heavy metals emissions	Dust 70-100	Highly case-specific		
	ESP (cold-side)	Pb, Cd: > 90 Dust: > 99.5	1,600 US$/MWh	200 US$/MWh*year	
	Wet flue-gas desulphurization (FGD)	Pb, Cd: > 90;	15-30/Mg waste gas		
	FF	Cd: >95 Pb: > 99 Dust > 99.95	28,900 US$/MWh	5,800 US$/MWh*year	
Cement industry			**Mio. €**	**€/tonne clinker**	Referring to reducing the dust emission to 10-50 mg/m^3 and a kiln capacity of 3000 tonne clinker per day and initial emission up to 500 g dust/m^3
Direct emissions from rotary kilns	ESP	Pb, Cd: > 95	2.1 - 4.6	0.1 - 0.2	
	FF	-	2.1 - 4.3	0.15 - 0.35	
Direct emissions from clinker coolers	ESP	Pb, Cd: > 95	0.8 - 1.2	0.09 - 0.18	
	FF	-	1.0 - 1.4	0.1 - 0.15	
Direct emissions from cement mills	ESP	-	0.8 - 1.2	0.09 - 0.18	
	FF	Pb, Cd: > 95	0.3 - 0.5	0.03 - 0.04	
Direct emissions from crushers	FF	Pb, Cd: > 95	-	-	
Direct emissions from dryers	FF	Pb, Cd: > 95	-	-	
Glass industry			**Mio. €**	**Mio. € / year**	Costs indicate the range from small container glass plants to large floats plants
Direct emissions	FF	Dust: >98	0.2 - 2.75	0.037 - 0.186	
	ESP	Dust: > 90	0.5 - 2.75	0.037 - 0.186	
Waste incineration			**€ / t waste**		
Stack gases	High-efficiency scrubbers	Pd, Cd: >98	-	-	
	Dry ESP	Pb, Cd: 80 - 90	5.73 - 6.06		
	Wet ESP	Pb, Cd: 95 - 99	2.12 - 2.52		
	Fabric filters	Pb, Cd: 95 - 99	7.08 - 7.30		

1) ESP: electrostatic precipitator; FF: Fabric Filter

2) See main text regarding interpretation of costs estimates.

8.4 Waste management practices

553. A number of options exist for the treatment and disposal of solid waste depending on the waste types in question and the characteristics of the waste. The predominant waste management practices cover recycling, incineration, biological treatment and dumping/landfilling. The overall flow of heavy metals to waste is indicated in Figure 8-2. It should be noted that in practice, each step in the figure may consist of several minor steps, and that steps relating to treatment of wastewater, for example, are not indicated in the figure. Note that releases of lead from the treatment processes to the environment are not illustrated on the figure.

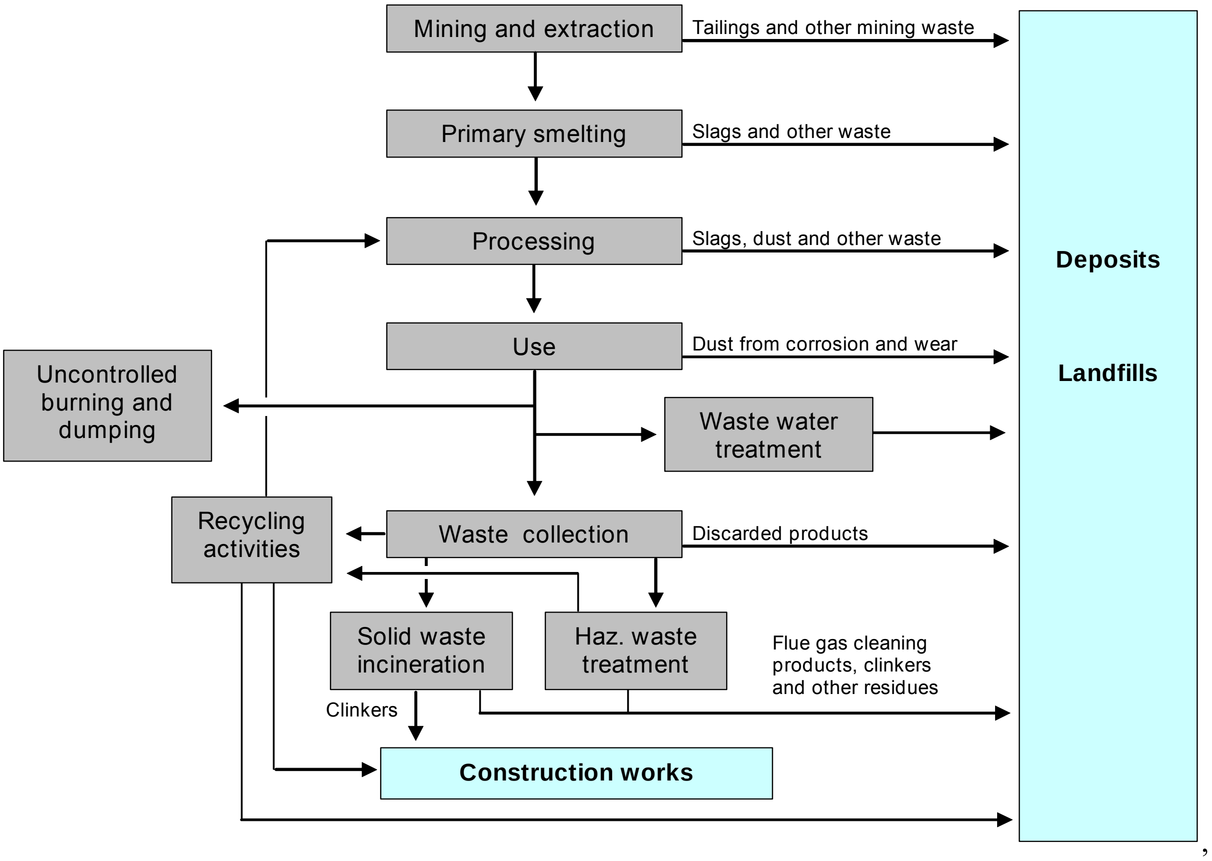


Figure 8-2 Schematic illustration of the overall flow of heavy metals to waste

554. Lead in waste may be a significant source of lead releases to the environment, at short term and in particular in the long term. In fact many waste management practices focus on preventing short term releases to the environment and to prevent immediate exposure of the population to lead in the waste.

555. Waste streams that may cause releases of lead to the environment are listed in Table 8-6.

Table 8-6 Waste streams causing release lead to the environment

Emissions of lead to the atmosphere

- Combustible waste directed to municipal waste incineration plants;
- Sewage sludge directed to sewage sludge incineration;
- Combustible waste burned uncontrolled in dumpsites, backyards etc.
- Lead contained in scrap treated for recovery of the lead.

Discharges of lead to aquatic environments

- Direct discharges from industry and households to water recipients;
- Indirect discharges via wastewater treatment systems;
- Uncontrolled dumping in the water, and surface run-off from uncontrolled dumping on land;
- Discharge of leachate from landfills/dumpsites without leachate collection and treatment;
- Discharge of lead from recycling operation, in particular recycling of lead batteries;

Releases of lead to the terrestrial environment

- Uncontrolled dumping of waste on land including residues from uncontrolled burning of waste and from recycling operations;
- Application of sewage sludge or waste products from biological waste treatment to soil;
- Use of solid residues from waste incineration, coal combustion etc. for construction works like road construction;
- Future erosion of landfills and depots caused by geological events, etc.

Prevention and control measures

556. The options for preventing and controlling lead emissions related to waste management are briefly presented in the following section. In this section, it is assumed that lead is already present in the waste. The issue of substitution as a way of eliminating lead from waste in the longer-term perspective is only briefly addressed in this section; for more detail see the section below on landfilling. As in the case of industrial releases, one may consider a range of non-technical and technical measures that might be applied.

A. Non-technical measures

557. Non-technical measures for preventing and controlling releases from waste streams may typically be divided among regulatory/prescriptive measures, economic measures, and educational/information measures, some examples include:

(1) Regulatory/prescriptive measures

- Prohibit lead in product waste, etc. from being released directly to the environment, by means of an effective waste collection service;
- Prohibit lead in product waste, etc. from being mixed with less hazardous waste in the general waste stream, by ensuring separate collection and treatment;
- Set limit values for the allowable lead content in sewage sludge and product from biological waste treatment applied to agricultural land and other parts of the terrestrial environment;
- Restrict the use of solid incineration residues for construction works such as road-building, where its long-term control cannot be assured;
- Prohibit illegal dumping of wastes;
- Prohibit any direct or indirect discharges of lead to normal drains or the water treatment system, or any disposal of lead in water;
- Prohibit or restrict cross-border transport of lead (and other hazardous) wastes;
- Require that any lead-containing waste or materials stored on-site by an industry or commercial operation must be in waterproof containers, and that the organization must have a written plan and schedule for eventual proper disposal of the materials;

- Prohibit the disposal on land of any sewage sludge, fertilizer, or other material that exceeds responsible international standards for lead content;
- Put in place an environmental management strategy that includes responsible monitoring and enforcement of lead regulations, tracking of all lead movements (from raw material to process to product to waste), and periodic independent control.

(2) Economic measures

- Set taxes and fees on lead-waste disposal which fully reflect the real long-term costs to society and the environment of not dealing with these hazardous substances responsibly.

(3) Information and educational measures

- Educate the public about proper disposal of lead-containing products;
- Provide collection points where the public may easily deliver these separated products;
- Devise several key indicators and publicize the progress that is being made with regard to responsible management of lead.

B. Technical measures

558. Technical measures for dealing with lead consist first of all of emission-control measures, such as:

- Require landfills to be properly licensed and equipped for the type of waste they accept, including membranes to prevent lead from leaching, collection and treatment of landfill effluent, routine and long-term testing of groundwater quality, air emissions, etc.;

- Ensure that lead wastes are incinerated only at facilities equipped with best-available-technology dust collectors and flue gas control, etc.;

C. Long-term solutions

559. Most of the options described above are short- to medium-term measures. One of the only real long-term measures is prevention (keeping lead out of the waste stream). Once present in the general waste stream (if pollution control is considered a priority), lead contributes to the need for emission controls on incinerators, special disposal of incinerator residues, landfill leachate treatment, etc. – all associated with extra costs. Even those countries that make an effort to separate lead products from the general waste stream have found it difficult to achieve satisfactory collection rates for other products than batteries, and they have discovered that separate collection and treatment implies significant extra costs to society. Therefore, with regard to lead in products, minimising the intentional use of lead may be a highly desirable objective. This has been the main driving force behind the lead substitution policy of the countries where such a policy has been implemented.

Recycling

560. Collection of lead-containing products and recovery of lead from the products is a measure to reduce the amount of lead releases directly to the environment or directed to landfills and incineration.

561. As stated in section 6.1, recycled lead account for approximately 45 percent of the production of refined lead. Discarded lead-acid batteries are the principal input source for recycling operations. Other end-products collected for recycling will include lead pipes, sheets, cable sheathing and wastes from fabricating/processing operations. In addition, some plastics containing lead pigment or stabilizers may be recycled as well, whereby the lead compounds are reused.

562. Regarding lead-acid batteries, the rate of collection and recycling is generally assumed to be very high. For Japan as well as Sweden, figures above 95 percent are achieved, explained by a well-organized collection and recycling system which in some countries - e.g. Sweden - is supported by a compulsory fee arrangement to ensure that collection of lead-acid batteries is feasible even at times when the market price of secondary lead is low (ILZSG, 2001). Also, in non-OECD countries and developing countries, the collection rate for lead-acid batteries will be high. According to (ILZSG, 2001),

new regulations have recently come into effect in India, which state that it is now the responsibility of each battery manufacturer, importer, assembler and recycler to ensure that the number of used lead-acid batteries collected is equal to the number of new lead-acid batteries sold. In many countries, the collection rate is likely high because the value of the lead can cover the costs of collection and recycling. However, it cannot be ruled out that a small number of batteries consumed will be disposed of with municipal solid waste or by other means.

563. For other lead metal applications, recovery rates are assumed to be high, although no precise figures are available. The basic pre-condition for successful collection and recycling operations is generally that the metal of concern is available in such quantities and conditions that separation, collection and recycling are economically and practically feasible. This pre-condition will generally be fulfilled for lead products such as pipes, sheets (e.g. used for flashing), roofing materials, cable sheathing, wheel balancing weights, etc. On the other hand, it is not likely that lead used in alloys in small quantities such as solders, fire alarm systems, etc., will be recycled to any significant extent unless specifically prescribed by regulation.

564. Lead used as pigments or stabilisers, as well as for many other minor purposes, is not likely be to be recycled to any significant extent. However, lead in plastics may follow recycled plastic materials, whereby the final disposal of lead may be delayed for several years. Mechanical recycling of source-separated PVC is today technically relatively simple and common practice in Europe (ECVM, 2006).

565. By recycling of lead metal, attention should be drawn to the fact that metal scrap is often stored outside and frequently/occasionally on bare ground (this varies between countries due to national regulations and their enforcement). Corrosion and wear of surfaces will often take place, leading to soil contamination in addition to small metal parts being buried in mud during rainy seasons.

566. **Recycling of batteries** - Recycling of batteries may result in particularly high releases of lead to the environment as lead is present in the batteries not only in metallic form, but also as chemical and dissolved in sulphuric acid. The Secretariat of the Basel convention has recently published "Technical guidelines for the environmentally sound management of waste lead-acid batteries" (Basel, 2003) giving detailed guidance regarding collection, storage, transport, battery braking, lead refining, etc. Further, the secretariat has prepared a "Training manual for the preparation of national used lead acid batteries environmentally sound management plans in the context of the implementation of the Basel Convention (Basel, 2004).

567. The different steps in the battery braking process is shown in Figure 8-3. Breakage of the batteries may result in significant soil pollution, often leading to surface water or groundwater contamination; in particularly if the acid electrolyte is not treated properly. The acid electrolyte must be treated before its lead content may be sent to the smelting furnace. This is carried out by neutralization of the electrolyte solution with sodium hydroxide, which precipitates the present lead as lead hydroxide ($Pb(OH)_2$). This compound is then removed by decantation or filtration. The metallic fraction and the lead compounds derived from the de-sulphurization and neutralization processes are then added to the furnace and smelted with fluxing and reducing agents (Basel, 2003).

568. Electrolyte may also be released by breakage of the batteries during transport and storage prior to the final treatment, and in some countries legislation have been established requiring lead-acid batteries to be stored and transported in acid-resistant containers protected against rain.

569. The releases of lead from recycling operations and the occupational exposure of lead vary considerable among countries as illustrated below with examples from Honduras, Brazil, Costa Rica and Sweden.

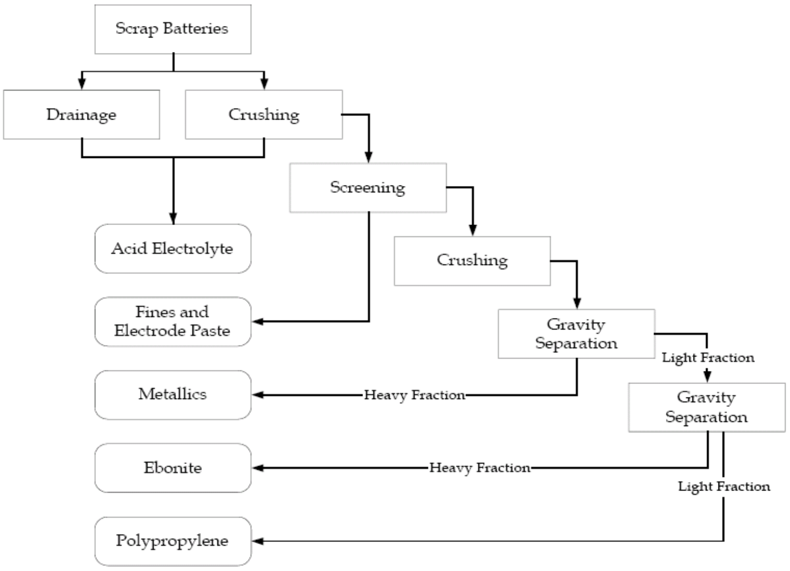


Figure 8-3 Battery breaking process (Basel, 2003)

570. **Battery recycling in Honduras** - Although no lead battery collection system has been officially established in Honduras, a significant flow of batteries are collected by the informal and formal economic sectors (Honduras' submission, 2006). The scrap metal collectors, who form part of the informal sector, play a very important role, as they are in charge of recovering and recycling the batteries and establish commercialization links with the formal sector, particularly the lead smelters and battery producers. A part of the collected batteries is exported to the Republic of El Salvador, whereas the remaining part is recycled in a number of workshops in Honduras. In the capital, Tegucigalpa, 27 establishments were identified involved in the recovery and recycling of lead from used batteries. All of these establishments operate under inadequate environmental and occupational health conditions (Honduras' submission, 2006).

