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Chemicals Branch, DTIE

Final review of scientific information on cadmium

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Table of Contents

Key scientific findings for cadmium

I. Hazardous properties, exposures and effects

1. Cadmium is a non-essential and toxic element for humans mainly affecting kidneys and the skeleton. It is also a carcinogen by inhalation. Cadmium is accumulated in bone and may serve as a source of exposure later in life.

2. In the environment, cadmium is toxic to plants, animals and micro-organisms. Being an element, cadmium is persistent – it cannot be broken down into less toxic substances in the environment. The degree of bioavailability and potential for effects varies depending on the form of cadmium. Cadmium bioaccumulates mainly in the kidneys and liver of vertebrates and in aquatic invertebrates and algae.

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

3. Cadmium is released by various natural and anthropogenic sources to the atmosphere, aquatic environments (fresh and salt water environments) and terrestrial environments. There are fluxes between these compartments. Cadmium released to the atmosphere can deposit to land and aquatic environments, and some cadmium released to soil over time will be washed out to the aquatic environments. The long-term sinks are deep-sea sediments and, to a certain extent, controlled landfills, in cases where, owing to its physico-chemical properties, cadmium is immobilized and remains undisturbed by anthropogenic or natural activity (climatic and geological).

4. Cadmium, once emitted to air, is subject to atmospheric transport. It is mainly emitted to the atmosphere in particle form. The atmospheric transport of cadmium is governed by aerosol (particle) transport mechanisms: in the atmosphere, cadmium may be transported on local, national, regional or intercontinental scales, depending on various factors, including, for both natural and anthropogenic sources, particle size, the height of emission outlets and meteorology. Because it has a relatively short residence time in the atmosphere (days or weeks), however, this metal is mainly transported over local, national or regional distances.

5. Based on the relatively scarce specific evidence available, cadmium is considered to be subject to a certain degree of long-range air transport on an intercontinental scale. Intercontinental transport is, however, expected to make only a minor contribution to cadmium levels in regions affected by other, local emitting sources. The regional and intercontinental atmospheric transport of cadmium contributes to deposition in remote regions, such as the Arctic, where there are few local sources for cadmium releases.

6. There is no hemispheric transport modelling for cadmium. As cadmium transport is governed by aerosol transport mechanisms similar to those governing the transport of lead (both are transported on aerosol particles with similar properties), the transport of lead might be used as a rough surrogate of the potential intercontinental transport of cadmium. Lead modelling is described in the UNEP review of scientific information on lead. Taking into account the general similarities between the long-range atmospheric transport of cadmium and lead and building on observations for lead, major contributions to Arctic cadmium pollution can be expected, as is the case with lead pollution, to come from sources located in Europe and in Siberia.

7. With regard to aquatic systems, rivers transport cadmium and other heavy metals on a national and regional scale. Ocean transport also occurs. The oceanic residence time of cadmium has been estimated at about 15,000 years. This indicates that cadmium may be accumulated and transported in sig-

nificant amounts over long distances in the ocean. It should be noted, however, that oceans have large natural reservoirs of cadmium. The contribution of cadmium via rivers into the marine environment of the North Sea is in the same order of magnitude as the atmospheric deposition, which is the other main pathway of cadmium inputs in the region.

III. Sources of releases

8. Important releases of cadmium may be grouped in the following categories: releases from natural sources, in other words, releases resulting from natural mobilization of naturally occurring cadmium from the Earth's crust and mantle, such as volcanic activity and weathering of rocks; current anthropogenic releases from the mobilization of cadmium impurities in raw materials such as phosphate minerals, fossil fuels and other extracted, treated and recycled metals - particularly zinc and copper; current anthropogenic releases of cadmium used in products and processes, as a result of use, disposal, recycling, reclamation, open burning or incineration; releases from municipal installations; and the mobilization of historical anthropogenic and natural cadmium releases previously deposited in soils, sediments, landfills and waste or tailings piles.

A. Atmospheric releases (emissions)

9. The most recent study of global anthropogenic emissions estimated the total in the mid-1990's at 2,983 tonnes. Newer estimates are not available. Available data indicate, however, that anthropogenic emissions of cadmium have decreased by an average of about 50 per cent from 1990 to 2003 in developed countries. Adequate data are not available to evaluate trends in developing countries. The main sources of emissions are non-ferrous metal production and fossil fuel combustion. Other sources include iron and steel production, waste incineration and cement production. In some developing countries, open burning of cadmium-containing products and indiscriminate dumping contribute to local and regional exposure.

10. The major natural sources for emission to air are volcanoes, airborne soil particles, sea spray, biogenic material and forest fires. Very different estimates of total releases of cadmium to the atmosphere by natural processes have been reported. A study from 1989 estimates the total emissions in 1983 at between 150 and 2,600 tonnes per year, whereas a new study estimates the total emissions from natural sources at between 15,000 and 88,000 tonnes per year. The large discrepancy is mainly due to different estimates of the amount of cadmium released to air with soil particles. Because of the limited data and huge differences between the findings of these two studies, there is uncertainty about the relative magnitude of natural emissions as compared to anthropogenic emissions. The more recent study suggests that natural emissions might be between 5 and 30 times higher than anthropogenic emissions.

11. Various human activities (such as mining, metal production, combustion of fossil fuels and other industrial processes) have resulted, however, in elevated cadmium concentrations in the environment. For example, cadmium deposition in the 1960's and 1970's in the Greenland ice core was eight times higher than in pre-industrial times. These data suggest that industrial emissions have been more important as a source of deposition in Greenland – and perhaps other Arctic areas – than natural emissions. Recent data indicate that cadmium deposition levels have steady declined since the 1970's.

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

B. Releases to land and aquatic systems

13. Some cadmium-containing products are disposed of in various waste deposits, released to soil or the aquatic environment. Major categories of these releases include residues from coal combustion, mine tailings, and smelter slag and waste. In recent years, nickel-cadmium (NiCd) batteries and primary batteries with cadmium content have constituted a major source of cadmium disposed of in landfills with municipal waste. The long-term fate of the cadmium accumulating in the landfills is uncertain and

may represent a future source of releases. The handling of wastes may lead to elevated local and regional release levels for developing countries.

14. Atmospheric deposition, phosphate fertilizers and sewage sludge appear to be the major contributors to cadmium levels in agricultural soils. In a number of European countries, atmospheric deposition, animal manures, sewage sludge and the presence of cadmium in fertilizers are causing the content of cadmium in topsoil to increase. Atmospheric deposition has been decreasing, but in the late 1990's it was still a major source of cadmium input to agricultural soils. As cadmium is taken up by plants, increased soil concentrations can result in increased concentrations in food products.

15. The weathering of rocks releases cadmium to soils and aquatic systems and plays a significant role in the global cadmium cycle. This release is enhanced by acidic emissions. Weathering and erosion result in the transport by rivers of large quantities of cadmium to the world's oceans. An annual gross input of 15,000 tonnes of cadmium has been estimated. Moreover, between about 900 and 3,600 tonnes of cadmium are estimated to be deposited to aquatic environments throughout the world through atmospheric deposition of emissions originating from anthropogenic and natural sources.

16. The open burning in some developing countries of waste products containing cadmium could be an important source of local and regional cadmium releases to land and aquatic systems.

IV. Production and uses of cadmium

17. Cadmium is produced mainly as a by-product of mining, smelting and refining of zinc and, to a lesser degree, as a by-product of lead and copper production. It is therefore primarily a function of zinc production rather than cadmium demand. Global cadmium production almost doubled between 1950 and 1990. Since 1990, global consumption has remained constant, at about 20,000 tonnes per year, although major changes have occurred with the geographical distribution of this production. Until 1997, production in Europe, the Americas and Asia remained constant. Since 1997, however, production in Asia has increased sharply, whereas the production in Europe has decreased. Major shifts in smelting and refining technology by many of the world's zinc refiners from pyrometallurgical to hydrometallurgical processes (50 per cent in 1958 to 81 per cent of capacity in 2003) have led to significant decreases in releases of cadmium to the environment.

18. Recycled cadmium accounts for about 18 per cent of total global supply. Countries with significant collection and recycling activities include France, Germany, Japan, the Republic of Korea, Sweden and the United States of America.

19. Cadmium is used and traded globally as a metal and as a component in various products. A growing proportion of refined cadmium consumption is accounted for by NiCd batteries, which in 2004 represented 81 per cent of the total. Other major uses of refined cadmium are: pigments for plastics, ceramics and enamels; stabilizers for plastics; plating on iron and steel; and as an alloying element of some lead, copper and tin alloys. Since 1990, consumption for pigments, stabilizers, alloys and other uses has decreased significantly.

20. Products containing cadmium are not typically collected separately from the general waste stream in developing countries. Therefore cadmium discards will end up in municipal waste and disposed of in landfills, incineration, open burning or indiscriminate dumping. Some of the cadmium in these products will be released to the environment, the extent of which depends on disposal method, control technologies applied and other factors.

V. Cadmium issues in developing countries

21. As awareness of the adverse impacts of cadmium 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 cadmium into the environment. That said, however, some of the uses of cadmium which have been phased out in

industrialized countries have continued in developing countries. In addition, use of cadmium has continued or increased in some less developed regions or countries, e.g., 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 cadmium. These hazardous disposal practices include open burning and indiscriminate dumping in sensitive ecosystems such as rivers and wetlands.

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

VI. Levels and time trends in air and deposition

23. Most of the identified monitoring measurements for atmospheric cadmium concentrations and deposition come from Europe and the United States of America; data from Japan, China, Canada, Antarctica and New Zealand are, however, also available. Data are very limited to assess trends. In Europe, however, between the early 1990's and 2003, average concentrations of cadmium in air decreased by about 50 per cent in central and north-western Europe. Measured concentrations in precipitation decreased by about 65–75 per cent in central and north-western Europe. From 1990 to 2003 in the northern part of Europe and from 1990 to 1996 in a few North American locations, there were no observable trends in concentrations of precipitation.

24. 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 the models and to uncertainties in reported emissions.

25. Measured air levels tend to be much higher near sources and in urban areas compared to remote locations. For example, in remote areas of the United States of America, atmospheric cadmium concentrations are generally below 1 ng/m^3. Levels in urban air are significantly higher (3–40 ng/m^3). Over the Great Lakes, atmospheric cadmium concentrations ranged from 0.2 to 0.6 ng/m^3. These data indicate that atmospheric cadmium concentrations are much higher close to sources of emissions and that long-range transport results in much lower levels in the atmosphere.

26. Cadmium concentrations in Spitsbergen, Norway, did not exhibit any noticeable trend over the period 1994–2003. Cadmium appears to deposit more readily in the Arctic than other particulate elements. In these areas, however, the total cadmium deposition and atmospheric depositions is much lower than in industrial areas.

27. The main factors affecting the range and deposition of cadmium 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 cadmium 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

28. Cadmium is a non-essential and toxic element for humans. Attention is drawn to the following:

- The kidney is considered the critical target organ for toxicity of cadmium in humans. The main critical effects include an increased excretion of proteins in urine as a result of proximal tubular cell damage. The severity of the effect depends on duration and magnitude of exposure

- Skeletal damage is another critical effect of chronic cadmium exposure at levels somewhat higher than those for which kidney proteinuria is an early effects indicator

- Cadmium is a human carcinogen by the inhalation route. Epidemiological data from occupational settings confirm lungs being the primary target organ. Cadmium is not considered a carcinogen by ingestion

- Cadmium is mainly stored in the liver and kidneys. Excretion is slow, with a very long half-life (decades) in the human body. Cadmium concentrations in most tissues increase with age

29. There are multiple sources of cadmium exposure in the general population. Attention is drawn to the following:

- Food accounts for approximately 90 per cent in the general, non-smoking population

- Cadmium in crops is due to the uptake of cadmium from soils and the rate of uptake is influenced by factors such as soil pH, salinity, humus content, crop species and varieties and the presence of other elements (e.g., zinc)

- Less than 10 per cent of the total exposures among general populations occur due to inhalation of low levels of cadmium in ambient air and through drinking water

- The kidney burden resulting from cumulative exposure to cadmium can be assessed by measuring cadmium in urine

30. Some population groups are especially vulnerable to increased exposure and uptake of cadmium. Attention is drawn to the following:

- Cadmium occurs in all food, but agricultural crops (particularly irrigated rice) generally account for most of the intake. Vegetarians and high cereal-consuming and pulse-consuming groups are likely to have higher exposures compared to the general population

- People with a high intake of shellfish and organ meat from marine animals may have a particularly high intake of cadmium

- People with low body iron stores, especially pregnant women, or low zinc intake will exhibit higher rates of cadmium uptake

- People with other nutritional deficiencies may also be at risk

- Tobacco is an important source of cadmium uptake in smokers and may also affect non-smokers through passive exposure to secondary smoke

- People living in the vicinity of industrial sources and other point sources of cadmium release can be exposed to an increased level of cadmium

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

- People who have medical detriments from a range of other clinical conditions, particularly those related to renal insufficiency (e.g. diabetes) and multiparous women with inadequate nutrition, are more susceptible

- Renal efficiency normally decreases with age and can be exacerbated by exposure to cadmium

32. The level of dietary exposure can exceed the guidelines set by the United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO). Attention is drawn to the following:

- According to available data, the average weekly intake of cadmium from food in most countries is within the range of 0.7–2.8 µg/kg body weight

- Although available data indicate that most people have intake levels below the provisional tolerable weekly intake (PTWI) (7 µg/kg body weight per week), WHO recognizes that the margin between the PTWI and the actual weekly intake of cadmium by the general population is small, less than 10-fold, and that this margin may be even smaller in smokers

- In some populations at high risk, the margin may be non-existent

VIII. Impacts on the ecosystem

33. Cadmium is a non-essential heavy metal. Some cadmium compounds are relatively water soluble, mobile in soil and bioavailable, depending on the water and soil chemistries. It tends to bioaccumulate in organs such as the kidney and liver of vertebrates, but aquatic invertebrates and algae can also build up relatively high concentrations. Effects on birds and mammals are mainly due to kidney damage. In sea birds and marine mammals in particular, cadmium accumulates to relatively high levels.