571. A number of studies of lead contamination of soil and air in and around the facilities and of lead blood level of workers have been undertaken in Honduras. Among the impacts identified are soil contamination by lead, particularly in industrial and semi-industrial areas as well as in garbage dumps, contamination of water bodies through discharge of sulphuric acid without prior treatment, contamination of the air within and outside of the industrial facilities and informal lead smelters, exposure to the workers with elevated blood concentrations of lead with associated higher risk of acute or chronic intoxication than that of the population in general and finally, exposure of the population that lives near contaminating sources and that carries out the recovery of materials from the garbage dumps (Honduras' submission, 2006).

572. As an example, analyses undertaken in 2000 and in 2001 in one factory showed that the emissions with high lead concentrations originated from an old revolving furnace, manually fed by the operators, which was lacking an emission control system that would prevent or minimize the release of toxic gases into the occupational and general environment. The high lead concentrations in the air at this factory were related to the high levels of lead in the blood of the workers. The releases of lead resulted in high concentrations of lead in the surroundings and a lead concentration of up to 41,590 mg Pb/kg in samples from ground soil was detected.

573. A study carried out in 2002 in another factory compared the level of lead exposure and potential health effects in a group of workers from a battery factory in Tegucigalpa with a reference group. The main findings of this study indicate that 33 percent of the workers exposed to lead stated that they suffered from certain symptoms especially of the central nervous system such as migraine and nausea followed by lethargy and irritability and in lesser degree, symptoms of the peripheral nervous system.

The levels of lead detected in this group of workers were 65 µg/dL) compared to the levels of the control group of 2.25 µg/dL (Honduras' submission, 2006).

574. **Battery recycling in Brazil and Costa Rica** - The following examples illustrate how trade of products containing lead may influence the environment under less controlled conditions. A large number of similar studies can be found in the literature in journals on industrial ecology, life cycle analysis and so-called "ecological footprint" of industrial products and processes (Working Group comments from Denmark, Brazil and Costa Rica, Geneva, September 2006).

575. In Brazil approximately 95 per cent of all used lead-acid batteries are recycled to recover the lead. Despite of this high recycling rate not all of them are recycled in well controlled secondary lead smelters. The largest battery manufactures collect the majority of the lead-acid batteries from the final consumers and send them to be processed in licensed smelters. Parts of the batteries are however sent to small recyclers that produce lead bullion (unrefined lead), for which environmental emissions and occupational exposures are not in compliance with existing regulation. The produced bullion is sent to be refined in the licensed smelters which in turn send the lead to battery manufacturers. So part of the lead batteries produced are based on lead produced under unsustainable conditions. The largest manufacturers export batteries and supply batteries to the car industry which in turn exports part of its production to many countries (Trivalto, 2006).

576. This situation is reflected in several developing countries; for example in Costa Rica where the average amount of imported lead-acid batteries was 2,660 tonnes/year in the period 1998-2001. Part of these batteries are collected and sent to El Salvador or to the national lead smelter for lead recovery, yet it is a very informal collection system. The amount of batteries collected has not been quantified. Spent batteries not recovered in the country or exported to El Salvador are disposed in landfills and waste dumps, often in areas of sensitive ecosystems (Proarca *et al.*, 2002).

577. **Battery recycling in Sweden** - By recovery of lead from batteries in closed systems with efficient emission controls and efficient recovery of lead in treatment residues, it is possible to establish a nearly 100 percent recycling system. The flow of lead-containing materials in the lead battery system for Sweden has been described by Karlsson (1999). Of the total turnover of lead in the secondary lead smelter Rönskar, 0.001 percent was emitted to the air while about 1 percent ended up in the lead matte (residue). The matte was exported for further recovery of the lead in Belgium. Karlsson (1999) estimates that the total losses to air, water and landfills by the recovery activity is about 0.06 percent of the amount disposed of to recovery. The efficiency of the entire recycling system will in this case depend on the battery collection efficiency.

578. **Battery recycling in Hungary** - There is a system in place to take back used or out of date/expired batteries from the consumers. According to the KöM No. 9/2001. (IV.9.) the manufacturers and suppliers of batteries are obliged to report the yearly quantity of batteries that are taken back. A certain fraction of the batteries are processed, others are managed as wastes. In 2004, 20,000 kg of batteries were taken back, in 2005, 27,200 kg and in 2006, 29,600 kg (Hungary's submission, 2007).

579. **Lead batteries in Cameroon** – In a study undertaken by S. Tetsopgang *et al.* (CREPD's submission, 2007), the authors estimated that lead found in lead batteries in Cameroon for the period 1992 – 2005 potentially could amount to28,900 tons. The two major findings of the sudy were a lack of records on recycled lead trading and weakness about the sound management of lead recovery process from acid batteries suggests. For the sound management of these huge quantities of lead, they made the following reccomandations:

- necessity to inform and train the authorities on the importance of keeping the records of-movement (national and international trade, transformation etc.) of hazardous substances as lead in their traceability and elimination processes;
- necessity to reconsider commitments of lead recycling facilities or plants in observing international compliances on the handling of matter containing heavy metals to avoid harmful effects on human and environment

- enhance the awareness of employees on their rights to denounce any aspect of lead processing that threatens their health

580. **Lead wastes in Trinidad and Tobago.** In Trinidad and Tobago, for the period 2004 – 2008 the main sources of lead derived from the recently concluded National Hazardous Waste Inventory include lead acid batteries, repair and servicing of circuit boards and laboratory analyses. While used lead acid batteries were generally recycled, the other forms of lead waste were disposed of by land filling (Trinidad and Tobago's submission, 2010).

Incineration

581. Combustible waste will in many countries be directed to incineration in order to reduce the volume of waste and recover the energy contained in the waste. With modern technology, the energy can be utilised for electricity as well as heat production. Being an element, lead will obviously not be destructed by the process, but is released to the environment or directed to various waste products from the incineration process. The fate of the heavy metals by the incineration depends on the actual process, especially the flue gas cleaning technology. A schematic view of the flow of heavy metals through an incinerator using wet scrubber for flue gas cleaning is shown in Figure 8-4. It should be noted that many modern incinerators of this type in addition may have carbon filter for dioxin and mercury retention and specific processes for further treatment of the residues e.g. by gypsum precipitation, and washing and stabilisation of the residues.

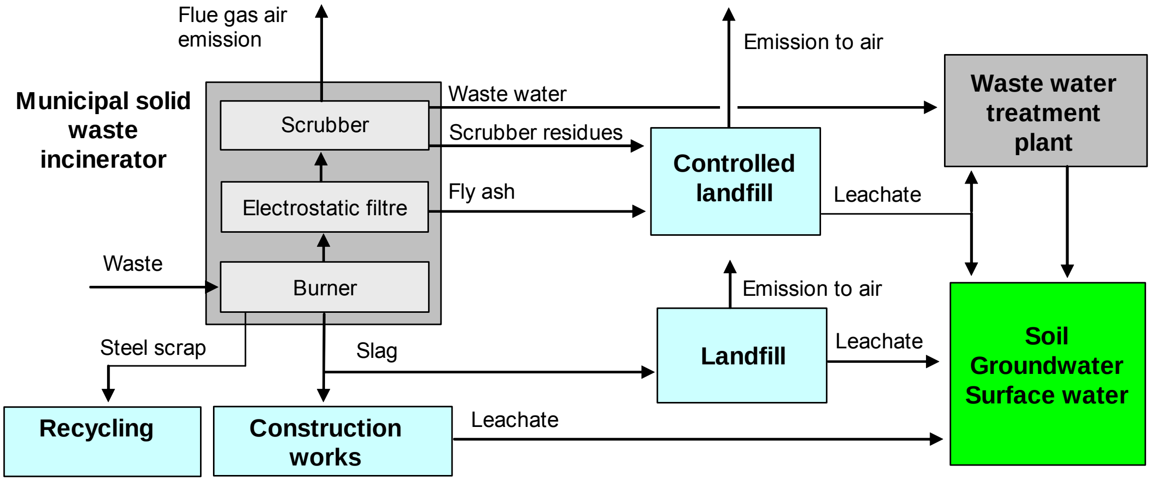


Figure 8-4 Schematic view of the flow of heavy metals by incineration using wet acid gas cleaning process (Hansen et al., 2002)

582. The incineration process typically takes place at temperatures around 1000°C, at which temperature organic materials will burn and be mineralised. At this temperature lead will melt and to some extent vaporise depending on the form in which the lead is present in waste.

583. Lead is collected with bottom ash (clinker) as well as with filter dust and other air cleaning residues. Table 8-7 presents examples of the distribution of lead among outlets from modern European and Japanese incinerators. The main part of the lead in all four incinerators ended up in the bottom ash (clinker). Due to advanced emission abatement technology, the emission of lead to air from modern incineration plants is relatively small.

Table 8-7 Lead in outlets from MSWI plant incinerating clean household waste

Metal	**Percentage of total output to:**				
	Emission to air	**Electrostatic filter dust**	**Flue gas cleaning filter cake**	**Wastewater**	**Bottom ash / clinker**
MSWI plant Spittelau, Austria 1)	<1	28	<1	<1	72
MSWI plant Amagerforbrænding, Denmark 2)	0.04	44		0.01	56
MSWI plant, Japan (A) 3)	2.5	38.1			59.4
MSWI plant, Japan (B) 3)	0.8	32.2			66

Notes:

1 (Schachermayer *et al*., 1995) . Equipped with electrostatic precipitator (ESP) followed by a denox flue-gas cleaning system.

2 (Amagerforbrænding, 2000) quoted by (Hansen *et al*., 2002). Equipped with bagfilters - acid gasses are neutralised by spraying a slurry of lime into the flue gas.

3 (Nakamura *et. al*., 1996). (A): Equipped with ESP followed by and slaked lime injection. (B): Equipped with ESP and wet scrubber for acid gas removal.

584. Waste disposed of for incineration may contain many different lead-containing products, and the distribution between different product groups most probably vary by country. Principal sources in European countries around 2000 included lead glass in cathode ray tubes, crystal glass and optical glass, fishing sinkers and other equipment, pigments in paint and plastics, stabilisers in PVC and solders, but lead will furthermore be supplied by a number of minor sources such as lead curtain weights, ceramics, lead sheets for decoration purposes, toys (as miniature figures), ammunition, etc. (Hansen *et al.,* 2002). Since then some of the main sources of lead in the incinerated waste has been reduced by the implementation of the Directive on Waste Electrical and Electronic Equipment (WEEE Directive, see section 9.1)

585. Whereas air cleaning residues for the incineration generally are directed to landfills, the clinker may in some countries be utilised for civil works such as road construction in order to save landfill capacity and minimize consumption of sand, gravel and similar construction materials. The content of lead in clinker from incineration plants in Europe is generally in the range of 98-13,700 mg Pb/kg (EEA, 1998). In Denmark in 2000, the average lead content of the clinkers was in the range of 860-1,300 mg Pb/kg. Utilisation of incineration residues for construction works (e.g. of unpaved roads) allows a small part to be dispersed to the surroundings as dust during the disposal operation. Furthermore, later changes to the construction involving rearrangement of the residues will cause fractions to be released to the environment as dust, to be washed away by rain, or to be mixed up with soil or other construction materials like sand and gravel. It must be recognised that the amount of lead stored in civil works represents a potential for future release to the environment.

Landfilling

586. Landfilling is a waste management option that can be used for all types of waste. In non-OECD countries landfilling is generally the options of choice, but also in the EU, most waste will today be landfilled. Some 57 percent of municipal waste in western Europe was landfilled in 1999 (EEA, 2003).

587. Landfills range from unlicensed simple dumpsites without any leachate control to highly-controlled landfills for hazardous waste. The general measures to minimise releases from landfills, are to establish caps, covers and liners and to treat the leachate before it is directed to recipients.

588. Heavy metals in leachate from landfills have been extensively studied and monitored. Compared to the total amount of heavy metals disposed in landfills, the content of heavy metals in leachate is relatively low. The major part of the metals is retained in the landfill. As a consequence, it must be expected that leaching of heavy metals from landfills will continue for a long time. The amount of lead

to be released with leachate from waste in sanitary landfills for municipal solid waste and similar depots within the first 100 years after disposal is typically well below 1 percent of the lead landfilled (Hansen *et al.*, 2002; Hansen *et al.,* 2004b).

589. Leachate will typically be collected and undergo wastewater treatment. The amount retained in sludge may be directed to farmland (if leachate is mixed with municipal waste water), incineration or deposited again on landfills. A cycle is therefore created that over time will allow all or most heavy metals in leachate to be emitted to the environment. Furthermore, leachate collection cannot be expected to continue for more than 50-100 years, after which the leachate generated is allowed to find its own way into the environment.

590. The question remains to what extent landfills in the longer-term perspective can be regarded as a permanent containment of lead. The longer-term perspective is often, due to the high uncertainties, excluded from assessments. For example long-term releases from landfills are not covered by the Technical Guidance Document used for EU Risk Assessment and are also excluded from most of the methods used for life cycle assessments (LCA). In order to include such releases in the life cycle assessments according to the EDIP method developed by the Danish EPA, Hansen *et al.* (2004b) undertook a study of the possible long term fate of persistent hazardous substances (among these lead) directed to landfills. Besides ordinary leaching it was considered that geological mechanisms causing erosion such as flooding, earthquakes, etc., may also be assumed to have a significant impact depending on the location of the landfill or depot in question. It was recognised that the amount of lead stored in roads and other construction works represents a potential for future release to the environment (Hansen *et al.*, 2004b). In a long term perspective, when the landfill is abandoned, the landfill may actually be considered a highly contaminated part of the environment and the distinction between the landfill and the surrounding environment may not be relevant.

591. Costa Rica is an example of a country where lead-containing batteries and waste electronics are disposed of in landfills. Nearly two percent of the waste amount disposed in the landfills of the Valle Central Region consists of electronic waste such as old computers (with lead solders and other toxic constituents). At the moment there is no other treatment for this particular waste in the country (Proarca *et al.*, 2002, as cited by Costa Rica at the Lead and CadmiumWorking Group meeting, Geneva, September 2006).

592. **Tailings and other mining waste** - Depots of tailings and other types of mining waste are a special form of landfill/dumpsite, which may cause significant emissions of heavy metals depending on the metals present in the waste. The basic problem is that tailings often contain metal sulphides, which are oxidised when exposed to oxygen and water. Acid is thereby generated, dissolving the metals present (JRC, 2003). Again, leachate may be generated over a long period of time, and tailing depots represent a significant potential for future releases to the environment.

593. **Residues from coal combustion -** Bottom ash and fly ash from coal-fired power plants, as well as residues from specific industries, may be used for construction works by e.g. being used for cements and concrete production.

Uncontrolled burning and dumping

594. Uncontrolled burning of waste by households (backyard burning) and enterprises or on landfills, in order to reduce the amount of waste, is a common practice in many countries.

595. Uncontrolled burning will inevitably cause emissions of lead to the atmosphere and ground. As the temperature is not as high as in incineration plants, metals cannot be assumed to evaporate to the same extent, but uncontrolled burning will still release lead from plastics and other organic materials in which it is integrated. In addition, considering that no air emission abatement is possible while dealing with uncontrolled burning, the actual emissions per tonne of waste may well be significantly higher than for incineration plants. However, no measurements of lead emissions from uncontrolled burning have been identified, and it is so far not possible to quantify the emissions. An indication of the quantity can be obtained by looking at the flue gasses from incinerators before the flue gas treatment. Japan (Ja-

pan's submission, 2005) report emission factors of 8-100 g Pb/ton waste in flue gas before treatment, and estimate the total emission from Japanese incinerators before treatment at 6,900-9,000 tonnes/year. After flue gas treatment the total emission was <7.4 tonnes. As the temperatures by uncontrolled burning are generally lower, and a number of products, which are ending up in incinerators, most probably are not are burned in the backyard (e.g. large electronic products), the data indicates that substantial amounts of lead may be released by uncontrolled burning.

596. The main measures to reduce releases of lead from uncontrolled burning are implementation of efficient waste collection systems and practices for prevention of releases from landfills by covering the landfill by soil.

597. Uncontrolled burning and dumping of waste is known to take place in many countries worldwide, although the amount of waste disposed of and the emissions caused are generally not quantified. Uncontrolled burning obviously takes place in countries without efficient waste collection systems, but may also take place in rural areas of countries with waste collection systems. In the U.S.A, the results of a survey conducted in the early 1990s of residents in five central Illinois counties indicated that about 40 percent of the residents in a typical rural Illinois county burn household waste. The survey also found that, on average, those households that burn waste dispose of approximately 63 percent of their household waste through burning in barrels (U.S. EPA, 1998b). In New Zealand, the amount of household waste burned in backyard fires is about 1 percent of the total amount of domestic waste landfilled in the country (NZ MfE, 2001).

Wastewater treatment

598. Wastewater may be treated by mechanical, biological and chemical treatment techniques. Removal of lead by wastewater treatment will depend on the actual technique employed. Danish experiences indicate an average removal rate of 83 percent for municipal wastewater partly mixed with industrial wastewater (Lassen *et al.,* 2004). The lead removed from wastewater will be retained in sludge that is directed to agricultural areas, incineration or landfills.