34. In terrestrial ecosystems, soil micro-organisms and plants are more sensitive to cadmium than soil invertebrates. Both invertebrates and plants can accumulate cadmium. Predators feeding on such soil invertebrates can introduce cadmium into the food chain, which suggests a risk of secondary poisoning through the food chain from worms to higher trophic levels (birds or mammals). The accumulation of cadmium by plants results in this contaminant entering the human food chain. In some European areas, the cadmium concentrations measured and estimated are exceeding the threshold concentration for adverse effects on terrestrial ecosystems. In the United Nations Economic Commission for Europe region, available information indicates that levels of cadmium in terrestrial wildlife are generally low and do not exceed thresholds for effects.

35. Aquatic fresh and marine invertebrates are the organisms most sensitive to cadmium. The dissolved cadmium concentrations measured in some European waters (mainly rivers) are exceeding the threshold concentration producing adverse effects of cadmium in the aquatic ecosystem. Some studies suggest that levels in water, sediment and soil are at or above known biological effect levels. Despite relatively high levels of cadmium in seabirds and marine mammals in Greenland, no evidence has been found of effects in ringed seals with very high cadmium levels in their kidneys. Arctic seabirds in general are known to accumulate high levels of cadmium found naturally in the marine environment and are therefore considered to be not as sensitive as terrestrial birds. Kidney damage has, however, been reported in wild colonies of Arctic pelagic seabirds having cadmium levels of 60-480 µg/g in the kidney. Spatial distribution of cadmium in marine biota appears to be driven by regional geology or geochemistry. Monitoring data on cadmium in the Arctic abiotic and biotic environment to date, however, provide no conclusive evidence of trends or effects.

IX. Data gaps

36. 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 information to improve understanding of the inconsistencies between official reported emissions and observed cadmium concentration and depositions

- The need for substance flow analysis in the economy on a national and global basis in order to identify the sources of risk

- The need for hemispheric modelling and modelling for other countries and continents, and for better understanding of ocean transport, re-emissions and natural releases and data to support such modelling

- The need for assessment of the extent of risks to humans, the ecosystem or animals from exposure to cadmium, the role of long-range environmental transport, the contribution of anthropogenic versus natural sources and the influence of local, regional, and global sources
- Relative contributions of anthropogenic and natural of cadmium emissions on a global basis
- The need to monitor and assess cadmium 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 cadmium, 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 cadmium disposed of in the environment, especially in developing countries, where the open burning of cadmium-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 cadmium as a result of leaching from landfills, especially in developing countries
- Transport by rivers to marine environments on a global scale
- The need to collect data on concentration levels in large migrating marine mammals
- The need for better understanding of the health risks due to exposure to cadmium and various factors that affect that risk
- The need to investigate the magnitude of natural emissions versus anthropogenic emissions, in particular with regard to particle size
- The need to examine the global flow of cadmium in products.

Extended summary

CHAPTER 1 - Introduction

37. 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.

38. 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 organisations and non-governmental organisations. Working Group members assisted first through a comment round by mail, then through a meeting of the Working Group, which took place 18 to 22 September 2006 in Geneva, Switzerland.

39. Chapters 7, 5, 4 and 3 of this report respond directly to the Governing Council request, and were address specifically, and in that order of priority, by the Working Group at its meeting. Chapter 6, relating to production, use and trade, and Chapter 2, relating to chemistry, were considered by the Working Group to be necessary information to provide a more complete 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.

40. 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.

41. The Working Group recognised that, as there was ongoing work underway in other forums on this metal and related issues, 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’.

42. 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. This draft final version of the review of scientific information on cadmium was presented for the information of the Governing Council in its 25th session on February 2009.

43. 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

44. Cadmium is in its elemental form a soft, silver-white metal. It is not usually present in the environment as a pure metal, but is most often present as complex oxides, sulphides, and carbonates in zinc, lead, and copper ores. Cadmium does not have any recognizable taste or odour. Cadmium sulphate and cadmium chloride are quite soluble in water, whereas elemental cadmium, cadmium oxide and cadmium sulphide are almost insoluble.

45. Cadmium is mainly emitted to the atmosphere in particle form. From combustion sources, cadmium may, however, be emitted partly as elemental gaseous cadmium, but as it is cooled, this cadmium is also quickly bound to particulate matter. Atmospheric transport of cadmium is governed by aerosol (particle) transport mechanisms.

46. In soil, the chemistry of cadmium is to a great extent controlled by pH. Cadmium may be adsorbed on clay minerals, carbonates or hydrous oxides of iron and manganese or may be precipitated as cadmium carbonate, hydroxide, and phosphate. Under acidic conditions cadmium solubility increases, and very little adsorption of cadmium by soil colloids, hydrous oxides, and organic matter takes place. Both toxicity and bioavailability of cadmium are influenced by soil characteristics (ECB, 2005). Soil characteristics influence cadmium sorption and therefore its bioavailability and toxicity (ECB, 2005). Cadmium mobility and bioavailability are higher in noncalcareous than in calcareous soils (Thornton 1992, as cited by ATSDR, 1999). Liming of soil raises the pH, increasing cadmium adsorption to the soil and reducing bioavailability (He and Singh 1994; Thornton 1992, as cited by ATSDR, 1999)

CHAPTER 3 – Human exposure and health effect

47. Cadmium is a non-essential and toxic element for humans. The kidney is considered the critical target organ for toxicity of cadmium in humans. The main critical effects include an increased excretion of proteins in urine as a result of proximal tubular cell damage. The severity of the effect depends on duration and magnitude of exposure.

48. Skeletal damage is another critical effect of chronic cadmium exposure at levels somewhat higher than those for which kidney proteinuria occurs. Kidney proteinuria is an early effects indicator.

49. The International Agency for Research on Cancer (IARC) classifies cadmium in Group 1: carcinogenic to humans and the US Environmental Protection Agency (EPA) has determined that cadmium is a probable human carcinogen by inhalation Epidemiological data from occupational settings confirm lungs being the primary target organ. Cadmium is not considered a carcinogen by ingestion.

50. Cadmium is mainly stored in the liver and kidneys. Excretion is normally slow, and the biological half-life is very long (decades) in the muscles, kidneys, liver, and whole body. Cadmium concentrations in most tissues increase with age. In exposed people with renal damage, urinary excretion of cadmium increases and so the whole body half-life is shortened. Cadmium concentrations in most tissues increase with age. The kidney burden resulting from cumulative exposure to cadmium can be assessed by measuring cadmium in urine.

51. There are multiple sources of cadmium exposure in the general population. Food accounts for approximately 90 per cent in the general, non-smoking population. Cadmium in crops is due to the uptake of cadmium from soils and the rate of uptake is influenced by factors such as soil pH, salinity, humus content, crop species and varieties and the presence of other elements (e.g., zinc). Less than 10 per cent of the total exposures among general populations occur due to inhalation of low levels of cadmium in ambient air and through drinking water.

52. Some population groups are especially vulnerable to increased exposure and uptake of cadmium. Vegetarians and high cereal-consuming and pulse-consuming groups are likely to have higher exposures compared to the general population. People with a high intake of shellfish and organ meat from marine animals may have a particularly high intake of cadmium. People with low body iron stores, especially pregnant women, or low zinc intake will exhibit higher rates of cadmium uptake. People with other nutritional deficiencies may also be at risk. Tobacco is an important source of cadmium uptake in smokers and may also affect non-smokers through passive exposure to secondary smoke. People living in the vicinity of industrial sources and other point sources of cadmium release can be exposed to an increased level of cadmium.

53. Certain population groups are vulnerable and especially susceptible to cadmium. People who have medical detriments from a range of other clinical conditions, particularly those related to renal in-

sufficiency (e.g. diabetes) and multiparous women with inadequate nutrition, are more susceptible. Renal efficiency normally decreases with age and can be exacerbated by exposure to cadmium

54. The level of dietary exposure can exceed the guidelines set by the United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO). According to available data, the average weekly intake of cadmium from food in most countries is within the range of 0.7–2.8 µg/kg body weight. Available data indicate that most people have intake levels below the provisional tolerable weekly intake (PTWI) (7 µg/kg body weight per week). WHO considers that, recognizing the conservative nature of the derivation of PTWI, the margin between the PTWI and the actual weekly intake of cadmium by the general population is less than 10-fold, and that this margin may be even narrower in smokers. In some populations at high risk, the margin may be non-existent.

55. **Occupational exposure –** Workers may be exposed to cadmium in the zinc, copper and steel industries, in the manufacture of nickel-cadmium batteries, solar cells, and jewellery, in metal plating, production of plastics and many other industrial activities. Acute cadmium poisoning is characterized by irritation of the respiratory tract, while in chronic poisoning the main target organ is the renal tubule (Nogue *et al.*, 2004). The main route of cadmium exposure in the occupational setting is via the respiratory tract. Air concentrations of cadmium fumes or dust vary considerably between different industries, such as smelters, pigment plants and battery factories (Järup *et al.*, 1998a). Workers exposed to high levels of cadmium may develop renal proximal tubular dysfunction, glomerular damage with progressive renal disease, and respiratory symptoms, including pneumonitis and emphysema, and acute respiratory distress syndromes (Barbee and Prince, 1999). In one estimate, workers with cumulative cadmium exposure equivalent to a blood concentration of 10 µg/L for 20 years would be expected to have a 14 percent incidence of renal dysfunction (Järup *et al.*, 1998a). Recent biological exposure index data from Japan show cadmium levels for workers exposed to cadmium at 5 µg/L in blood and 5 µg/g creatinine in urine (Japan's submission, 2007). Changes in blood and urine cadmium in workers accompanying the change in atmospheric cadmium concentration in cadmium pigment factories over a four year period are approximately as follows: ambient concentration (mg/m3) 0.62 to 0.16; blood cadmium (µg/100g) 2.15 to 1.56; and urinary cadmium (µg/g creatinine) 14.2 to 7.8 (Kawasaki *et al.*, 2004 in Japan's submission, 2007). To minimize risk exposure to Cd and its compounds at workplaces, the International Cadmium Association has submitted a guideline document entitled "Managing risks to workers exposed to chronic exposure to Cadmium and its compounds" that could be useful to workers directly exposed to these compounds (ICdA submission, 2006).

CHAPTER 4 - Impacts on the environment

56. Cadmium is a non-essential heavy metal. Some cadmium compounds are relatively water soluble, mobile in soil and bioavailable, depending on the water and soil chemistries. It tends to bioaccumulate in organs such as the kidney and liver of vertebrates, but aquatic invertebrates and algae can also build up relatively high concentrations.

57. The levels of cadmium in the environment have decreased markedly in the western world from the 1970's until today.

58. In terrestrial ecosystems, soil micro-organisms and plants are more sensitive to cadmium than soil invertebrates. Both invertebrates and plants can accumulate cadmium. Predators feeding on such soil invertebrates can introduce cadmium into the food chain, which suggests a risk of secondary poisoning through the food chain from worms to higher trophic levels (birds or mammals). The accumulation of cadmium by plants results in this contaminant entering the human food chain. In some European areas, the cadmium concentrations measured and estimated are exceeding the threshold concentration for adverse effects on terrestrial ecosystems. In the United Nations Economic Commission for Europe region, available information indicates that levels of cadmium in terrestrial wildlife are generally low and do not exceed thresholds for effects.

59. Effects on birds and mammals are mainly due to kidney damage (dysfunction), and in sea birds and marine mammals in particular, cadmium accumulates to relatively high levels. In the terrestrial environment, vascular plants and micro-organisms are more sensitive to cadmium than soil fauna. Inhibition of nitrogen-fixation in soil occurs at moderate cadmium pollution levels.

60. In the aquatic environment, cadmium toxicity varies considerably even between rather closely related species, but overall the sensitivity decreases in the following order: invertebrates > fish and amphibians > primary producers (such as algae). Generally, cadmium toxicity decreases with increasing water hardness. Reproduction processes and early life stages are the most sensitive.

61. Aquatic fresh and marine invertebrates are the organisms most sensitive to cadmium. The dissolved cadmium concentrations measured in some European waters (mainly rivers) are exceeding the threshold concentration producing adverse effects of cadmium in the aquatic ecosystem. Some studies suggest that levels in water, sediment and soil are at or above known biological effect levels. With regard to vertebrates, despite relatively high levels of cadmium in seabirds and marine mammals in Greenland, no evidence has been found of effects in ringed seals with very high cadmium levels in their kidneys. Arctic seabirds in general are known to accumulate high levels of cadmium found naturally in the marine environment and are therefore considered to be not as sensitive as terrestrial birds. Kidney damage has, however, been reported in wild colonies of Arctic pelagic seabirds having cadmium levels of 60-480 µg/g in the kidney. Spatial distribution of cadmium in marine biota appears to be driven by regional geology or geochemistry. Monitoring data on cadmium in the Arctic abiotic and biotic environment to date, however, provide no conclusive evidence of trends or effects.