9 Initiatives for preventing or controlling releases and limiting exposures

599. The information presented in this chapter on initiatives and actions for management and control of releases and exposures of lead indicates which adverse effects on human health and the environment various countries and international organisations have considered to be significant enough to merit restriction measures. The global coverage of these organisations shows how important such adverse effects have been.

9.1 National initiatives

Overview of existing national initiatives

600. Table 9-1 gives an overview of types of implemented measures of importance to the management of releases from point sources and control of lead, as related to its production and use life-cycle, and an indication of their status of implementation. As can be seen from the table, existing types of measures cover most phases in the life-cycle of lead products and processes from which lead is emitted.

Common features of existing national initiatives

601. A number of countries have implemented national initiatives and actions, including legislation, to manage and control releases and limit use and exposures of lead within their territories.

602. Legislation provides an impetus and a framework for the safe management of chemicals, including lead and lead compounds. It may take the form of laws, decrees, orders, regulations, rules, standards, norms and similar written statements of national policy and requirements for behaviour. National legislation is often composed of one or more general or “umbrella” laws, implemented by specific subsidiary regulations. Countries rarely have a single law to cover chemicals, including lead; instead, separate pieces of legislation and separate ministries are commonly involved, highlighting the need for cooperation between government ministries in the development, implementation and enforcement of legislation on chemicals.

603. Although legislation is the key component of most initiatives, safe management of lead may also include efforts to reduce the volume of lead in use by developing and introducing safer alternatives and cleaner technology. It may also include other national measures, such as the use of subsidies to support substitution efforts and voluntary agreements with industry or users of lead.

Table 9-1 Overview of implemented measures of importance to lead, as related to its production and use life-cycle, and an indication of status of implementation, based on information submitted for this report.

TYPE AND AIM OF MEASURE		STATE OF IMPLEMENTATION
Production and use phases of life cycle and/or releases from sources that mobilize lead from raw materials		
POINT SOURCES	Apply emission-control technologies to limit emissions of lead from combustion of fossil fuels and processing of mineral materials	Implemented in many countries
	Prevent or limit the release of lead from industrial processes to the wastewater treatment system	Implemented in many countries
	Require use of best available technology to reduce or prevent lead releases	Implemented in some countries, especially OECD countries
PRODUCTS	Prevent or limit products containing lead from being marketed nationally	General bans implemented in a few countries only. Bans or limits on specific products are more widespread, such as gasoline and paint . In EU the use of lead has been restricted or prohibited for use in electric and electronic equipment as well as in vehicles
	Limit the allowed contents of lead in commercial foodstuffs and feed.	Implemented in some countries, especially OECD countries. WHO guidelines used by some countries
Disposal phase of life cycle		
Prevent lead in products and process waste from being released directly to the environment, by efficient waste collection		Implemented in many countries, especially OECD countries
Prevent lead in products - especially batteries - and process waste from being mixed with less hazardous waste in the general waste stream, by separate collection and treatment		Implemented in many countries
Prevent or limit lead releases to the environment from incineration (and possibly other treatment) of household waste, hazardous waste and medical waste by emission control technologies		Likely implemented in all countries where organised waste treatment is taking place.
Set limit values for allowable lead contents in sewage sludge and other organic waste products used for land application		Implemented in a number of countries
Set limit values for lead in solid incineration residues used for road-building, construction and other applications		Implemented in some OECD countries

604. The overall aims of existing initiatives on lead are to reduce or prevent the release of lead to the environment, and to avoid direct/indirect impacts on human health and the environment. Many common features can be found among the countries from which information is available. The initiatives can generally be grouped as follows:

A. Environmental quality standards or guidelines, specifying maximum acceptable lead concentrations for different media (such as drinking water, surface waters, air, soil, and for foodstuffs and feed);

B. Environmental source actions and regulations that control lead releases into the environment, including limits on air and water point sources and promoting use of best available technologies and waste treatment and waste disposal restrictions;

C. Product control actions and regulations for lead-containing products, such as petrol, ammunition, paints, vehicles, electrical and electronic equipment etc.;

D. Other standards, actions and programmes, such as regulations or guidance on exposures to lead in the workplace, requirements for information and reporting on use and releases of lead in industry, and consumer safety measures.

605. Based on the information reviewed for this report, it appears that, no country has so far developed comprehensive legislation covering the life-cycle of lead. Many countries have a number of actions and regulations covering specific uses or releases - in a few of these countries, the implemented actions in total cover the full life-cycle of lead. Frequently, legislation related to production, marketing and use of lead and lead-containing products is specific to lead, whereas legislation on releases and the disposal of wastes is often more general and includes other heavy metals, particulate matter (PM) and/or specific inorganic and organic pollutants.

606. It should be noted that considerable variation exists between countries and regions with regard to the types and numbers of uses and releases controlled. It must be kept in mind that the existence or not of initiatives and legislation on lead in a country must be seen in connection with the use and release patterns of that country, and the need to address specific risks to health and the environment posed by these uses or releases. In Sweden, lead is regulated by several European Union directives and are included in section 4 of the Appendix to the current review. These are reproduced from Annex 3 to the report "Lead in Articles" published by the Swedish Chemicals Agency and the Swedish Environment Protection Agency (Sweden's submission, 2007).

607. It should be pointed out the important initiative of OECD countries to reduce risk regarding lead as stated in a final resolution of the Council (OECD, 1996).

Common types of national initiatives

608. This section contains a summary of some of the most common types of initiatives implemented within each of the 4 groups described above. It should be noted that the descriptions are general, and that some countries might have even more restrictive measures in place. Moreover, in this description, EU legislation is referred to as national legislation, although some of EU legislation must be implemented in each of its 25 Member-States.

609. A more detailed compilation of national initiatives, including legislation, in each individual country is contained in an appendix to this report, entitled "Overview of existing and future national actions, including legislation, relevant to lead". The Appendix is published in a separate document. The information compiled therein has been extracted from the national submissions received from countries under this project and is organized along the same lines as this section, thus making it possible to identify additional examples of most of the types of measures described in this section.

A. Environmental media standards and guidelines, specifying a maximum acceptable or tolerable lead concentration for different media

610. **Water, air and soil -** In order to limit the general population's exposure to lead and lead compounds, a number of countries have established standards setting maximum acceptable concentration limits for lead in a number of different media, such as water (drinking water, surface waters, groundwater, etc.), air (ambient air) and soil. In contrast to source-related regulations, which apply directly to individual sources, these environmental standards have an indirect effect on individual sources and releases. Often, they form the basis for regulation of individual sources. As an example of such limits, the Islamic Republic of Iran has established a water-quality standard for lead in natural waters of max. 0.05 ppm (Iran's submission, 2005), while the Republic of Moldova has established a standard for lead and its compounds in the air of residential areas of 0.001 mg/m^3 (Moldova's submission, 2005).

611. It should also be noted that WHO has developed guidelines for drinking water quality (WHO, 2004) and air quality (WHO, 2000a) that provide a basis for protecting public health from adverse effects of air pollution and for eliminating, or reducing to a minimum, those contaminants that are known to be hazardous to human health and well being. Both of these guidelines also cover lead. The guidelines provide background information that can help countries with setting national quality standards. In moving from guidelines to standards, various other factors such as the extent of exposures and environmental, social, economic and cultural conditions in the country, usually need to be taken into ac-

count. In certain circumstances, there may be valid reasons to pursue policies that will result standards for in pollutant concentrations that are set above or below the guideline values.

612. **Foodstuffs** - In order to limit the general population's exposure to lead and lead compounds, some countries - e.g. EU (see Directive 466/200/EC) - have established standards setting maximum acceptable concentration limits in a number of foodstuffs. Standards exist for a wide range of different foodstuffs.

613. **Exposure** - The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established a provisional tolerable weekly intake (PTWI) for lead of 25 µg/kg body weight per week (FAO/WHO, 2002)

B. Environmental source controls/regulations that control lead releases into the environment

614. **Emission limits for air and water point sources** - Many countries have legislation prescribing maximum allowable releases of lead (and other pollutants) from various types of industrial and other facilities (point sources) to air, water and soil/groundwater. The types of point sources covered by such legislation include incineration facilities for household waste and hazardous waste respectively and other industries.

615. In the EU, several Community Directives exist which together limit lead pollution of inland surface, territorial and internal coastal waters and set Community-wide standards regarding discharges of lead for a considerable number of industrial sectors. Also, a new Water Framework Directive has been approved, laying down an integrated EU strategy for harmonised water-quality standards and controls. Lead is subject to review as a possible "priority hazardous substance", for which releases to the aquatic environment are to be phased out within 20 years.

616. In addition, an EU Community Directive exists on the incineration of waste. The aim of this Directive is to prevent or limit, as far as possible, the negative effects on the environment, in particular pollution by emissions to air, soil, surface water and groundwater, and the resulting risks to human health, from the incineration and co-incineration of waste. The Directive sets out air emission limit values for waste incineration and co-incineration plants and for discharges of wastewater from the cleaning of exhaust gases. The provisions apply to new installations as from 28 December 2002, and to existing installations as from 28 December 2005.

617. **Best available techniques** [8] - For certain types of potentially heavily-polluting industries, legislation and/or regulations might not be limited to setting emission limits to air, water and soil, but might also require the use of "best available techniques" or similar approaches, which may require specific, less-polluting production methods, various control technologies and/or pollution-prevention measures.

618. For example, under the Clean Air Act Amendments of 1990, the U.S. EPA regulates Hazardous Air Pollutant Emissions by industrial source categories using Maximum Achievable Control Technology (MACT) standards for each "major source" in any source category. A MACT standard is defined based on an analysis of existing control technologies among the best-controlled sources in a given source category (U.S. EPA, 2006a).

619. Another example is the European Community Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control (IPPC). It requires the application of best available techniques (BAT) to prevent or reduce pollution of the air, water and land from a number of industrial activities in order to achieve a high level of protection of the environment taken as a whole.

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[8] As contrasted with "best available technologies," "best available techniques" (BAT) is a wider term that includes best available technologies but also considers other techniques such as process change. For example, BAT is increasingly used in regional forums (such as in the EU and in the Aarhus Heavy Metals Protocol to the LRTAP Convention) and global forums (such as the Stockholm Convention), where it is well defined and well accepted.

As part of the implementation of the Directive, reference documents on best available techniques (BREF) are developed for different sectors, e.g. the non-ferrous metal industry (EIPPCB, 2006).

620. Another recently prepared report "Assessment of technological developments: Best Available Techniques (BAT) and limit values" includes information on lead. The report provides an overview on most recent technological BAT developments on industrial emission sources of the heavy metals covered by the UNECE Protocol (mercury, cadmium and lead). Additional information is given for emerging technologies, on techniques with regard to application, environmental performance etc. The final report is based on joint work of Germany, Canada, Austria, Poland, the Netherlands and the United States of America and can be found at: http://www.unece.org/env/tfhm/third%20meeting/Background_BAT-ELV_060407.doc (Germany's submission, 2007).

621. **Utilisation of waste and wastewater treatment residues** - Legislation exists that prescribes maximum allowable concentrations of lead, often together with other pollutants, in wastewater sludge and other waste materials to be used as fertiliser on agricultural land or soil improvement material.

622. For example, in Denmark, sludge from wastewater treatment plants and other organic waste materials may be used for agricultural purposes only if the concentration of lead in the pre-treated sludge is below 120 mg/kg dry weight or 10 g/kg total phosphor (Danish EPA, 2003).

623. **Utilisation of residues from municipal solid waste incineration** - Legislation exists - e.g. in Denmark - that prescribes maximum allowable concentrations of lead, often together with other pollutants, in residues from municipal solid waste incineration to be used for civil works such as road construction, etc.

624. **Waste treatment –** In a number of countries -, legislation exists prescribing separate collection and disposal arrangements specifically addressing lead-acid batteries. The aim of such legislation is to prevent or minimise the diffuse spreading of lead and limit the amount of lead waste in the general household waste stream. In order to facilitate separation and collection, labelling of batteries may be required. Collection arrangements may be supported by deposit systems (EU Directive 91/157/EEC).

C. Product control regulations or agreements for lead-containing products

625. Regulatory measures limiting or preventing products containing lead from being marketed nationally, and in some cases also prohibiting import, have been implemented in some countries throughout the world. Such measures may include economic incentives and voluntary agreements between governments and national industry associations.

626. **Leaded gasoline** - Most countries world-wide have restricted the use of lead additives in petrol for vehicle transport in order to reduce lead emissions to air and the subsequent contamination of soil in city areas and near traffic routes, and the resulting impact on humans, etc. Today, leaded gasoline for vehicles is, by and large, phased out in Europe, North America, Latin America and sub-Saharan Africa, and also in most of the rest of Africa and Asia (reference is made to section 9.3.7 on UNEP - Partnership for Clean Fuels and Vehicles).

627. At the moment, restriction of the use of leaded petrol for aviation is not implemented in any country.

628. **Pesticides** - Several pesticides containing lead were legally phased out in the U.S.A., and in 1992, there was no known pesticides using lead as an ingredient (OECD, 1993).

629. **Pipes, solders and joints for drinking water supply** - Restrictions on the use of lead materials (pipes, solders, joints) in drinking water systems due to the heath risk involved have been implemented in many countries world-wide. An example is the Guam lead ban (Guam, 1999). Restrictions generally deal with new installations and do not require replacement of existing installations.

630. **Paint -** Restrictions on the use of lead-based paint exist in several countries. However, the precise scope and content of these restrictions may differ from country to country. Many countries have a ban on lead carbonate - or "white lead" paint - while "red lead" for anti-corrosion purposes and lead-chromates for exterior surfaces may be allowed. Some countries have a complete ban on the use of lead in residential paint, while other countries are relying on voluntary agreements to avoid the use of lead paint for toys and house hold painting (OECD, 1993). In the U.S.A (and possibly other countries) regulations regarding renovation of old houses and removal of lead based paints from houses have been established and guidelines for reducing lead hazards, when remodelling houses, has been issued.

631. **Ammunition -** Lead shot for hunting in wetlands has been banned in several countries due to the consequences to birds, and in particular water fowl, that may ingest the lead shot. Some countries have established a more general restriction on the use of lead shot in forests and other terrestrial environments, while Denmark and Sweden have also restricted lead shot for clay target shooting. In Sweden, furthermore, a use restriction on the use of lead for rifle ammunition will come into force on 1 January 2008. This regulation concerns rifle cartridges for both hunting and shooting, but lead-containing bullets may be used on shooting ranges if the used bullets are managed properly from an environmental and health perspective (Hansen *et al.,* 2004a).

632. **Fishing equipment -** The risk of water-bird ingestion of lead sinkers similar to lead shot has led to a ban in the United Kingdom on the use of lead split shot and lead sinkers above 0.06 g and below 28.35 g (one ounce) in fresh water. Denmark has, for more general environmental reasons, established a total ban on the use of lead in fishing equipment, covering angling equipment as well as equipment for commercial fishing. The Danish ban on equipment is, however, only partly implemented due to a lack of commercially sustainable alternatives to lead-based equipment for commercial fishing. The use of lead equipment is, furthermore, banned in national parks in Canada. In Sweden, voluntary restrictions on the use of lead fishing sinkers in specific fresh waters have been introduced (Hansen *et al.,* 2004a; Hansen and Havelund, 2006; Environment Canada, 2006).

633. **Tableware, ceramic objects intended for food contact and toys, etc. -** Leaching of lead from certain articles intended to be in contact with food such as tableware, or otherwise subject to actions by children or older persons (such as chewing or sucking) which may dissolve lead used in the product, is regulated by some countries. Examples include the Tableware Act from California, U.S.A. (SGS, 2005), and the EU Directive 88/378/EEC on the safety of toys.

634. **Electrical and electronic equipment -** EU Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (the RoHS Directive) bans the import and sale of electrical and electronic equipment containing lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenylethers (PBDE), in effect from 1 July 2006. The ban also covers spare parts for the equipment in question. For lead, a threshold of 0.1 percent by weight for the individual homogeneous parts of the product has been established.

635. The Directive covers the following categories of electrical and electronic equipment:

1. Large household appliances;
2. Small household appliances;
3. IT and telecommunications equipment;
4. Consumer equipment;
5. Lighting equipment;
6. Electrical and electronic tools (with the exception of large-scale stationary industrial tools);
7. Toys, leisure and sports equipment;
8. Automatic dispensers.

636. Equipment for specific military purposes, medical devices and monitoring and control equipment are beyond the scope of the directive. Furthermore, a few specific applications of lead, e.g. lead in optical glass, glass for fluorescent tubes, lead solders in networks, etc. are currently exempted from the directive.

637. **Cosmetics** - According to Directive76/768/EEU (and its amendments 2000/6/EU and 2000/11/EC) lead and lead compounds are not allowed as ingredients in cosmetics that are marketed within the European Community, with the exception of lead acetate (for use in hair treatment products only).