CHAPTER 5 - Sources and releases to the environment

62. The important releases of cadmium to the biosphere may be grouped in the following categories:

- Natural sources - releases due to natural mobilisation of naturally occurring cadmium from 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 cadmium impurities in raw materials such as phosphate minerals, fossil fuels and other extracted, treated and recycled materials - particularly zinc and copper;
- Current anthropogenic releases resulting from cadmium used intentionally in products and processes, due to releases by manufacturing, use, disposal, recycling, reclamation or incineration of products;

63. In addition to these categories, may be considered the remobilisation of historic anthropogenic cadmium releases previously deposited in soils, sediments, landfills and waste/tailings piles.

64. The recipients of cadmium releases to the environment include: the atmosphere, aquatic environments (fresh and salt water environments) and terrestrial environment (soil and biota). Within the environment, cadmium will flux between these compartments. Cadmium released to the atmosphere will be redirected to the terrestrial and aquatic environments as atmospheric deposition, whereas some cadmium released to soil over time will be washed out to the aquatic environments. It is also important to assess the bioavailability of cadmium in soils or sediments. For example, complexed to organic substances or bound to sulphides, cadmium may not be bioavailable. Other parameters like high pH soil values will also render cadmium less bioavailable as reported in chapter 2.

65. Cadmium is persistent – it cannot be broken down into less toxic substances in the environment. The only long-term sinks for removal of cadmium from the biosphere are deep-sea sediments and, to a certain extent, controlled landfills, in cases where the cadmium is physico-chemically immobilised and remains undisturbed by anthropogenic or natural activity (climatic and geological). This also implies that even as the anthropogenic releases of cadmium are gradually eliminated, decreases in some cadmium concentrations – and related environmental improvements – will occur more slowly, most

likely over several decades or longer. However, improvements may occur more quickly in specific locations or regions that are highly impacted by local or regional sources.

Sources of cadmium emission to the atmosphere

66. The major natural sources for mobilisation of cadmium from the Earth's lithosphere to the biosphere are volcanoes and weathering of rocks. In addition, insignificant amounts of cadmium enter the biosphere as meteorite dust. The atmospheric emission from volcanoes in 1983 is estimated at 140-1,500 tonnes, and in a more recent study from 2001 at 380-3,800 tonnes.

67. Within the biosphere, cadmium is translocated by different processes. The major natural sources for emission to air are volcanoes, airborne soil particles, sea spray, biogenic material and forest fires. Very different estimates of total releases of cadmium to the atmosphere by natural processes have been reported. A frequently cited study from 1989 estimates the total emission in 1983 at 150-2,600 tonnes/year, whereas a new study estimates the total emissions from natural sources to be 15,000 - 88,000 tonnes/year. The large difference is mainly due to different estimates of the amount of cadmium released to air with soil particles.

68. Compared to the figures for natural sources, the most recent study of total global anthropogenic atmospheric emissions estimated the total emissions in the mid-1990's at 2,983 tonnes. Newer estimates of the total global atmospheric released have not been available, but in the industrialised countries the emissions have been decreasing since that time.

69. The trend in the industrialised countries is illustrated in Figure 1 showing the decrease in total cadmium atmospheric emission in Europe from 1990 to 2003 [1]. During that period the emissions approximately halved.

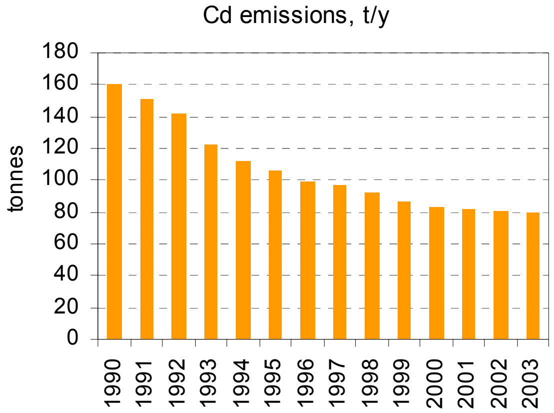

Figure 1

Trends in atmospheric emission of cadmium in Europe (24 countries within the EMEP area) (tonnes/year) 1990- 2003 (UNECE, 2006a)

70. The principal anthropogenic sources of cadmium to air are non-ferrous metal production, probably manufacturing of base metals such as zinc and lead, followed by fossil fuel combustion. Waste incineration seems, on a global scale, to be a smaller source. Waste incineration is mainly applied in densely populated areas of industrialised countries and usually subject to effective emission control.

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[1] Similar decreases occurred in North America. For example, in Canada the cadmium emissions in 2003 were about one third of the 1990 level, and in the United States cadmium emissions decreased by an estimated 55 percent between 1990 to 2002 (Data from U.S. EPA, 2008)."

Some additional examples could also be found through the following authors: Elgersma 1992, Cook and Morrow 1995, Mukunoki and Fujimoto 1996, and Van Assche and Ciarletta 1992. Some of these studies have shown cadmium air emission decreases as high as 98 percent, again depending upon the time period involved, region, or data basis (measurement vs. model).

However, it must be noted that emission estimates in general do not include releases from uncontrolled burning of waste on dumpsites or other locations (such as barrels in the backyard of rural homes), a frequent practice in countries or regions with less developed waste disposal systems.

The total reported emission and distribution by sources varies considerably among countries, as illustrated in Figure 2 by data for Europe (2000) and Australia (2003/4). Detailed emission inventories have not been available from developing countries for this review.

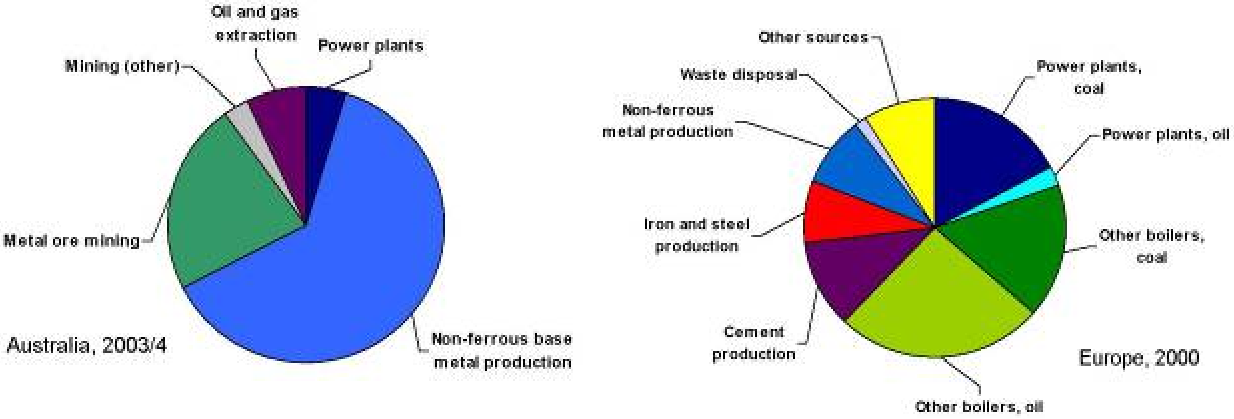

Figure 2 Distribution of reported atmospheric cadmium emission in Australia 2003/4 (Australia's submission, 2005) and in Europe 2000 (Data for Europe based on expert estimates from Norwegian Institute for Air Research, NILU (ESPREME, 2006)).