638. **Wine foil wrappers and lead solder in food cans** - Lead foil wrappers on wine bottles are banned, e.g. in the U.S.A., due to the risk of the wraps increasing the level of lead present in wine after it is poured from the bottle (Virginia, 2005). Also, the use of lead solder in food cans is banned in the U.S.A. (NSC, 2004).

639. **Lead candle wicks** - Candle wicks containing lead have been banned in Australia, U.S.A., Canada and Denmark and are also restricted for indoor use in Finland. They are in reality also removed from the market in the EU due to a voluntary agreement between European manufacturers (Hansen *et al.,* 2004a).

640. **Packaging and packaging waste –** EU Directive 94/62/EC on packaging and packaging waste aims to harmonize national measures concerning the management of packaging and packaging waste in order to prevent any impact thereof on the environment and to avoid obstacles to trade within the Community. The directive states that the sum of concentration levels of lead, cadmium, mercury and hexavalent chromium present in packaging or packaging components shall not exceed 100 ppm by weight by 30 June 2001, at the latest.

641. **Vehicles** - European Community Directive 2000/53/EC on end-of-life vehicles lays down measures that aim at the prevention of waste from vehicles and the promotion of reuse, recycling and other forms of recovery of end-of-life vehicles and their components. According to Article 4 of this Directive, lead is restricted in materials and components of vehicles - e.g. in wheel balancing weights. Materials and components of vehicles put on the market after 1 July 2003 shall not contain lead. Furthermore, a few specific applications of lead, e.g. lead in batteries, vibration damping, pyrotechnical initiators for airbags, etc. are currently exempted from the directive.

642. **Other products** - In Denmark, rather comprehensive legislation on lead and lead products was established in 2000. The legislation covers a ban on lead in chemical compounds with some exemptions, combined with a ban on selected uses of lead as metal. The use of lead metal is banned for lead roofing, flashing around windows and chimneys, curtain weights, decorative purposes, cable sheaths for electrical ground cables below 24 kV, fishing equipment and in a number of minor uses. This legislation is in the process of being revised (Hansen and Havelund, 2006).

643. In several countries, voluntary agreements between industrial associations and environmental authorities have been used as an alternative to formal regulation. As an example of such an agreement, all members of the European Stabilisers Producers Association (ESPA) have agreed on a 15 percent reduction in the consumption of lead stabilizers from 2005, increasing to a 50 percent reduction from 2010 and a 100 percent reduction from 2015, as compared to the 2000 consumption level (ESPA, 2001).

D. Other standards and programmes

644. **Occupational health and safety** - A number of countries have implemented measures to ensure occupational safety and health of workers and regulate exposures to lead in the workplace, often by establishing exposure limits, such as the Permissible Exposure Limits (PELs) established in the U.S.A. Limits vary from country to country.

645. **Surveillance of lead blood level** - Some countries have programmes for surveillance of lead blood level. In the U.S.A., the U.S. Centers for Disease Control and Prevention conducts surveillance of blood lead levels in children and adult (U.S. CDC, 2006).

646. **Information and reporting requirements –** Several countries - e.g. Australia, Japan, Canada and the U.S.A., have developed systems to collect and disseminate data on environmental releases and

transfers of toxic chemicals from industrial facilities, often known as Pollutant Release and Transfer Registers (PRTRs). PRTRs have proven valuable, not only to track the environmental performance of industrial facilities and the effectiveness of government programmes and policies that apply to them, but also to stimulate voluntary initiatives by companies to reduce their releases and transfers of toxic chemicals. The PRTR protocol to the Århus Convention is the first legally binding international instrument on PRTRs (UNECE, 2003).

647. **Classification, packaging and labelling of hazardous substances** - Within the EU, all chemical products, inclusive of paint, varnishes and printing inks, that contain at least one percent by weight of heavy metals (including lead) must be classified, packaged and labelled according to EU standards (77/728/EEC).

9.2 International Conventions and Treaties

648. The following section includes information on international conventions and treaties that specifically addresses releases of lead.

9.2.1 The Convention on Long-Range Transboundary Air Pollution and its 1998 Aarhus Protocol on Heavy Metals (LRTAP Convention)

649. The objective of the Convention on Long-Range Transboundary Air Pollution is to protect humans and the environment against air pollution and to endeavour to limit and, as far as possible, gradually reduce and prevent air pollution including, long-range transboundary air pollution. The Convention sets up an institutional framework, bringing together policy and research components. It establishes a number of cooperative programmes for assessing and monitoring the effects of air pollution. Further information can be obtained through the UNECE's website at http://www.unece.org/env/lrtap/hm_h1.htm.

The 1998 Aarhus Protocol on Heavy Metals and its relevance to lead

650. The Executive Body of the Convention adopted the Protocol on Heavy Metals on 24 June 1998 in Aarhus, Denmark. It targets three particularly harmful metals: cadmium, lead and mercury, and requires Parties to the Protocol to reduce their releases of these three metals. It aims to cut emissions from industrial sources (iron and steel industry, non-ferrous metal industry), combustion processes (power generation, road transport) and waste incineration. It lays down stringent limit values for emissions from stationary sources and suggests best available techniques for these sources. The Protocol requires Parties to phase out leaded petrol, and introduces measures to lower heavy metal releases from other products. Emission levels must be reported using, as a minimum, methodologies specified by the Steering Body of EMEP, the Cooperative Programme for Monitoring and Evaluation of Long-range Transmission of Air Pollutants in Europe.

651. Article 3 describes the basic obligations set out in the Protocol; below is a summary of those especially relevant to lead:

A) **Reduction of total annual emissions of lead into the atmosphere,** compared to the reference year for the Party (1990, or an alternative year between 1985 and 1995 set when becoming a Party), through application of best available techniques (BAT), product control measures or other emission reduction strategies.

B) **Use of best available techniques for stationary sources** - for new plants within 2 years of the date that the Protocol entered into force (i.e., by December 2005), for existing plants within 8 years. The best available techniques are described in Annex III to the Protocol. The Annex specifies a number of control techniques that address lead emission together with other pollutants, such as particulate matter (PM).

C) Application of limit values to control emissions from major stationary sources, both new and existing – Limit values for a number of sources are specified in Annex V of the Protocol. The Annex sets a specific limit value for lead emissions from the glass industry at 5 mg/m^{3,} and limit values for particulate emissions from combustion plants, cement industry, waste incinerators and a number of sources within the metallurgical industry.

D) Application of product control measures concerning lead – The Protocol requires that the lead content of marketed petrol intended for on-road vehicles shall not exceed 0.013 g/L. Parties marketing unleaded petrol with a lead content lower than 0.013 g/L shall endeavour to maintain or lower that level.

652. A document entitled Assessment of Technological Developments and Improved Product Control and Product Management Measures was prepared by the Task Force on Heavy Metals in June 2006. Annex VI of the Heavy Metals Protocol contains binding product control measures and Annex VII contains guidance to Parties on a range of possible product management measures. The above-mentioned document describes how measures and technological developments have improved relative to the measures given in the two annexes of the Heavy Metals Protocol. It includes information on how many Parties have undertaken measures, what kinds of management measures have been introduced, changes in the consumption of heavy metals and estimates of the products contributions to air emissions where available. In 10 Annex E of the document, regulatory measures, non-regulatory measures, technological developments, use and emissions and a summary are, where possible, provided for lead in electrical and electronic equipment, lead containing batteries, lead-containing paint, lead stabilisers in PVC products and heavy metals in packaging, sewage sludge and vehicles.

Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe

653. Associated with the LRTAP-process, the main objective of the EMEP programme (Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe) is to regularly provide Governments and subsidiary bodies under the LRTAP Convention with qualified scientific information to support the development and further evaluation of the international protocols on release reductions negotiated within the Convention. Initially, the EMEP programme focused on assessing the transboundary transport of acidification and eutrophication; later, the scope of the programme widened to address other issues covered by the Convention, such as POPs, heavy metals including lead, and particulate matter. For further information is referred to EMEP's website at http://www.emep.int/index.html;

Task Force to Phase out Leaded Gasoline

654. In 1996, the United Nations Economic Commission for Europe (UNECE) established the Task Force to Phase Out Leaded Gasoline, with the participation of Western European countries, CEE and NIS countries in transition, the World Bank, the European Bank for Reconstruction and Development (EBRD), the European Union (EU) and nongovernmental organizations (NGOs). The task force prepared a regional strategy for the elimination of gasoline lead by 2005 and set several intermediate targets. The strategy was broadly endorsed by the Fourth Environment for Europe Ministerial Conference, held in Århus, Denmark, in June 1998.

9.2.2 The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)

655. The objectives of the 1992 OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic are: to take all possible steps to prevent and eliminate pollution; to take the necessary measures to protect the sea area against the adverse effects of human activities and to safeguard human health; and to conserve marine ecosystems and, where practicable, to restore marine areas which have been adversely affected. The Convention contains annexes addressing different sources of pollution, such as prevention and elimination of pollution from land-based sources; prevention and elimination of pollution by dumping or incineration (which prohibits incineration); prevention and elimination of pollution from offshore sources; assessment of the quality of the marine environment and

protection and conservation of the ecosystems and biological diversity of the maritime area. For further information regarding the convention is referred to OSPAR's website at http://www.ospar.org.

The OSPAR Strategy with regard to Hazardous Substances, and its relevance to lead

656. In 1998, at Sintra, Portugal, the first ministerial meeting of the OSPAR Commission adopted, among others, a Strategy with regard to Hazardous Substances, with a view to the further implementation of the OSPAR Convention, which had just come into force. The objective of the Strategy is to prevent pollution of the maritime area by continuing to reduce discharges, emissions and losses of hazardous substances, with the ultimate aim of achieving concentrations in the marine environment near background-values for naturally-occurring substances and close to zero for man-made synthetic substances.

657. The Strategy also includes a time frame, setting out the basis for OSPAR's work for achieving the objective - every endeavour will be made to move toward the target of cessation of discharges, emissions and losses of hazardous substances by the year 2020. To this end, a process has been established to identify the OSPAR list of chemicals for priority action. This list was revised in 2005, and currently contains 44 substances or groups of substances, including lead and organic lead compounds. These chemicals are being addressed by preparing (for those in use in the OSPAR area) background documents for each substance or group specifying the sources of inputs to the marine environment, the threat posed and possible measures. Such measures are then considered. An OSPAR Background Document on lead was endorsed by OSPAR in 2002, and updated in 2004 – a monitory strategy was added in Annex 2- (OSPAR, 2004) and in 2009 (OSPAR, 2009).

658. Quality Status Report summarises advances and trends in the last 10 years for the OSPAR areas of work. The chapter 5 on Hazardous Substances covers monitoring information and levels of lead in environmental compartments and biota, among other aspects (QSR, 2010).

659. The actions recommended there are taken into account, when appropriate, in the work of OSPAR.

660. A number of OSPAR or PARCOM decisions and recommendations address measures on Best Available Techniques (BAT) for various industrial installations and measures for reduction of discharges from offshore gas and oil installations, which will help to limit discharges, emissions and losses of lead. None of the OSPAR or PARCOM decisions or recommendations address measures on lead alone. Of particular importance concerning the reduction of lead emission are the following recommendations

661. **Non-ferrous metal industry** - *OSPAR Recommendation 98/1 concerning Best Available Techniques and Best Environmental Practice for the Primary Non-Ferrous Metal Industry (Zinc, Copper, Lead and Nickel Works)* recommend Best Available Techniques (BAT) for waste management, and prevention of atmospheric, water and soil pollution from the non-ferrous metal industry.

662. **Large combustion plants** - *PARCOM Recommendation 97/2 on Measures to be Taken to Prevent or Reduce Emissions of Heavy Metals and Persistent Organic Pollutants Due to Large Combustion Plants (* 50 MWth)* recommend that the combustion processes, the measures taken or the equipments implemented to prevent or reduce the emissions into the air, the emissions to water and the generation of waste from large combustion plants should be designed, optimized and operated with particular attention to controlling the emissions of toxic, persistent and bioaccumulative pollutants.

9.2.3 The Convention on the Protection of the Marine Environment of the Baltic Sea Area (Helsinki Convention)

663. The objectives of the Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area, adopted on 9 April 1992, are to take all appropriate measures, individually or by means of regional cooperation, to prevent and eliminate pollution in order to promote the ecological restoration of the Baltic Sea Area and the preservation of its ecological balance. For further information regarding the convention is referred to HELCOM's website at http://www.helcom.fi.

664. In 1998, HELCOM established an objective with regard to hazardous substances, and a strategy to implement the objective, through the adoption of HELCOM Recommendation 19/5. The objective is to prevent pollution of the Convention Area by continuously reducing discharges, emissions and losses of hazardous substances towards the target of their cessation by the year 2020, with the ultimate aim of achieving concentrations in the environment near background-values for naturally-occurring substances, and close to zero for man-made synthetic substances. So far, a total of 42 chemicals have been selected by HELCOM for immediate priority action, including lead and its compounds.

665. The following valid (April 2006) HELCOM recommendations specifically relate to lead :

- HELCOM Recommendation 9/4 (adopted 15 February 1988): Recommendation concerning reduction of emissions of lead from combustion of leaded gasoline.
- HELCOM Recommendation 13/4 (adopted 5 February 1992, under revision): Atmospheric pollution related to the use of scrap material in the iron and steel industry.
- HELCOM Recommendation 14/3 (adopted 3 February 1993): Limitation of emissions to the atmosphere and discharges into water from the glass industry.
- HELCOM Recommendation 17/1 (adopted 13 March 1996): Reduction of emissions from transport sector affecting the Baltic Sea.
- HELCOM Recommendation 19/5 (adopted 26 March 1998): HELCOM objective with regard to hazardous substances.
- HELCOM Recommendation 23/5 (adopted 6 March 2002, superseding 5/1 and 17/7): Reduction of discharges from urban areas by the proper management of storm water systems.
- HELCOM Recommendation 23/7 (adopted 6 March 2002, superseding 16/6): Reduction of discharges and emissions from the metal surface treatment.
- HELCOM Recommendation 23/11 (adopted 6 March 2002, superseding 20E/6): Requirements for discharging of wastewater from the chemical industry.
- HELCOM Recommendation 24/2 (adopted 25 June 2003, superseding 14/5):Batteries containing mercury, cadmium or lead
- HELCOM Recommendation 24/4: (adopted 25 June 2003, superseding 11/7, 13/4 and 17/5): Reduction of emissions and discharges from the iron and steel industry.
- HELCOM Recommendation 25/2: (adopted 2 March 2004): Reduction of emissions and discharges from industry by effective use of BAT.
- HELCOM Recommendation 27/1 (adopted 8 March 2006, superseding 16/8): Limitation of emissions into atmosphere and discharges into water from incineration of household waste

666. The HELCOM strategy on hazardous substances, including lead, in many areas parallels the work implemented within the context of the OSPAR Convention.

9.2.4 The Convention on Cooperation for the Protection and Sustainable Use of the River Danube

667. The Convention on Cooperation for the Protection and Sustainable Use of the River Danube (Danube River Protection Convention) forms the overall legal instrument for cooperation and transboundary water management in the Danube River Basin. The main objective of the Danube River Protection Convention (DRPC) is to ensure that surface waters and groundwater within the Danube River Basin are managed and used sustainable and equitably. This involves:

- The conservation, improvement and rational use of surface waters and groundwater;
- Preventive measures to control hazards originating from accidents involving floods, ice or hazardous substances;
- Measures to reduce the pollution loads entering the Black Sea from sources in the Danube River Basin.

668. For further information regarding the convention is referred to ICPDR's website http://www.icpdr.org/.

669. Lead and lead compounds are included in the List of Priority Substances for the Danube River Basin. Eight heavy metals are regularly analysed within the TransNational Monitoring Network (TNMN). These are: arsenic, copper, chromium, zinc, cadmium, lead, mercury and nickel, which are priority substances for the Danube River Basin.

9.2.5 The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (Basel Convention)

670. The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, adopted on 22 March 1989, strictly regulates the transboundary movements of hazardous wastes and establishes obligations for its Parties to ensure that such wastes are managed and disposed of in an environmentally-sound manner. For further information regarding the convention is referred to the secretariat's website at http://www.basel.int/.

671. According to Article 1, paragraph 1 (a) of the Convention, lead or its compounds (as being a part of Annex I to the Convention) is considered a hazardous waste and is covered by the provisions of the Convention if the lead or its compounds possess any of the characteristics contained in Annex III to the Convention In addition, the general obligations of the Basel Convention concerning the need to manage hazardous wastes in an environmentally sound manner would apply to such wastes, including those not being shipped abroad for recovery or disposal operations, but required to be managed locally..