71. The global significance of anthropogenic versus natural emissions is indicated by ice core records from the Greenland ice sheet. Cadmium deposition in the 1960’s and 1970’s was eight times higher than in pre-industrial times. However, data indicate that cadmium deposition levels have steady declined since the 1970’s. Nonetheless, these data indicate that industrial emissions have been more important as a source of cadmium deposition in Greenland - and perhaps also other arctic areas - than natural emissions. Also, whereas releases of cadmium to the atmosphere by natural processes seem to exceed anthropogenic releases, differences in particle size may make natural releases less significant in terms of long-range transport of cadmium.

Sources of cadmium releases to land

72. Human activities significantly influence the global cycle of cadmium. In 2004, an estimated 18,800 tonnes of cadmium were extracted by humans from the Earth's crust and brought into circulation in the society. Besides this, a significant amount of cadmium ended up in metal extraction residues or was mobilised as an impurity during the extraction and use of other minerals like coal and lime.

73. The only comprehensive assessment of the global anthropogenic cadmium releases to soil and waste deposits dates back to 1983. It was estimated that in total 7,800-36,600 tonnes cadmium were directed to waste deposits or released to soil at that time. In addition 2,200-8,400 tonnes of cadmium were estimated to be deposited to lands throughout the world through atmospheric deposition of emissions originating from anthropogenic and natural sources. Major categories were: residues from coal combustion, urban refuse, mine tailings and smelter slag and waste.

74. The single major source of cadmium directed to landfills with municipal solid waste is nickel-cadmium batteries (NiCd batteries). The long-term fate of the cadmium accumulating in the landfills is uncertain, and may represent a future source of cadmium releases to the environment. Note that a full targeted risk assessment of NiCd batteries including the reviewing of the environmental impact of the full life cycle of NiCd batteries is reported in the final EU risk assessment on Cd and its compounds (EU, 2007).

75. If not managed in an environmentally sound manner, some of the cadmium ending up in tailings and other residues from mining and base metal production could be releases to water resources and soils.

Cadmium balances in agricultural soils

76. Of particular concern have been the input of cadmium to farmland by atmospheric deposition and the application of phosphate fertilizers and sewage sludge. The significance of cadmium accumulation in agricultural topsoil has been demonstrated in several European countries. In a number of European countries, the presence of cadmium in fertilizers and atmospheric deposition was causing the content of cadmium in topsoil to increase. The increase in soil cadmium concentration in Austria, Denmark, Finland, Greece, Ireland and the United Kingdom over the period of 100 years was estimated at the current fertilizer cadmium concentrations to increase by 7 to 43 percent, varying among the countries.

77. Atmospheric deposition has been decreasing as a result of decreased emissions, but atmospheric deposition was in the late 1990's still the major source of cadmium input to agricultural soils in many of the European countries for which cadmium balances for agricultural soils have been reported. As cadmium is taken up by plants, increased soil concentration results in an increased cadmium concentration in food products. In response to the recognition of this problem, many countries have introduced limit values for cadmium concentration in phosphate fertilizers.

Sources of cadmium releases to aquatic environments

78. The weathering of rocks releases cadmium to soils and aquatic systems and plays a significant role in the global cadmium cycle. Weathering and erosion result in the transport by rivers of large quantities of cadmium to the world's oceans. An annual gross input of 15,000 tonnes cadmium has been estimated.

79. New estimates on the total global releases of cadmium to the aquatic environment have not been available. In 1983, the total anthropogenic releases to aquatic environments were estimated at 1,200-13,400 tonnes. The main sources of these reported cadmium releases were non-ferrous smelting and refining, manufacturing of metals and chemicals, and domestic wastewater. As a consequence of improved waste water treatment, the releases in industrialised countries are expected to be significantly lower today. In addition, 900-3,600 tonnes of cadmium were estimated to be deposited to aquatic environments throughout the world trough atmospheric deposition of cadmium emitted from anthropogenic and natural sources.

CHAPTER 6 - Production, use and trade patterns

80. Cadmium is produced mainly as a by-product from mining, smelting and refining of zinc, and to a lesser degree as a by-product of lead and copper production. Cadmium minerals do not occur in concentrations and quantities sufficient to justify mining them in their own right. As it is a by-product of zinc mining, the production of cadmium is more dependent on zinc-refining volumes than on market demand.

81. Cadmium is refined in a number of countries as illustrated in Figure 3.

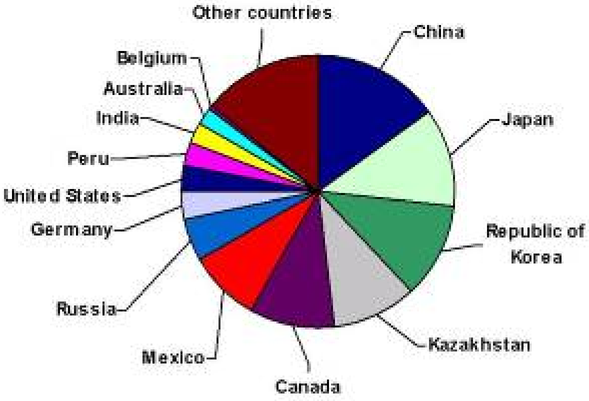

Figure 3
Global refinery production by country in 2004 (U.S.GS, 2006)

82. Global cadmium production increased during the period from 1970 to 2004 from about 17,000 tonnes to about 22,000 tonnes. Over the last 15 years, global consumption has remained constant, at around 20,000 tonnes.

83. Major changes have taken place with regard to the geographical distribution of cadmium production from mining sources. In 1997, the production in Europe, the Americas and Asia was about the same size. As can be seen in Figure 4, since 1997 production in Asia has increased sharply, whereas the production in Europe has decreased correspondingly. In 2004, the production in Asia was about 5 times the production in Europe.

84. It is estimated that recycled cadmium today accounts for 3,500 tonnes, corresponding to about 18 percent of the total global supply[2]. Countries with significant recycling production include the United States, Sweden, France, Germany and Japan.

85. Cadmium is used and traded internationally as a metal and as a chemical compound in many different types of products. Cadmium is, furthermore, mobilised as a natural contaminant in other materials, e.g. in fossil fuels and phosphate fertilizers. Cadmium may also be present as a trace pollutant in recycled materials such as recycled plastics containing cadmium pigments.