672. Annex IX provides a list of waste not falling under article 1,1(a) of the Convention. Waste containing lead may be found under the following Annex IX categories (the list below is not meant to be exhaustive):

A1010 - Metal wastes and waste consisting of alloys of any of the following: (…), Lead, (…);
A1020 - Waste having as constituents or contaminants, excluding metal waste in massive form, any of the following: (…) Lead, lead compounds;
A1050 - Galvanic sludges;
A1080 - Waste zinc residues not included on list B, containing lead and cadmium in concentrations sufficient to exhibit Annex III characteristics;
A1160 - Waste lead-acid batteries, whole or crushed;
A1170 - Unsorted waste batteries excluding mixtures of only list B batteries. Waste batteries not specified on list B containing Annex I constituents to an extent to render them hazardous;
A1180 - Waste electrical and electronic assemblies or scrap containing components such as accumulators and other batteries included on list A, mercury-switches, glass from cathode-ray tubes and other activated glass and PCB-capacitors, or contaminated with Annex I constituents (e.g., cadmium, mercury, lead, polychlorinated biphenyl) to an extent that they possess any of the characteristics contained in Annex III (note the related entry on list B B1110);
A2010 - Glass waste from cathode-ray tubes and other activated glasses;
A3030 - Wastes that contain, consist of or are contaminated with leaded anti-knock compound sludges;
A3120 - Fluff - light fraction from shredding;
A4020 - Clinical and related wastes; that is wastes arising from medical, nursing, dental, veterinary, or similar practices, and wastes generated in hospitals or other facilities during the investigation or treatment of patients, or research projects;
A4070 - Wastes from the production, formulation and use of inks, dyes, pigments, paints, lacquers, varnish excluding any such waste specified on list B (note the related entry on list B B4010);

673. Clean, uncontaminated lead scrap, including alloys, in bulk finished form (sheet, plate, beams, rods, etc), is not considered hazardous waste under this Convention, unless it contains material which gives it hazardous waste-like characteristics ("Annex III" characteristic).

674. The Basel Secretariat has recently published technical guidelines for the environmentally sound management of waste lead batteries and a training manual for the preparation of national management plans for lead batteries in the context of the implementation of the Basel Convention (Basel 2003;

Basel, 2004). Further the Secretariat has published "Technical guidelines on the environmentally sound recycling/reclamation of metals and metals compounds" and "Basel Convention technical guidelines on hazardous waste physicochemical treatment (D9) / bio-logical treatment (D8)".

9.2.6 The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (Rotterdam Convention)

675. The objectives of the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade, adopted on 10 September 1998, are:

- To promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm; and

- To contribute to the environmentally-sound use of those hazardous chemicals, by facilitating information exchange about their characteristics, by providing for a national decision-making process on their import and export, and by disseminating these decisions to Parties.

676. For further information regarding the convention is referred to the secretariat's website at http://www.pic.int.

677. The Convention establishes a specific procedure to identify and include chemicals in the Convention, based on actions taken by Parties to ban or severely restrict the use of a pesticide or industrial chemical or a Party is experiencing problems with a severely hazardous pesticide formulation under conditions of use. The Convention initially covers 22 pesticides (including five severely hazardous pesticide formulations) and five industrial chemicals, but many more are expected to be added in the future. As of 6 April 2006, the Convention lists a total of 39 chemicals. Among these chemicals are 24 pesticides, 11 industrial chemicals and 4 severely hazardous pesticide formulations.

678. At present, tetraethyl lead and tetramethyl lead are covered by the Rotterdam Convention. The two compounds can be used as anti-knocking agents in petrol. The Convention does not make any specific recommendations with regards to reducing or eliminating use of these compounds; however, it ensures that international trade does not take place if an importing Party decides to prohibit use of these compounds in the country.

9.2.7 The Agreement on the Conservation of African-Eurasian Migratory Waterbirds

679. The Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA), is developed under the Convention on the Conservation of Migratory Species of Wild Animals, commonly referred to as the Bonn Convention (see http://www.cms.int). The aim of AEWA is to maintain or restore migratory waterbird in Africa and Eurasia at a favourable conservation status. For further information regarding the convention is referred to the AEWA's website at http://www.unep-aewa.org/.

680. The geographic scope of AEWA is the area of the migration systems of African-Eurasian waterbirds: Europe, parts of Asia and Canada, the Middle East and Africa. In fact, the geographical area covered by the AEWA stretches from the northern reaches of Canada and the Russian Federation to the southern-most tip of Africa. In principle, all Range States, or regional economic integration organizations, can become a Party.

681. An Action Plan (Annex 3 of the Agreement), that lists actions that the Parties shall undertake in relation to priority species and issues specifies, in section 4.1.4, states that Parties shall endeavour to phase out the use of lead shot for hunting in wetlands by the year 2000. Meanwhile the Parties to the Agreement decided at its second session; which took place in September 2002 in Bonn, that each Party is called upon to report to each ordinary session of the Meeting of the Parties on progress made to phase

out lead shot in accordance with self-imposed and published timetables, and specify how they plan to overcome any problems encountered.

682. The Agreement Secretariat organised special awareness raising workshops (Romanian (2001); Senegal (2004) and Tunisia (2006)) on the need to phase out the use of lead shot for hunting in wetlands.

683. At regular intervals the phasing out of lead shot for waterbird hunting among the AEWA Range States is reviewed.

9.3 International organizations and programmes

9.3.1 The International Agency for Research on Cancer (IARC)

684. The International Agency for Research on Cancer (IARC) is part of the World Health Organization. IARC's mission is to coordinate and conduct research on the causes of human cancer, the mechanisms of carcinogenesis, and to develop scientific strategies for cancer control. For further information is referred to IARC's website at http://www.iarc.fr/.

685. The Monographs from IARC represent the first step in carcinogenic risk assessment, which involves examination of all relevant information in order to assess the strength of the available evidence that certain exposures could alter the incidence of cancer in humans.

686. The Monograph on lead has been updated several times; the latest update, Volume 23 (suppl. 7) of the IARC Monographs, dates from 1987. The evaluation of inorganic and organic lead compounds has recently been updated and is currently in preparation as Volume 87 of the IARC Monographs: *Inorganic and Organic Lead Compounds*. In its overall evaluation of carcinogenicity to humans the working group of Volume 87 reached the following overall evaluation: Inorganic lead compounds are probably carcinogenic to humans (Group 2A). Organic lead compounds are not classifiable as to their carcinogenicity to humans (Group 3). (reported at http://monographs.iarc.fr/ENG/Meetings/vol87.php)

9.3.2 International Labour Organization (ILO)

687. The International Labour Organization, ILO is the UN specialised agency that seeks the promotion of social justice and internationally recognised human and labour rights. The ILO formulates international labour standards in the form of conventions and recommendations, setting minimum standards of basic labour rights. For further information is referred to ILO's website at http://www.ilo.org.

688. In the field of chemicals control, there have been a number of conventions, recommendations and guidance materials issued, including the Convention concerning the Prevention of Major Industrial Accidents (No. 174) and accompanying Recommendation (No. 181), adopted in 1993 and the Convention concerning Safety in the Use of Chemicals at Work (No.170) and its accompanying Recommendation (No. 177), adopted in 1990. The purpose of the last Convention is to protect workers from risks associated with the use of chemicals at their workplace. It sets out responsibilities of employers, suppliers, and workers. States ratifying the Convention are required to work out a national policy for safety in the use of chemicals at work in accordance with specified principles, adopt classification and labelling systems for all such substances, and introduce chemical safety data sheets.

689. Other standards and guidance documents concerned with chemical safety include a number of other conventions and recommendations addressing the risks of specific toxic substances including asbestos, white lead, and benzene. In addition, ILO has published Occupational Exposure Limits For Airborne Substances Harmful to Health: A Code of Practice (1991) and Guidelines on Occupational Safety and Health Management Systems (2001).

9.3.3 International Programme on Chemical Safety (IPCS)

690. The International Programme on Chemical Safety, IPCS, was established in 1980 as a co-operative programme of WHO, ILO and UNEP to provide internationally evaluated assessments of the risks caused by chemicals to human health and the environment, which countries may use in developing their own chemical safety measures and to strengthen national capabilities for preventing and treating harmful effects of chemicals and for managing the health aspects of chemical emergencies. For further information is referred to IPCS's website at http://www.who.int/pcs/index.htm.

691. The documents, prepared by internationally-renowned experts and peer-reviewed by leading independent experts, are designed to be used by readers with different levels of technical expertise and include the following:

- Environmental Health Criteria (EHC) monographs - extensive documents designed for scientific experts responsible for the evaluation of risks posed by chemicals;
- Concise International Chemical Assessment Documents (CICADs) - concise documents that provide summaries of the relevant scientific information concerning the potential effects of chemicals on human health and/or the environment;
- Health and Safety Guides (HSG) - provide concise information for decision-makers on risks from exposure to chemicals, with practical advise on medical and administrative issues; and
- International Chemical Safety Cards (ICSC) - summarize health and safety information for individuals at the workplace, including symptoms of poisoning, safety procedures and first aid.

692. IPCS has published the following Environmental Health Criteria relevant to lead:

EHC 3 (1977): *Lead*; (IPCS, 1977)
EHC 85 (1989); *Lead - environmental aspects*; (IPCS, 1989)
EHC 165 (1995); *Inorganic lead*. (IPCS, 1995)

693. In addition, the Joint FAO/WHO Expert Group on Food Additives and Contaminants evaluated lead and cadmium, among other compounds, in 1972, and the evaluation was published in the *WHO Technical Report series* 505 (FAO/WHO, 1972). These documents are all available on the IPCS website at http://www.who.int/pcs/pcs_pubs.html.

694. IPCS has also developed Poisons Information Monographs (PIMs) on organic and inorganic lead (http://www.who.int/ipcs/en/).

9.3.4 World Health Organisation

695. The World Health Organization (WHO) is the United Nations specialized agency for health. It was established on 7 April 1948. WHO's objective, as set out in its Constitution, is the attainment by all peoples of the highest possible level of health. For further information is referred to WHO's website at http://www.who.int.

696. A substantial part of the activities of WHO related to chemical risks are included in the activities of the International Programme on Chemical Safety (IPCS) (section 9.3.3.), the International Agency for Research on Cancer IARC (section 9.3.1), the Intergovernmental Forum on Chemical Safety (IFCS) and the Inter-Organization Programme for the Sound Management of Chemicals (IOMC).

697. Since 1976, WHO has implemented the Global Environment Monitoring System - Food Contamination Monitoring and Assessment Programme (GEMS/Food), which has informed governments, the Codex Alimentarius Commission and other relevant institutions, as well as the public, on levels and trends of contaminants, among these lead, in food, their contribution to total human exposure, and significance with regard to public health and trade.

698. WHO produces international norms on water quality, air and human health in the form of guidelines that are used as the basis for regulation and standard setting, in developing and developed countries world-wide. Among these are water quality guidelines for lead (WHO, 2004) and Air Quality Guidelines for Europe (WHO, 2000a).

699. In the context of the WHO activities on Children's Health and the Environment, training materials (lead module) and awareness-raising leaflets have been prepared in 2005.

9.3.5 The Organization of Economic Cooperation and Development (OECD)

700. The Organization of Economic Cooperation and Development, OECD, is an inter-governmental organisation bringing together 30 member countries in a forum where governments can compare experience, discuss issues of concern, and seek and design solutions including, where appropriate, common or cooperative actions. For further information is referred to OECD's website at http://www.oecd.org.

701. The Environment Programme, one of many areas of work within the OECD, addresses a wide range of issues of concern to member-countries. Of particular interest to this publication is the Environment, Health and Safety Programme, which includes the Chemicals Programme, as well as work on pesticides, chemical accidents, harmonisation of regulatory oversight in biotechnology, Pollutant Release and Transfer Registers and food safety.

702. In 1990, the Council of the OECD adopted a Decision-Recommendation on the Cooperative Investigation and Risk Reduction of Existing Chemicals. The Clearing House countries completed the Risk Reduction Monograph No. 1: *Lead*, published in 1993 (OECD, 1993). The Monograph provides a summary of information regarding releases of lead to the environment, environmental and human exposures and the way OECD member-countries perceived the risks associated with exposure to lead, and describes the actions member-countries and industry have taken, or contemplated taking to reduce risks associated with exposure to lead.

703. In 1996, the OECD Environment Ministers adopted the *Declaration on Risk Reduction for Lead*. The purpose of this Declaration was to advance national and cooperative efforts to reduce risks from lead exposure. The Ministers declared that they would:

- Develop, continue or strengthen national and cooperative efforts to reduce risks from exposure to lead;
- Give highest priority to actions addressing the risk of exposure from food and beverages, water, air, occupational exposure and other potential pathways;
- Continue to review lead levels in the environment, and the exposure to lead of sensitive and high risk populations;
- Promote and maximise the use of environmentally-sound and economically-viable collection and recycling programmes for lead and lead-containing products;
- Extend cooperative efforts to share (including with non-OECD countries) information about exposures of concern, risk reduction options, and environmentally-sound and economically-viable technologies;
- Encourage the lead-producing and lead-using industries to make best use of their expertise on the management of risks from lead, and to make this expertise available to OECD and non-OECD countries;
- Work with the lead-producing industry to develop its voluntary action programme to reduce exposure to lead (which will be implemented in cooperation with national authorities in OECD and interested non-OECD countries) and encourage user-industries to develop similar programmes.

704. They also declared that the OECD should review progress made by member-countries in pursuance of the Declaration three years after adoption and assess the need for further action.

705. In 1998, the OECD surveyed member-countries, the European Commission and industry to determine what actions had been taken to implement the 1996 OECD Environment Ministers' Declaration on Risk Reduction for Lead. Twenty-three countries and the European Commission responded to the member-country questionnaire; thirteen companies and nine industry associations responded to the lead industry questionnaire. The questionnaires were designed to obtain information on activities completed since 1992, or still ongoing. The responses were summarised in the report *Lead Risk Management Activities in OECD Member Countries (1993 to 1998)* (OECD, 2000)

9.3.6 United Nations Environment Programme - The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (Global Programme of Action)

706. The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) seeks to prevent the degradation of the marine environment from land-based activities by facilitating realisation of the duty of states to preserve and protect the marine environment. It is designed to be a source of conceptual and practical guidance to be drawn upon by national and regional authorities in devising and implementing sustained action to prevent, reduce, control and/or eliminate marine degradation from land-based activities. For further information is referred to GPA's website at http://www.gpa.unep.org.

707. The programme has a special section for recommendations regarding heavy metals, including lead. The objective/proposed target is to reduce and/or eliminate anthropogenic emissions and discharges in order to prevent, reduce and eliminate pollution caused by heavy metals. Although there are no specific goals set with regards to lead, the programme provides detailed guidance on possible/proposed steps in the pursuit of reduced environmental effects from heavy metals and other pollutants.

9.3.7 United Nations Environment Programme - Partnership for Clean Fuels and Vehicles

708. The Partnership for Clean Fuels and Vehicles (PCFV) is the leading global initiative promoting better urban air quality through the use of cleaner fuels and vehicles. Established at the World Summit for Sustainable Development in 2002, as of 1 January 2006 it has over 80 member organisations including governments, international organisations, industry groups, and non-governmental organisations involved in efforts to eliminate leaded gasoline worldwide and promote low sulphur in fuels concurrently with the introduction of cleaner vehicles and vehicle technology.

709. Partnership activities focus on building consensus between all sectors and facilitating the transfer of knowledge and technology on cleaner fuels and vehicles from developed to developing countries. The PCFV, whose Clearing-House is based at the United Nations Environment Programme (UNEP) headquarters in Nairobi, Kenya, provides technical, networking and financial support for regional, national and local activities promoting cleaner fuels and vehicles.

710. The PCFV has been instrumental in working at the regional and national levels to support countries in the complete phase-out of leaded gasoline in Sub-Saharan Africa by January 2006, actively supporting cleaner fuel and vehicle dialogue sessions, training for decision makers, policy development, and awareness campaigns. The PCFV has also published a report *Eliminating Lead From Gasoline: Valve Seat Recession (PCFV, 2004)* to address concerns of leaded gasoline phase-out on older vehicles. Through its global, multi-sectoral Working Groups the PCFV gives recommendation and advice on sulphur reduction, cleaner new and second-hand vehicles, public awareness, and octane issues.

711. It has supported national projects and regional consensus-building on the elimination of leaded gasoline, co-organised 2 Sub-Saharan Africa (SSA) regional conferences on leaded gasoline phase-out in Senegal and Kenya, 5 SSA sub-regional workshops on lead elimination in Senegal, Benin, Kenya, South Africa and Cameroon, a technical experts group meeting in Mali, a Refining Expert Meeting in

South Africa, a SSA regional workshop in Uganda and national workshops, public awareness campaigns (including radio and print ads) and environmental training events in Burundi, Benin, Tanzania, The Gambia, Uganda, Malawi, Rwanda, Kenya, Ghana, Togo, Democratic Republic of the Congo, Zambia, Djibouti, Mozambique and Somalia. UNEP has worked to train fuel pump attendants on the benefits of unleaded gasoline in order to equip them with the knowledge to answer concerns from the public and has also conducted blood lead level testing in children in Kenya to assess the health effects and social costs of leaded fuel.

712. An upcoming PCFV publication (to be released autumn 2006) of the PCFV Octane Working Group will discuss costs of additives other than lead.