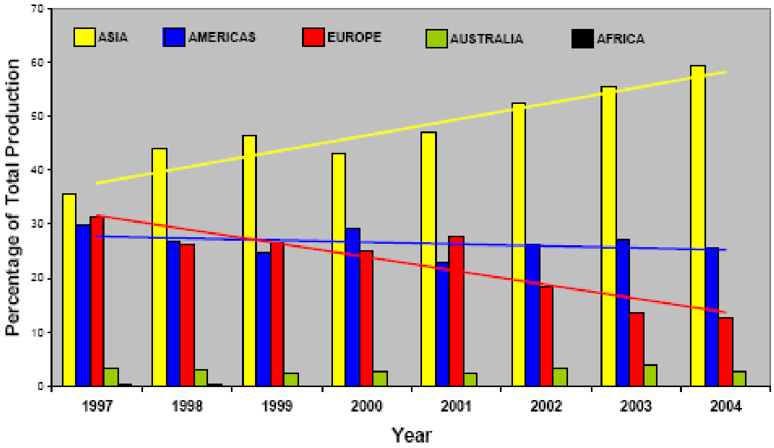

Figure 4

Trends in primary cadmium metal production (original figure submitted by International Cadmium Association, ICdA)

86. An increasing part of the global cadmium consumption is used for nickel-cadmium (NiCd) batteries, which in 2005 accounted for 82 percent of the total cadmium consumption, as can be seen from Figure 5 [3]. Other major uses are: pigments for plastics, ceramics, and enamels; stabilisers for plastics, in particular polyvinyl chloride (PVC); plating on iron and steel; and as an alloying element of some lead, copper and tin alloys. Since 1990, the cadmium consumption for pigments, stabilisers, alloys and other uses has decreased significantly.

87. Many products in which cadmium is used intentionally are traded globally. This is the case in particular for its dominant use - NiCd batteries - but also for many applications in alloys, plastics, plating and in electronic and electrical equipment. In this context, a consequence of international trade is that products containing cadmium will be spread to consumers in countries worldwide.

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[2] According to the International Cadmium Association, ICdA, the current (2007) estimate of secondary or recycled cadmium is about 5,500 mt or about 25 percent of the total global supply.

[3] According to the International Cadmium Association, ICdA, In 2007, the estimated cadmium usage in NiCd batteries was 83 percent of total cadmium consumption.

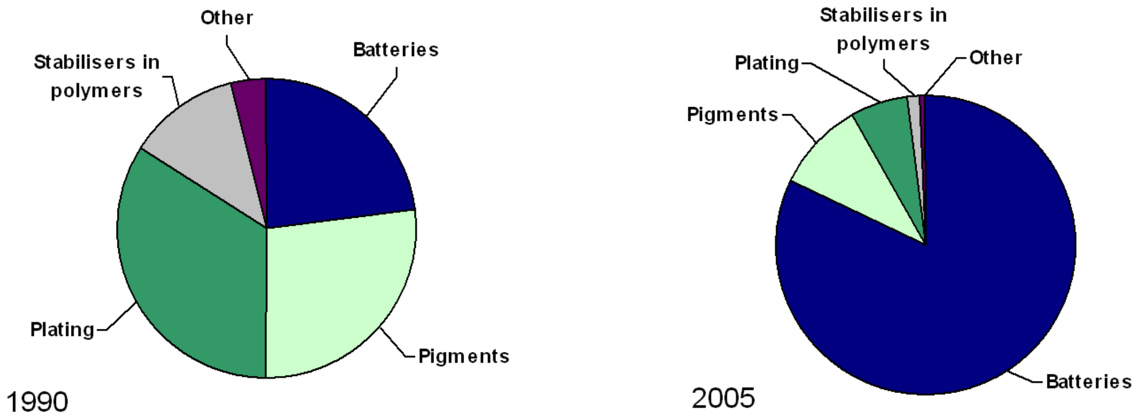


Figure 5 *Consumption of primary cadmium by end-uses in 1990 and 2005 (data compiled by ICdA, 2005)*

CHAPTER 7 - Long-range transport in the environment

88. 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 cadmium beyond the local scale.

89. Long-range transport in the environment here refers to transport in air or water of substances (e.g. cadmium) 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 cadmium

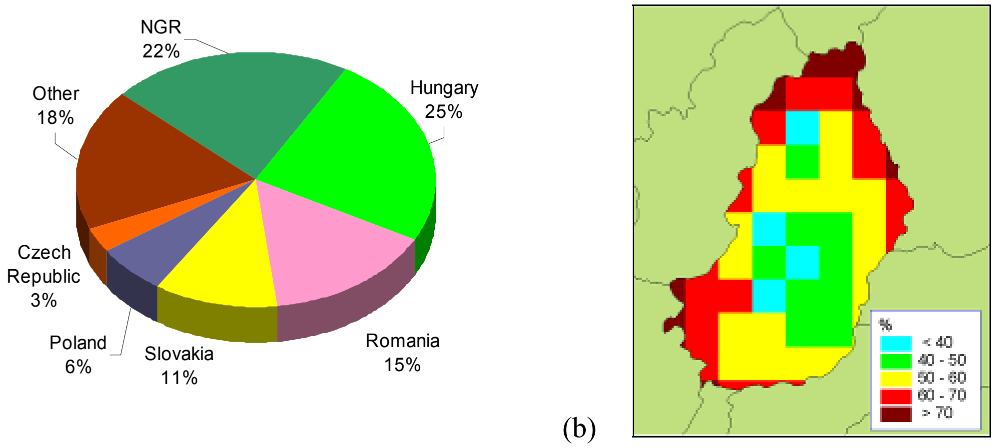
90. Atmospheric transport is currently considered the most important mechanism of long-range cadmium dispersion in the environment. It is mainly emitted to the atmosphere in particle form. The atmospheric transport of cadmium is governed by aerosol (particle) transport mechanisms. Once emitted to the atmosphere, cadmium may be transported locally, regionally, or intercontinentally depending on various factors, including particle size, stack height, 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. However, under certain conditions, cadmium can be transported by airflows over hundreds or even thousands of kilometres and contribute to the impact on human health and ecosystems far away from the emission source.

91. Various human activities (such as mining, metal production, combustion of fossil fuels, and other industrial processes) have resulted in elevated cadmium concentrations in the environment. Measurements of cadmium concentration in ice cores, freshwater sediments and peat bogs demonstrate an essential increase of airborne cadmium depositions compared to the pre-industrial period. Cadmium mass concentrations measured in atmospheric aerosols in various locations were much higher (up to 1,000 times) than its natural content in the Earth crust due to cadmium anthropogenic emissions to the atmosphere. This kind of enrichment was observed even in such remote locations as Greenland, the Bolivian Andes, New Zealand and Antarctica.

Regional scale atmospheric transboundary transport

92. Emitted cadmium is primarily transported atmospherically over local, national or regional distances; that is, within the region or continent where the cadmium was originally emitted. Figure 6 illustrates an example of the assessment of transboundary cadmium transport in one of the European countries – Hungary. As shown in figure 6, an estimated 25 percent of the cadmium deposition in Hungary

comes from anthropogenic emissions sources within Hungary, about 53 percent of total cadmium depositions to this country are defined by the atmospheric transport from anthropogenic sources located in other nearby countries (such as Romania, Slovakia, Poland and Czech Republic) and 22 percent from a combination of natural sources, re-emission of former anthropogenic releases and global sources. In regions close to national borders, the contribution from sources outside the country can exceed 70 percent, whereas in the central part of the country it can be less than 40 percent.