713. For more information on the PCFV and its work, please visit www.unep.org/pcfv.

9.3.8 United Nations Industrial Development Organization (UNIDO)

714. The United Nations Industrial Development Organization, UNIDO, was created in 1967 and, since 1985, has been a specialised agency of the United Nations dedicated to promoting sustainable industrial development in developing countries and countries in economic transition. UNIDO brings together representatives of government, industry and the public and private sector, providing a forum for consideration of issues related to sustainable development. UNIDO is also involved in work related to environmental management in various industrial sectors and related to monitoring, treatment, recycling, and disposal of toxic and hazardous chemical wastes and remediation of contaminated sites. For further information is referred to UNIDO's website at http://www.unido.org.

9.3.9 The World Bank Group

715. Founded in 1944, the World Bank Group is one of the world's largest sources of development assistance. For further information is referred to WB's website at http://www.worldbank.org/.

716. The WB has been very active in activities related to the phase-out of leaded gasoline and has published a number of reports on the issue, among these *Elimination of lead in gasoline in Latin America and the Caribbean - Status Report* (WB 1997a), *Phasing Out Lead from Gasoline in Central and Eastern Europe: Health Issues, Feasibility, and Policies* (WB 1997b), and *Phasing Out Lead from Gasoline: Worldwide Experience and Policy Implications* (WB, 1998).

717. In April of 2007 new versions of the World Bank Group Environmental, Health and Safety Guidelines were published. These are general guidelines that address performance levels and measures related to Environmental, Occupational Health and Safety, Community Health and Safety and Construction and Decommissioning as well as industry specific guidelines including ones for Base Metal Smelting and Refining. A copy of the general guidelines is available at: http://www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines. The Environmental, Health and Safety guidelines for Base Metal Smelting and Refining can be downloaded at http://www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_EHSGuidelines2007_SmeltingandRefining/$FILE/Final+-+Smelting+and+Refining.pdf (ILZRO's submission, 2007).

718. The World Bank's portfolio of projects with clear environmental objectives currently amounts to $US 10.7 billion (2005). Some of the activities of relevance to lead are:

- The Clean Air Initiative (CAI), launched in 1998, is a network involving city governments, private sector companies, international development agencies and foundations, non-governmental organizations and academic institutions. The WB co-founded the Clean Air Initiative for Latin American Cities at a launching workshop in December, 1998. It was also launched in Asia in 2001, and subsequently in Sub-Saharan Africa later that year. Today, the WB is a leading player in all three CAI networks. The WB hosts the Clean Air Initiative website and serves as an electronic operational centre around which the partnership communicates. The Clean Air Initiative is further described in section 9.4.3

- Assistance to countries' phase-out of lead: In 2003, the WB obtained funding to assist Tanzania, Mauritania, Mali and Ethiopia to develop an action plan which demonstrated the benefits of leaded gasoline phase-out and outlined the necessary associated actions.

9.4 Sub-regional and regional initiatives

9.4.1 Arctic Council

719. The Arctic Council, established on 19 September 1996, is a high-level intergovernmental forum that provides a mechanism to address the common concerns and challenges faced by the Arctic governments and the people of the Arctic. For further information is referred to the council's website at http://www.arctic-council.org;

720. In 1991, the Council launched its Arctic Environmental Protection Strategy, through which member countries are committed to:

- Cooperating in scientific research to specify sources, pathways, sinks and effects of pollution, in particular: oil, acidification, persistent organic contaminants, radioactivity, noise and heavy metals as well as the sharing of these data;
- Assessing potential environmental impacts of development activities; and
- Full implementation and consideration of further measures to control pollutants and reduce their adverse effects to the Arctic environment.

721. The Arctic Monitoring and Assessment Programme, AMAP (http://www.amap.no/), was established in 1991 to implement components of the Arctic Environmental Protection Strategy. AMAP's objective is "providing reliable and sufficient information on the status of, and threats to, the Arctic environment, and providing scientific advice on actions to be taken in order to support Arctic governments in their efforts to take remedial and preventive actions relating to contaminants".

722. AMAP has completed two assessments of the *State of the Arctic Environment* with respect to pollution issues. The first of these was published in 1997, and the second in 2002 (AMAP, 1997; AMAP, 2002). These comprehensive reports constitute a compilation of current knowledge about the Arctic region, an evaluation of this information in relation to agreed criteria of environmental quality, and a statement of the prevailing conditions in the area. They each contain a separate chapter on heavy metals, including lead, describing the concentrations found in the Arctic area in terrestrial, fresh water and marine ecosystems. In addition, in 2005, AMAP published the report *AMAP Assessment 2002: Heavy Metals in the Arctic* which assesses in detail all aspects related to heavy metals in the Arctic (AMAP, 2005).

9.4.2 The Great Lakes Binational Toxics Strategy

723. The Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes Basin, known as the Great Lakes Bi-national Toxics Strategy, provides a framework for actions to reduce or eliminate persistent toxic substances, especially those which bio-accumulate, from the Great Lakes Basin. For further information is referred to the strategy's web-site at http://www.epa.gov/glnpo/bns/

724. The Strategy establishes reduction challenges for an initial list of 12 persistent toxic substances targeted for virtual elimination, among these alkyl-lead. The U.S.A. has met the strategy challenge of confirming the non-use of alkyl-lead in automotive gasoline. Canada has met the challenge to reduce by 90 percent the use, generation and release of alkyl-lead.

9.4.3 Clean Air Initiative for Cities Around the World

725. The Clean Air Initiative for Cities Around the World (CAI), launched in 1998 at the initiative of the World Bank, is a network involving city governments, private sector companies, international development agencies and foundations, non-governmental organizations, and academic institutions. The major goals of the Clean Air Initiative are to:

- Share knowledge and experience on air-quality management;
- Improve policy and regulatory frameworks at the regional level;
- Promote the implementation of integrated air-quality strategies;
- Pilot projects to encourage innovation.

726. The CAI consists today of three regional programmes in Asia, Latin America and Sub-Saharan Africa. A fourth programme in Eastern Europe and Central Asia is no longer active. The regional programmes function relatively independently, each with its own set of goals, activities and partners. However, they share a key strategy: cross-sectoral partnership and the exchange of knowledge. Face-to-face meetings, along with distance learning and the exchange of information through media such as the CAI website, are intended to encourage thinking and action related to the air quality of major cities.

727. The CAI-Asia programme is specifically based on the sharing of knowledge about air quality management, as well as efforts to improve policy and regulatory frameworks. The CAI in Latin American Cities (CAI-LAC) focuses on reversing the deterioration of urban air quality resulting from rapid urbanisation, increased vehicular transport and industrial production. The CAI in Sub-Saharan Africa has concentrated its main efforts on the phase-out of lead from gasoline, and is described in more detail below.

728. The World Bank hosts the Clean Air Initiative website, which consists of individual websites for the four regional programmes. A large number of publications, action plans, road-maps, etc. are available at CAI's website at http://www.cleanairnet.org.

Clean Air Initiative in Sub-Saharan African Cities

729. The objective of the Clean Air Initiative in Sub-Saharan African Cities (CAI-SSA), launched in 1998, is to improve air quality through the reduction of air pollution originating in particular from motorized transport.

730. The CAI-SSA is sponsored by the World Bank in collaboration with a number of partners, in particular the World Health Organization, the United Nations Environment Programme, the European Union, the Belgium Cooperation, the Nordic Trust Fund for Environmentally and Socially Sustainable Development, the Energy Sector Management Assistance Programme, the International Petroleum Industry Environmental Conservation Association and national environmental protection agencies, in particular the U.S. EPA.

731. The CAI-SSA has concentrated its efforts on the phase-out of lead from gasoline throughout the continent as a first priority. To launch the Initiative, a regional conference was held in June, 2001 in Dakar, where the decision was made by the represented governments and the oil industry to eliminate lead in gasoline throughout sub-Saharan Africa by the end of 2005. The Conference was attended by almost 200 participants from 25 different countries, representing a diverse range of national and local government bodies, research and academic institutions, NGOs and international organizations. A working group was formed for each of five sub-regions: West Africa, Nigeria and neighbouring countries, West Central Africa, Southern Africa and East Africa. Each sub-regional group produced a preliminary "action plan" for lead phase-out. Subsequently, regional conferences were held in sub-regions and Action Plans was developed.

732. A Steering Committee meeting in March, 2003, confirmed the priority of lead phase-out, while a second regional conference, held in Nairobi in May of 2004, demonstrated that considerable progress has been achieved: In 2003, over 50 percent of all gasoline sold in sub-Saharan Africa was unleaded, and eight sub-Saharan African countries had completely phased out leaded gasoline. By the end of

2005, virtually all of the sub-Saharan African countries are expected to have phased out leaded gasoline, with only a few countries in East Africa possibly failing to meet the target.

9.4.4 Commission for Environmental Cooperation

733. The Commission for Environmental Cooperation (CEC) is an international organization created by Canada, Mexico and the United States of America under the North American Agreement on Environmental Cooperation (NAAEC). The CEC was established to address regional environmental concerns, help prevent potential trade and environmental conflicts, and to promote the effective enforcement of environmental law. For further information is referred to the CEC's web-site at http://www.cec.org.

734. The Commission provided the mechanism for the three member countries to negotiate an agreement, Council Regulation #95-5 on the Sound Management of Chemicals, which was agreed upon on 13 October 1995. The resolution sets out a framework, together with specific commitments, to work collaboratively in addressing the sound management of chemicals in the region. Since then, five North American Regional Action Plans (NARAP) on DDT, chlordane, PCBs, mercury, dioxin, furans and hexachlorobenzene (HCB) have been developed and are now at various stages of implementation. Furthermore, a Council Resolution on developing a NARAP on lindane has been adopted.

735. The task force of the Sound Management of Chemicals Working Group that implements the review process for candidate substances has determined that mutual concern exists among the three countries to act cooperatively on lead, and they are now in the final stage of preparing a decision document, inclusive of recommendations for actions (CEC, 2003).

9.4.5 The North Sea Conferences

736. The aim of the International Conferences on the Protection of the North Sea was to provide political impetus for the intensification of the work within relevant international bodies, and to ensure more efficient implementation of the existing international rules relating to the marine environment in all North Sea states. For further information is referred to http://odin.dep.no/md/nsc/

737. In 1990, ambitious targets were agreed on to reduce inputs of 36 hazardous substances, including lead, by 50 percent, and for substances that cause a major threat, to reduce inputs by 70 percent. The long-term target agreed on at the Esbjerg Conference in 1995 - of continuously reducing discharges, emissions and losses of hazardous substances, thereby moving towards the target of their cessation within one generation - has now been adopted by the OSPAR Convention and has thus become legally binding. According to the Progress report for the 5th Conference in Bergen in March, 2002, all the countries participating in the North Sea cooperation had achieved the 70 percent target for lead, while all but one country had done so for cadmium (North Sea, 2002).

9.4.6 South Asia Cooperative Environment Programme (SACEP)

738. South Asia Cooperative Environment Programme (SACEP) is an inter-governmental organization, established in 1982 by the Governments of South Asia. For further information is referred to SACEP's web-site http://www.sacep.org/. The mission of SACEP is to promote regional cooperation in South Asia in the field of environment, both natural and human in the context of sustainable development, and on issues of economic and social development which also impinge on the environment and vice versa; to support conservation and management of natural resources of the region and to work closely with all national, regional, and international institutions, governmental and non-governmental, as well as experts and groups engaged in such cooperation and conservation efforts.

739. The *Malé Declaration on Control and Prevention of Air Pollution and Its Likely Transboundary Effects for South Asia* was endorsed by the 7th Governing Council of SACEP in April, 1998 at Malé, Maldives. In the Declaration, the countries declare that they will initiate and/or carry forward programmes in each country to:

- Assess and analyse the origin and causes, nature, extent and effects of local and regional air pollution, using the identified in-house institutions, universities, colleges, etc., and building up or enhancing capacities in them where required;
- Develop and/or adopt strategies to prevent and minimise air pollution;
- Work in cooperation with each other to set up monitoring arrangements, beginning with the study of sulphur and nitrogen and volatile organic compounds emissions, concentrations and deposition;
- Cooperate in building up standardised methodologies to monitor phenomena like acid depositions and analyse their impacts without prejudice to the national activities in such fields;
- Take up the aforementioned programmes and training programmes, which involve the transfer of financial resources and technology, and work towards securing incremental assistance from bilateral and multilateral sources;
- Encourage economic analysis that will help to obtain optimal results;
- Engage other key stakeholders, for example industry, academic institutions, NGOs, communities and media, etc. in the effort and activities.

740. The declaration does not specifically address heavy metals, but includes the development and adoption of strategies to prevent and minimise air pollution.

9.4.7 International commissions for the protection of rivers

741. A number of international commissions for protection of transboundary rivers exist. Two examples are the International Commission for the Elbe River Protection (ICPE, IKSE, MKOL) (http://www.ikse.de/) and The International Commission on the Protection of the Oder against Pollution (ICPOAP) (http://www.mkoo.pl/index.php). Beside other activities, the contracting parties cooperate in the commissions to prevent the pollution of the rivers and their drainage areas with hazardous substances.

9.4.8 European Commission

742. A description of the various regulations and directives addressing lead and are an overview of the main provisions of European Community Legislation with a relevance to that substance (European Commission’s submission, 2007) are presented below. Additional information on selected regulations and directives mentioned below (Sweden’s submission) is provided in section 4 to the Appendix of the Interim Review on Lead.

Council Directive 67/548/EEC on the classification, packaging and labelling of dangerous substances

Lead metal, as the powder or in bulk form, is not (yet) classified. However, lead compounds not otherwise specified in Annex 1 of Directive 67/548/EEC are classified as follows:

- Repr. Cat. 1; R61 (risk to unborn child)
- Repr. Cat. 3; R62 (risk of impaired fertility)
- Xn; R20/22 (harmful by inhalation and ingestion)
- R33 (danger of cumulative effects)
- N; R50-53 Very toxic to aquatic organisms; may cause long-term adverse effects in the aquatic environment

Council Directive 1999/45/EC on the classification, packaging and labelling of dangerous preparations

All preparations containing dangerous substances classified under Directive 67/548/EEC above a certain threshold have to be classified accordingly

Commission Directive 2001/58/EC amending Directive 91/155/EEC defining and laying down detailed arrangements for the system of specific information relating to dangerous preparations and substances (safety data sheets)

For dangerous substances and dangerous preparations, professional users are entitled to receive a safety data sheet which contains information on the intrinsic properties of the substance / components of the preparations, their classification and labelling requirements, and information on for example storage, waste disposal, emergency measures etc.

Council Directive 76/769/EEC on restrictions on the marketing and use of certain dangerous substances and preparations

Bans the marketing and use of certain dangerous substances and preparations. With regard to lead and lead compounds, the following are restricted:

Lead-based Paint

The use of lead-based paint in residential applications was officially banned under EU Council Directive 89/677/EEC amending Council Directive 76/769/EEC (prohibits the use of lead carbonates and lead sulphates in paints except for the restoration of works of art and historic buildings)

Council Directive 98/24/EC on the protection of the health and safety of workers from the risks related to chemical agents at work (Fourteenth individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC)

Sets binding occupational exposure limits for lead and its ionic compounds in blood.

Council Directive 92/85/EEC on the introduction of measures to encourage improvements in the safety and health of pregnant workers and workers who have recently given birth or are breastfeeding (Tenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC)

Sets out measures to protect pregnant workers and workers who have recently given birth or are breast-feeding, including the requirement to assess exposure to health risks including lead compounds due to their reprotoxic effects.

Council Directive 94/33/EC on the protection of young people at work

Prohibits the use of certain chemical agents, including lead compounds as a reprotoxic agent, by young workers.

Council Directive 88/378/EEC on the safety of toys

Established extraction limits for the bioavailability any lead contained in children’s toys.

Council Directive 76/768/EEC on cosmetic products

Bans the use of lead and lead compounds in cosmetics with an exemption for the use of lead acetate in hair treatments.

Council Directive 91/689/EEC on hazardous waste

Sets out the requirements for the management of hazardous wastes, such as wastes containing lead compounds above a certain threshold.

European Parliament and Council Directive 94/62/EC on packaging and packaging waste as amended by Directive 2005/20/EC

The Directive eliminated this application of lead by reducing the sum of the amount of lead, cadmium, mercury and hexavalent chromium present in packaging or packaging components to 100 ppm by the year 2001

Council Directive 2002/95/EC of the European Parliament and of the Council on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)

Bans the use of lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) and polybrominated diphenyl ethers (PBDEs) in new electrical and electronic equipment put on the market from 1 July 2006. There are exemptions for certain uses such as lead as an alloying element in steel, aluminium and copper.

Directive 2002/96/EC of the European Parliament and of the Council on waste electrical and electronic equipment (WEEE) as amended by Directive 2003/108/EC

Sets criteria for the collection, treatment, recycling and recovery of waste electrical and electronic equipment and makes producers responsible for financing most of these activities.

Council Directive 2000/53/EC of the European Parliament and of the Council on end-of-life vehicles

Bans the use of lead, mercury, cadmium and hexavalent chromium in new vehicles put on the market from 1 July 2003. There are exemptions for certain uses such as lead as an alloying element in steel and copper, and lead in batteries and vibration dampers.

Council Directive 91/157/EEC on batteries and accumulators containing certain dangerous substances as amended by Directive 98/101/EC

Sets out measures relating to the recovery and disposal of spent batteries and accumulators containing certain dangerous substances, such as batteries containing greater than 0.4 percent lead by weight.

Council 85/210/EEC on the approximation of the laws of the Member States concerning the lead content of petrol – repealed by Directive 98/70/EC as amended

Restricts the content lead in petrol to 0,005 g/ltr.

Council Directive 96/62/EC on ambient air quality assessment and management

The Framework Directive 96/62/EC set-out a common strategy to define and set objectives for ambient air quality. Lead concentrations in the ambient air were addressed by the 1st Daughter Directive (1999/30/EC), and a limit value (expressed as an average over a calendar year) of 0.5 ng/m3 was specified based upon WHO guidelines.

Commission Decision 2000/479/EC on the implementation of a European pollutant emission register (EPER)

According to the EPER Decision, Member States have to produce a triennial report on the emissions of industrial facilities regulated under Council Directive 96/61/EC on integrated pollution prevention and control (IPPC) into the air and waters. The report covers 50 pollutants including lead.

Council Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy

Sets out objectives in the field of water policy including priority status and quality standard requirements for lead. Lead and its compounds are classed as '*priority substances under review*' under the Water Framework Directive; this classification means that the substances so listed may be proposed as priority hazardous substances if justified by further investigation.

Council Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture

This Directive prohibits the sludge from sewage treatment plants from being used in agriculture unless specified requirements are fulfilled, including the testing of the sludge and the soil. Parameters subject to the provisions of the Directive include amongst others the content of lead and cadmium.

Council Directive 84/500/EEC October 1984 on the approximation of the laws of the Member States relating to ceramic articles intended to come into contact with foodstuffs as amended by Directive 2005/31/EC

The Directive lays down maximum limits for the cadmium and lead transferred by ceramic objects to the foodstuffs with which they enter into contact.

Council Directive 98/83/EC on the quality of water intended for human consumption

In the Directive the guideline for Pb in drinking water is reduced from 50 µg Pb L^{-1} to 10 µg Pb L^{-1}, with a 15 year transition period to allow for replacing lead distribution pipes.

10 Data and information gaps

10.1 National research and information gaps

743. Several of the submissions to this review have pointed out national information and data needs. These are summarised briefly here:

- Development of national (and regional) exposure assessments, substance flow assessments (import, export, consumption etc.), and release inventories,
- Technical and financial assistance for - and implementation of - strategies development and legislation for the management of electronic wastes (etc.), and for capacity building activities such as conducting awareness raising workshops, performing pilot project for data collection, training workers about health risks and safer work procedures (in formal as well as informal sectors), training authorities in risk assessment, etc.
- Methodologies and guidelines for training human resources in evaluation and risk management methods as well as decontamination or remedial evaluation of lead contaminated sites.
- Guidelines and methodologies for reduction or prevention of heavy metal releases to the environment.
- Guidelines and methodologies for the formulation and execution of substance and hazardous residues management plans.
- Methodologies to evaluate the efficiency of the interventions.

10.2 Data gaps of a general, global character

744. The following issues have been pointed out as general data gaps in this report and in review comments (please see the relevant sections to understand the context better, if needed):

- Updated global release inventories for lead. The latest global inventory of atmospheric emission is based on 1995 data, whereas global releases to land and water concern 1983 data;
- More data on releases to the environment in developing countries are especially needed; in order to obtain a better understanding of the source categories in this part of the world, and for improving the general global understanding and global release inventories, as well as for use in the national context as noted above;
- There is a need to develop atmospheric transport models for lead in the Southern hemisphere -, regionally, hemispheric and/or global models - to better understand the regional and intercontinental atmospheric transport of lead;
- Ocean transport of lead in general is poorly understood and seems to warrant more investigation; inclusion of lead in existing ocean transport models would be one element in establishing a better understanding of the long-range transport of lead with ocean currents;
- Also in the developed regions, the release inventory database needs to be improved:
  - Develop/improve emission factors for various major source categories (coal and oil contents and releases, releases from ferrous and non-ferrous metal industry;

  - Improve understanding of the contributions of natural sources and re-suspension of historical depositions to lead pollution levels;
  - Improve data quality of national release inventories.
- Develop guidelines for monitoring activities (air, soil, precipitation, human blood etc.);
- The mechanism of lead toxicity is not well understood. There is a controversy on whether the endogenous exposure from bone-Pb is a particular risk because it affects Pb-B, which in turn hits the target organs. Exposure-response relationship is incomplete for many effects. A series of deterministic risk assessments exist but there is a lack of probabilistic risk assessments.
- The substance flows as a consequence of trade and waste disposal, mainly in developing and transition countries are major causes of human exposure to lead. There are gaps on lead flows so research in this area is necessary in order to set priorities to global action to reduce risks

Data gaps between developed and developing countries

745. Concentrations of PTE in many African ecosystems are reaching unprecedented levels (Nriagu, 1992) with some of the highest ambient concentrations in the world. Mining and smelting, industrialisation, use of pesticides and general urbanisation are important sources. Major African cities discharge untreated wastewater directly to rivers or the oceans. Relatively few studies have focused on measurement of the environmental impact of metals released on human health or natural resources, but some continent-wide information is beginning to emerge (Biney, 1994) as well as more specific data focussing on contamination and management issues relating to the marine environment (Kouassi and Biney, 1999).

11 Glossary, acronyms, abbreviations and units

AD	Anno Domini (years after Christ in the Christian calendar)
AEWA	Agreement on the Conservation of African-Eurasian Migratory Waterbirds
AMAP	Arctic Monitoring and Assessment Programme
As	Symbol for arsenic in the Periodic Table
ASPEN	Assessment System for Population Exposure Nationwide
ATSDR	U.S.A. Agency for Toxic Substances and Disease Registry
BAT	Best available techniques. As contrasted with “best available technologies,” “best available techniques” (BAT) is a wider term that includes best available technologies but also considers other techniques such as process change, etc. BAT is increasingly used in regional (e.g. EU and the Aarhus Heavy Metals Protocol to the LRTAP Convention) and global (e.g. the Stockholm Convention) forums, where it is well defined and well accepted
BC	Before Christ (in the Christian calendar)
Benelux countries	Belgium, the Netherlands and Luxembourg
CAI	Clean Air Initiative for Cities Around the World
Cd	Symbol for cadmium in the Periodic Table
CEC	Commission for Environmental Cooperation
CRT	Cathode ray tube
CORINAIR	CORe INventory of AIR emissions (in the EU)
CSTEE	EU's Scientific Committee on Environmental Toxicology
Dry deposition	Process of species transport from the atmosphere to the underlying surface at their direct (without precipitation) physical-chemical interaction with elements of the underlying surface; dry deposition is of a continuous character independent of the occurrence or absence of atmospheric precipitation
DRPC	Danube River Protection Convention
DTIE	Division of Technology, Industry, and Economics
EC	European Community
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (under the LRTAP Convention)
ESP	Electrostatic precipitator; equipment used to reduce emissions of certain pollutants from combustion flue gases
EU	European Union: From 1 May 2004, the member states are EU15 (see below) and Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia. Also referred to as EU25
EU15	European Union before 1 May 2004 when it had only 15 Member States
€	Euro (currency)
FAO	Food and Agriculture Organization
FF	Fabric filter; filter type used to capture particulate matter (here: from combustion flue gases)

FGD	Flue gas desulphurization; process of/equipment for primarily minimizing emissions of sulphur from combustion flue gases
GC	Governing Council
HELCOM	Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area
HM	Heavy metals
IARC	International Agency for Research on Cancer
ILO	International Labor Organization
ILZRO	International Lead Zinc Research Organization, Inc.
ILZSG	International Lead and Zinc Study Group
IMPROVE	Interagency Monitoring of Protected Visual Environments
IPCS	International Programme on Chemical Safety
IPPC	Integrated pollution prevention and control
JECFA	Joint FAO/WHO Expert Committee on Food Additives
Load	The intensity of input of pollutants to a given ecosystem from the environment; atmospheric load - the intensity of input from the atmosphere
LRTAP Convention	Convention on Long-Range Transboundary Air Pollution
MAC	Maximum Acceptable Concentration
MACT	Maximum Achievable Control Technology
MATC	Maximum Acceptable Toxicant Limit
MPC	Maximum Permissible Concentration
MSC-E	Meteorological Synthesizing Centre – East (associated with the LRTAP Convention)
MSW	Municipal solid waste
MSWI	Municipal solid waste incinerator
NAAEC	North American Agreement on Environmental Cooperation
NABO	Swiss Soil Monitoring Network (Nationale Bodenbeobachtung)
NARAP	North American Regional Action Plans
NATA	National-Scale Air Toxics Assessment
Ni	Symbol for nickel in the Periodic Table
NGO	Non-governmental organization
NOEC	No Observed Effect Concentration
OECD	Organization for Economic Cooperation and Development
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
Pb	Symbol for lead in the Periodic Table
^{204}Pb	Lead isotope with the atomic weight 204 (similar notation for other isotopes)
PCFV	Partnership for Clean Fuels and Vehicles
PDP	Plasma display panel
PTE	Potentially toxic elements

pH	Expression for acidity
PM	Particulate matter
PM10	Particulate matter measuring 10µm or less
PNEC	Predicted No-Effect Concentration
POPs	Persistent Organic Pollutants
PRTR	Pollutant Release and Transfer Register
PTWI	Provisional Tolerable Weekly Intake
PVC	Poly vinyl chloride
SACEP	South Asia Cooperative Environment Programme
Slag	Waste material produced when coal is dug from the earth, or a substance produced by mixing chemicals with metal that has been heated until it is liquid in order to remove unwanted substances from it.
TML	Tetramethyllead
UN	United Nations
UN ECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
US$	United States dollar (currency)
U.S. EPA	Environmental Protection Agency of the United States of America
U.S.A.	United States of America
UV	Ultraviolet (radiation)
WB	World Bank
Wet deposition	Flux of substance from the atmosphere onto the underlying surface with atmospheric precipitation
WHO	World Health Organization
<	Less than
>	Greater than

UNITS:

%	percent
bw	Body weight
°C	Degree Celsius (centigrade)
dw	Dry weight
kg	Kilogram
l or L	Litre
m	meter
mg	Milligram (10^{-3} gram)
MW	Megawatt
MWth	Mega Watt Thermal (denotes thermal output of power plant)
ng	Nanogram (10^{-9} gram)
pg	Picogram (10^{-12} gram)

ppb	Parts per billion
ppm	Parts per million
t	tonne or metric ton = 1,000 kg = Gg
µg/kg bw per day	Micrograms per kilogram body weight per day; units used for describing intakes (or doses) of lead, such as intakes that are considered safe for humans. In some cases the time unit weeks is also used
µg	Microgram (10^{-6} gram)
µm	Micrometer (10^{-6} meter)

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13 Annex 1 Lead in soils

746. The ID numbers in the left-most column refer to a common index number for the two reviews of scientific information on lead and cadmium, respectively. Some of the quoted studies only give data on soil concentrations for one of the two substances for some of the samples. ID numbers (samples) for which only data on cadmium is provided are thus excluded in this table.

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference [9]
					min	max	mean	median	
1	Australia	-	Pb: The health-based investigation level (HIL) for lead in a standard residential setting is 300 mg/kg and the ecologically based investigation level (EIL) for lead in an urban environment is 600 mg/kg. The background level of lead in soils ranges from 2 to 200 mg/kg (Berkman, 2001, as cited by Australia's submission, 2005). Cd: The Ecological Investigation Level (EIL) for sites contaminated with cadmium is 3 mg/kg (EPHC, 1999, as cited by Australia's submission, 2005).	Topsoils - unspecified	2	200	-	-	Australia's submission, 2005
2	Bolivia	-	Level of metals in soil samples. Samples were collected at homes, children's recreational areas and schools. The maximum values were registered in a recreational area near the Bustos foundry. The mean levels are in the order of the basal value but the maximum range is far from this value.	Topsoils - specified	39	1317	109	-	Bolivia's submission, 2005
11	Czech Republic	-	Average contents of cadmium and lead in agricultural soils in the Czech Republic (extract of 2M HNO3). Based on analysis of 45,259 samples of cadmium and 46,281 samples of lead.	Agricultural soils	-	-	18.8	-	Czech Republic's submission, 2005
12	Czech Republic	-	Average contents of cadmium and lead in agricultural soils in the Czech Republic (extract of aqua-regia). Based on analysis of 2,961 samples.	Agricultural soils	-	-	22.6	-	Czech Republic's submission, 2005
13	Czech Republic	-	Lead in soil from a kindergarten in Plzen based on analyses of 25 samples. Median = 46,3 mg Pb/kg, arithmetic mean = 48,6, Xmin = 25,3 mg Pb/kg, Xmax = 88,2 mg Pb/kg, std. dev. = 15,6 mg Pb/kg, std. dev. (%) = 32,1. Analyses from 10 different kindergartens is presented in the Czech Republic's submission.	Topsoils - specified	25.3	88.2	48.6	46.3	Czech Republic's submission, 2005

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[9] All below-mentioned submissions can be found at : http://www.chem.unep.ch/Pb_and_Cd/Default.htm

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
14	Czech Republic	-	Lead in soil from a kindergarten in Jeseník based on analyses of 5 samples. Median = 27,6 mg Pb/kg, arithmetic mean = 30,0, Xmin = 16,2 mg Pb/kg, Xmax = 41,4 mg Pb/kg, std. dev. = 9,0 mg Pb/kg, std. dev. (%) = 29,9. Analyses from 10 different kindergartens is presented in the Czech Republic's submission.	Topsoils - specified	16.2	41.4	30.3	27.6	Czech Republic's submission, 2005
15	Czech Republic	-	Lead in soil from a kindergarten in Rokycany based on analyses of 5 samples. Median = 76,7 mg Pb/kg, arithmetic mean = 166,8, Xmin = 40,5 mg Pb/kg, Xmax = 584,0 mg Pb/kg, std. dev. = 209,1 mg Pb/kg, std. dev. (%) = 125,4 Analyses from 10 different kindergartens is presented in the Czech Republic's submission.	Topsoils - specified	40.5	584	166.8	76.7	Czech Republic's submission, 2005
	Czech Republic	Urban soil	Lead in urban soils from 124 localities (2004), 78 localities (2005) and 84 localities (2006)	Unspecified 2004 2005 2006	30.3 31.97 19.8	278.2 422.1 296			Czech Republic's submission, 2009
16	Denmark	-	Cadmium and lead concentrations in Danish natural topsoils, mg/kg dw.	Topsoils - unspecified	7	35	-	-	Friborg, 1992, as cited by Scott-Fordsmand and Pedersen, 1995
17	Denmark	-	Cadmium and lead concentrations in Danish natural topsoils, mg/kg dw.	Topsoils - unspecified	1	31	8	-	Århus Amt, 1992, as cited by Scott-Fordsmand and Pedersen, 1995
18	Denmark	-	Cadmium and lead concentrations in Danish agricultural soils, mg/kg dw.	Agricultural soils	3	32	16	-	Tjell and Hovmand, 1978, as cited by Scott-Fordsmand and Pedersen, 1995
19	Honduras	-	Concentrations of lead in ground soil of a site, where a battery factory used to operate. The presented data originates from samples of topsoil from two areas designated Area No. 4 and No. 5 located within the internal perimeter of the factory. Area No. 4 and No. 5 represents the the greatest lead concentrations (820 and 1 000 mg/kg), while concentrations at a football field and a control point does not exceed 20 mg/kg.	Highly contaminated soils	-	1000	820	-	Honduras's submission, 2006
20	Honduras	-	Concentrations of lead in ground soil of a site, where a battery factory used to operate. The presented data originates from samples of soil from 50 cm below surface from two areas designated Area No. 4 and No. 5 located within the internal perimeter of the factory.	Highly contaminated soils	50	600	-	-	Honduras's submission, 2006
21	Japan	-	Lead in earth crust: The average of the upper crustal lead composition in Japan is 16.9ppm (Togashi *et al*., 2001, as cited by Japan's submission, 2005). This estimation was made through strategic sampling based on the subsurface	Remote areas	-	-	16.9	-	Japan's submission, 2005

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
			geology, accurate analysis, and weighted averaging on the basis of geological distribution.						

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
22	Japan	-	Lead in supposedly non-contaminated soil: The average composition of lead in supposedly non-contaminated domestic soil is estimated to be within the range of 10 to several tens mg/kg dry weight (dw) from the following reasons: ● According to the review by Asami (2001, as cited by Japan's submission, 2005), the geometric means of the measurement results of 17.2 mg/kg dw, measured in soils verified to be substantially non-contaminated, would represent the most appropriate estimation. ● The measurements in other investigations cited in the review also show 17.12 to 29 mg/kg dw on the average and 20 to 35mg/kg dw as a median.	Remote areas	-	-	17.2	-	Japan's submission, 2005
24	Lithuania	All soils	Non-contaminated soil rock*	Remote areas	-	-	9.7	-	Lithuania's submission, 2005
25	Lithuania	All soils	Top layer, all soils	Topsoils - unspecified	-	-	15.1	-	Lithuania's submission, 2005
28	Lithuania	Sand	Non-contaminated soil rock*	Remote areas	-	-	7.6	-	Lithuania's submission, 2005
29	Lithuania	Sand	Top layer, sand	Topsoils - unspecified	-	-	14.8	-	Lithuania's submission, 2005
30	Lithuania	Sandy loam	Non-contaminated soil rock*	Remote areas	-	-	9	-	Lithuania's submission, 2005
31	Lithuania	Sandy loam	Top layer, sandy loam	Topsoils - unspecified	-	-	14.3	-	Lithuania's submission, 2005
32	Lithuania	Clay loam	Non-contaminated soil rock*	Remote areas	-	-	13	-	Lithuania's submission, 2005
33	Lithuania	Clay loam	Top layer, clay loam	Topsoils - unspecified	-	-	14.6	-	Lithuania's submission, 2005
34	Lithuania	Clay	Non-contaminated soil rock*	Remote areas	-	-	12	-	Lithuania's submission, 2005
35	Lithuania	Gravel	Non-contaminated soil rock*	Remote areas	-	-	8.3	-	Lithuania's submission, 2005
36	Lithuania	Peaty soil	Top layer, peaty soil	Topsoils - unspecified	-	-	18.1	-	Lithuania's submission, 2005
37	Moldova	-	Analysis results on determination of Lead and Cadmium (mobile forms) in soils	Topsoils - unspecified	0.33	4.41	1.48	-	Moldova's submission, 2005

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
38	Poland	-	Research on lead shows that the content of lead varies from 0.01 to 5,000 mg Pb/kg of soil, the average value being assumed as 13.6 mg Pb/kg of soil. The observed high lead concentrations in soil refer only to several places in Poland, where non-ferrous metal ores are processed and extracted [Trelak, 1997, as cited by Poland's submission, 2005]. The mentioned values indicate that the lead content in arable soil approaches average values, characterizing the average content of these metals in soil all over the world (Poland's submission, 2005).	Agricultural soils	0.01	5000	13.6	-	Poland's submission, 2005
40	Togo	-	Mining soils	Highly contaminated soils	15	140	-	-	Togo's submission, 2005
41	USA	-	Upper layer of soil beside roadways	Topsoils - specified	30	2000	-	-	ATSDR, 2005. Linked from submission.
42	USA	-	Soil adjacent to smelter in Missouri	Highly contaminated soils	-	-	60000	-	ATSDR, 2005. Linked from submission.
43	USA	-	Soils adjacent to houses with exterior lead-based paints may have lead levels of > 10000 mg/kg	Highly contaminated soils	-	-	10000	-	ATSDR, 2005. Linked from submission.
46	USA	-	Inner-city schools in New Orleans	Topsoils - specified	-	-	-	96.5	ATSDR, 2005. Linked from submission.
47	USA	-	Mid-city schools in New Orleans	Topsoils - specified	-	-	-	30	ATSDR, 2005. Linked from submission.
48	USA	-	Outer-city schools in New Orleans	Topsoils - specified	-	-	-	16.4	ATSDR, 2005. Linked from submission.
49	Canada	-	Topsoil	Topsoils - unspecified	7	43	20.7	-	Richardson *et al*., 2001
50	Canada	-	Agricultural soil (for Pb: Plowed agricultural soil)	Agricultural soils	3	192	-	14	Richardson *et al*., 2001
51	USA	-	Topsoil	Topsoils - unspecified	10	700	20	-	Richardson *et al*., 2001
52	USA	-	Topsoil	Topsoils - unspecified	14	96	44.1	-	Richardson *et al*., 2001
53	USA	-	Agricultural surface soil	Agricultural soils	1	135	12.3	11	Richardson *et al*., 2001
54	USA	-	Uncontaminated soil	Remote areas	-	-	18	-	Richardson *et al*., 2001

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
55	England	-	Uncontaminated soil	Remote areas	-	-	14	-	Richardson *et al*., 2001
56	England	-	Topsoil	Topsoils - unspecified	48	307	114	-	Richardson *et al*., 2001
57	England and Wales	-	Topsoil	Topsoils - unspecified	15	106	42	-	Richardson *et al*., 2001
59	Sweden	-	Topsoil	Topsoils - unspecified	2.2	364	15.9	-	Richardson *et al*., 2001
60	Sweden	-	Uncontaminated soil	Remote areas	-	-	12	-	Richardson *et al*., 2001
61	Denmark	-	Topsoil	Topsoils - unspecified	-	-	24.1	-	Richardson *et al*., 2001
62	Finland	-	Topsoil	Topsoils - unspecified	10	600	135	-	Richardson *et al*., 2001
63	Spain	-	Uncontaminated soil	Remote areas	-	-	10	-	Richardson *et al*., 2001
64	Italy	-	Uncontaminated soil	Remote areas	-	-	13	-	Richardson *et al*., 2001
65	Austria	-	Uncontaminated soil	Remote areas	-	-	16	-	Richardson *et al*., 2001
66	Belgium	-	Uncontaminated soil	Remote areas	-	-	21	-	Richardson *et al*., 2001
67	Silesia	-	Uncontaminated soil	Remote areas	-	-	28	-	Richardson *et al*., 2001
68	Russia	-	Uncontaminated soil	Remote areas	-	-	12	-	Richardson *et al*., 2001
69	Israel	-	Uncontaminated soil	Remote areas	-	-	15	-	Richardson *et al*., 2001
70	Egypt	-	Uncontaminated soil	Remote areas	-	-	21	-	Richardson *et al*., 2001
71	Cameroon	-	Uncontaminated soil	Remote areas	-	-	19	-	Richardson *et al*., 2001
72	Madagascar	-	Uncontaminated soil	Remote areas	-	-	20	-	Richardson *et al*., 2001
73	Nigeria	-	Uncontaminated soil	Remote areas	-	-	18	-	Richardson *et al*., 2001
74	Zambia	-	Uncontaminated soil	Remote areas	-	-	20	-	Richardson *et al*., 2001
75	South Africa	-	Uncontaminated soil	Remote areas	-	-	12	-	Richardson *et al*., 2001

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
76	Japan	-	Uncontaminated soil	Remote areas	-	-	11	-	Richardson *et al*., 2001
77	Australia	-	Uncontaminated soil	Remote areas	-	-	14	-	Richardson *et al*., 2001
79	New Zealand	-	Uncontaminated soil	Remote areas	-	-	16	-	Richardson *et al*., 2001
83	Trinidad and Tobago	-	(unspecified)	Highly contaminated soils	6.6	120000	-	-	Trinidad and Tobago's submission, 2006
84	Uzbekistan	-	Polluted soil around industrial waste site, Tashkent Region	Highly contaminated soils	-	-	57.6	-	Uzbekistan's submission, 2006
85	Uzbekistan	-	Polluted soil around industrial waste site, Tashkent Region	Highly contaminated soils	-	-	60.8	-	Uzbekistan's submission, 2006
86	Uzbekistan	-	Polluted soil around industrial waste site, Navoi Region	Highly contaminated soils	-	-	38.4	-	Uzbekistan's submission, 2006
89	Uzbekistan	-	Polluted soil around industrial waste site, Namangan Region	Highly contaminated soils	-	-	80	-	Uzbekistan's submission, 2006
91	Finland	Coarse mineral soil	Cultivated fields	Remote areas	2.1	57.9	8.3	-	Finland's submission, 2006
92	Finland	Clay soils	Cultivated fields	Remote areas	6.6	23	15.4	-	Finland's submission, 2006
93	Finland	Organic soils	Cultivated fields	Remote areas	3.5	21.4	9.7	-	Finland's submission, 2006
94	Finland	All soils	Cultivated fields	Remote areas	2.1	57.9	9.7	-	Finland's submission, 2006
95	Finland	Humus	Permanent national forest	Remote areas	10.3	236	36.6	33.6	Finland's submission, 2006
96	Finland	Podsol	Mainly forest land (<2mm)	Remote areas	3.99	48.4	13.26	12.5	Finland's submission, 2006
97	Finland	Podsol	Forest land (<1mm)	Remote areas	3.91	105	31.56	30.6	Finland's submission, 2006
98	Finland	Vertic cambisols	Topsoil, arable land, aqua regia	Agricultural soils	9.57	25.7	15.7	17.5	Finland's submission, 2006
99	Finland	Dystric cambisols	Topsoil, arable land, aqua regia	Agricultural soils	-	43.2	6.25	-	Finland's submission, 2006

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
100	Finland	Haplic podzols	Topsoil, arable land, aqua regia	Agricultural soils	-	8.2	4.68	6.53	Finland's submission, 2006
101	Finland	Fibric histosols	Topsoil, arable land, aqua regia	Agricultural soils	-	21	9	8.18	Finland's submission, 2006
102	Ghana	-	Topsoil samples along roadsides in Accra, the capital city of Ghana	Topsoils - specified	19.65	310.47	-	-	Ghana's submission, 2006
103	Mongolia	-	(unspecified)	Topsoils - unspecified	-	-	104.1	-	Mongolia's submission, 2006
105	Sweden	Till	Till. Fine fraction (<0.063 mm). Total contents XRF. Based on 24151 samples	Topsoils - unspecified	17	57	-	22	Sweden's submission, 2006
106	Sweden	Till	Till. Fine fraction (<0.063 mm). Acid leaching 7M HNO3. Total contents ICP-MS. Based on 8328 samples	Topsoils - unspecified	3.4	43.4	-	7.2	Sweden's submission, 2006
107	Sweden	Glacial sediments, mainly clays	Glacial sediments, mainly clays. Acid leaching. 7M HNO3. ICP-MS Based on 544 samples	Topsoils - unspecified	4.3	27.9	-	11.2	Sweden's submission, 2006
108	China	Rice soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	16.5	56	-	-	China's submission, 2006
109	China	Damp soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	13.5	23.9	-	-	China's submission, 2006
110	China	Drill soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	13.5	23.9	-	-	China's submission, 2006
111	China	Floss soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	18.5	23.9	-	-	China's submission, 2006
112	China	Black loamy soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	18.5	23.9	-	-	China's submission, 2006
113	China	Oasis soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	23.9	31.1	-	-	China's submission, 2006
114	Norway	-	Agricultural soil (0-5 cm)	Agricultural soils	3.5	77.7	23.9	-	Norway's submission, 2006
115	Norway	-	Agricultural soil (> 40 cm)	Agricultural soils	4.7	49.2	19.6	-	Norway's submission, 2006
116	Switzerland	-	Grassland (extensive) (Swiss soil monitoring network site	Topsoils - specified	15	80.5	29.8	27.8	Switzerland's submission, 2006
117	Switzerland	-	Grassland (intensive) (Swiss soil monitoring network site	Topsoils - specified	13.1	50	25.4	21.2	Switzerland's submission, 2006
118	Switzerland	-	Grassland (all)	Topsoils - specified	3.6	19430	95.8	29	Switzerland's submission, 2006
119	Switzerland	-	Agriculture (Swiss soil monitoring network site)	Agricultural soils	10.5	43.3	23.1	22.5	Switzerland's submission, 2006

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
120	Switzerland	-	Agriculture	Agricultural soils	1	2088	30.1	23	Switzerland's submission, 2006
121	Switzerland	-	Special crop (Swiss soil monitoring network site)	Agricultural soils	16.1	44.9	24.5	24.3	Switzerland's submission, 2006
122	Switzerland	-	Special crop	Agricultural soils	6.7	316.5	32.2	24	Switzerland's submission, 2006
123	Switzerland	-	Town park (Swiss soil monitoring network site)	Topsoils - specified	75.5	152.2	108.5	104.2	Switzerland's submission, 2006
124	Switzerland	-	Town park	Topsoils - specified	7	2703	101	49.5	Switzerland's submission, 2006
125	Switzerland	-	Protected area (Swiss soil monitoring network site)	Topsoils - unspecified	23.1	92.7	50.4	42.9	Switzerland's submission, 2006
126	Switzerland	-	Protected area	Topsoils - unspecified	9.1	5965	121	36.1	Switzerland's submission, 2006
127	Switzerland	-	Decidious forest (Swiss soil monitoring network site)	Topsoils - specified	12	106.6	30.5	24	Switzerland's submission, 2006
128	Switzerland	-	Decidious forest	Topsoils - specified	6.8	28520	246.9	27.4	Switzerland's submission, 2006
129	Switzerland	-	Coniferous forest (Swiss soil monitoring network site)	Topsoils - specified	15.1	59.5	35.8	35	Switzerland's submission, 2006
130	Switzerland	-	Coniferous forest	Topsoils - specified	9.4	597.8	33.1	26	Switzerland's submission, 2006
131	Russian Federation	-	Contents in topsoils at the Stations of Complex Background Monitoring (biosheric reservations) located in the European territory	Topsoils - unspecified	-	-	≤2.3	-	Russian Fedederation's submission, 2006
132	Russian Federation	-	Background lead content near big industrial cities	Topsoils - specified	-	-	4.0-16	-	Russian Fedederation's submission, 2006
133	Russian Federation	-	Highly contaminated soils in the city territories	Topsoils - specified	-	-	35-910	-	Russian Fedederation's submission, 2006

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
134	Spain	Agricultural topsoil	A large study on heavy metal content in agricultural soils in the entire Spanish peninsula took place between 2001 and 2003. A regular sampling grid was stablished and one plot was selected from each 64 sq. km of arable land area as well as from each 128 sq. km of grassland area. A total of 2,932 samples were taken and their heavy metals content was determined by extraction using acqua regia digestion. In the total sampling population of peninsular Spanish soils, 99 per cent of samples have less than 100 mg/kg of lead; 95 per cent have less than 42 mg/kg and 50 per cent have less than 16 mg/kg. The lead content is significantly correlated to organic matter and clay content (mean values, 2.53 and 21.77 percent, respectively). No significant relation is found with pH, probably because that correlation is linked to low soil pHs (even below 5), uncommon in Spain (mean pH value 7.47, median pH value 8.10).		-	-	21.294	16.000-	LÓPEZ-ARIAS, M. and GRAU-CORBÍ, J.M. 2004
135	Spain	Topsoils	535 samples belong to the 'grassland' category.	Grassland topsoil	-	-	25.806	21.000	LÓPEZ-ARIAS, M. and GRAU-CORBÍ, J.M. 2004
136	Spain	Topsoils	2,397 samples belong to the 'arable land' category.	Arable land topsoil	-	-	20.287	16.000	LÓPEZ-ARIAS, M. and GRAU-CORBÍ, J.M. 2004
	Switzerland		Grassland extensive (Swiss soil monitoring network site)	Grassland	15.0	80.5	29.8	27.8	Switzerland's submission 2007
	Switzerland		Grassland intensive (Swiss soil monitoring network site)	Grassland	13.1	50.0	25.4	21.2	Switzerland's submission 2007
	Switzerland		Grassland (all)	Grassland	3.6	19,430.0	95.8	29.0	Switzerland's submission 2007
	Switzerland		Agriculture (Swiss soil monitoring network site)	Agriculture	10.5	43.3	23.1	22.5	Switzerland's submission 2007
	Switzerland		Agriculture	Agriculture	1.0	2088.0	30.1	23.0	Switzerland's submission 2007
	Switzerland		Special crop (Swiss soil monitoring network site)		16.1	44.9	24.5	24.3	Switzerland's submission 2007
	Switzerland		Special crop		6.7	316.5	32.2	24.0	Switzerland's submission 2007
	Switzerland		Town park (Swiss soil monitoring network site)		75.5	152.2	108.5	104.2	Switzerland's submission 2007
	Switzerland		Town park		7.0	2703.0	101.0	49.5	Switzerland's submission 2007
	Switzerland		Protected area (Swiss soil monitoring network site)		23.1	92.7	50.4	42.9	Switzerland's submission 2007

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Pb/kg				Reference
					min	max	mean	median	
	Switzerland		Protected area		9.1	5965.0	121.0	36.1	Switzerland's submission 2007
	Switzerland		Deciduous forest (Swiss soil monitoring network site)		12.0	106.6	30.5	24.0	Switzerland's submission 2007
	Switzerland		Coniferous forest		6.8	28,520.0	246.9	27.4	Switzerland's submission 2007
	Switzerland		Coniferous forest (Swiss soil monitoring network site)		15.1	59.5	35.8	35.0	Switzerland's submission 2007
	Switzerland		Coniferous forest		9.4	597.8	33.1	26.0	Switzerland's submission 2007
	Moldova		Mobile forms – maximum permissible concentration			6.0			Moldova's submission 2007
	Moldova		Total forms – maximum permissible concentration			30.0			Moldova's submission2007
	Pakistan		Diferent types of soil (piedmont, floodplain and lascustrine) from Peshawar		< 0.5	495	122		Pakistan submission, 2010