(a) (b)

Figure 6 *Main contributors to deposition of cadmium in Hungary (a) (NGR - natural, global sources and re-emission). Spatial distribution of external anthropogenic sources of cadmium depositions in Hungary (b) (calculated with the MSCE-HM model, Ilyin et al., 2005).*

Intercontinental atmospheric transport

93. Specific evidence of cadmium intercontinental transport is very scarce. Due to the relatively short residence time of cadmium in the atmosphere (days or weeks), the airborne dispersion of cadmium has a pronounced local or regional character. However, data from ice core measurements in Greenland indicate that cadmium can be transported over distances of up to thousands of kilometres. Analysis of cadmium in aerosols in a few regions also illustrates long-range transport. Some small portion of anthropogenic cadmium from North America has been noted in the Russian Arctic. Further, aerosol measurements in Taiwan show that a portion of airborne cadmium can be transported over a thousand kilometres from developing areas of China.

94. Besides, some indication of cadmium potential to intercontinental transport can be 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 provide evidence that aerosols are transported intercontinentally, as well as from industrialised regions to remote regions with few local emission sources such as the Arctic. As cadmium is transported in the atmosphere adhered to aerosol particles, these studies indicate that cadmium has a potential to be transported intercontinentally.

95. Due to lack of hemispherical or global emission datasets, intercontinental cadmium transport has not been assessed in transport models so far. However, cadmium transport in the atmosphere is governed by the same transport principles as other particle-bound heavy metals, such as lead. Indeed, atmospheric transport characteristics of cadmium and lead are completely defined by properties of their carrier particles. According to available measurements, aerosol particles containing cadmium and lead are characterized in the ambient air by similar particle size distributions. This fact indicates that these two substances have similar removal properties (such as scavenging and dry deposition efficiency) defining their residence time in the atmosphere and dispersion distance. Therefore, some features of lead long-range transport described in the companion review report on lead can serve as a qualitative indication of the potential for very long distance atmospheric transport of cadmium.

96. Particularly, following the analogy with lead, cadmium is expected to be mainly transported over local or regional distances due to the relatively short residence time in the atmosphere. Intercontinental transport can make only minor contributions to regional environmental levels of cadmium in industrially developed regions on a long-term basis. Episodically, the contribution of intercontinental transport can be significantly higher at certain locations. However, theoretical assumptions on cadmium intercontinental transport mentioned above could be confirmed with direct modelling and additional measurements. Therefore further investigation may be warranted, particularly, for aggregation of a global set of emission data and development or application of existing models for assessment of intercontinental transport of cadmium.

Main principles of cadmium atmospheric transport

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

- Characteristics of emission sources (higher outlets and higher emission temperatures imply higher emission plumes and longer transport ranges);
- Physical and chemical forms of cadmium in the atmosphere:
  - Cadmium is emitted to the atmosphere primarily as a component of aerosol particles of various sizes; large particles deposit within short ranges, small particles may be transported over thousands of kilometres;
  - Wet deposition of cadmium-containing particles depends also 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 with diffusion;
- Atmospheric stability: Stable conditions keep pollution near the ground, resulting in short transport ranges and low dispersion; unstable conditions permit the pollution plume to rise to altitudes with stronger winds, which in turn transport pollution over longer distances;
- Wind speed: High 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 covered with vegetation (forest, shrubs etc.) and urban areas; the lowest dry depositions occur over smooth terrain (desert, snow cover) and water bodies.
- The physical resuspension of soil and marine aerosols is another factor that should be considered. These processes constitute a mechanism for the mobilization of non-volatile pollutants like cadmium from the surface of the earth either from naturally occurring sources or from anthropogenic activities like mining (Qureshi *et al.*, 2009).

Atmospheric transport models

98. Atmospheric transport models can add to the description and prediction of cadmium pollution provided by actual measurements of cadmium concentration in ambient air and precipitation. Notably, transport models can help explain the origins and pathways of transboundary atmospheric cadmium dispersion. A number of atmospheric transport models for atmospheric transport of heavy metals cover Europe and North America. No models covering other regions of the world have been identified.

99. Atmospheric transport models are routinely evaluated against 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 with available measured values. The ability of different models to predict actual situations is summarised in these studies. The assessed models tended to under-predict estimated air concentrations and deposition of cadmium compared to actual measurements. For one model, a satisfactory prediction was obtained using independent expert

estimates for emissions input data instead of reported emission estimates. The uncertainty of reported emission estimates, and lack of inclusion of natural emissions and re-emission of former cadmium depositions in the model inputs, are possible causes for the under-predictions.

Monitoring of air concentrations and atmospheric deposition

100. Most of the identified monitoring measurements for atmospheric cadmium concentrations and deposition come from Europe and the U.S.A.; results from Japan, China, Antarctica and New Zealand are, however, also available.

101. As an example, from the early 1990's to 2003, the country-averaged concentrations of cadmium in air approximately halved in central and north-western Europe. Moreover, measured concentrations in precipitation in central and north-western Europe decreased to between a fourth and a third of 1990 levels. On the other hand, in the northern part of Europe, changes in concentrations in air and precipitation are not evident during this time period (from 1990 to 2003)

Aquatic transport of cadmium

102. Quite extensive data sets of cadmium 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 have been identified of modelling or other quantifying of the general horizontal transport of cadmium - or any other heavy metals - with ocean currents. Only two examples of quantification of the exchange of heavy metals (lead and cadmium) with ocean currents between one specific ocean, the Arctic Ocean, and neighbouring oceans have been identified. These examples suggest that ocean transport may be an important pathway.

103. Also, the nature of ocean currents indicates their potential for global-scale transport of pollutants. 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, POPs) demonstrates that ocean modelling for heavy metals may be relevant.

104. Cadmium's behaviour in ocean waters is affected by its biological role in off-shore waters poor in nutrient and essential elements (the only known biological role of cadmium). This is because cadmium substitutes for zinc in some vital enzyme reactions in phytoplankton in situations where zinc is scarce in the biotope. By degradation of organic material and grazing by zoo-plankton, cadmium is partly recycled internally in the upper bio-zone, and partly sedimented with zoo-plankton faeces to sub-surface water layers, where some of the cadmium is re-dissolved through bacterial processes and re-distributed to the upper, biologically active water layers.

105. Metals like cadmium (with so-called nutrient-type distributions) exhibit a relatively low level of scavenging (flux out of water column due to sedimentation) in the deep sea, and thus their concentrations would tend to increase along the flow path of water in the world's oceans as the water ages. The oceanic residence time of nutrient-type metals like cadmium are characterised as intermediate; for cadmium it is estimated at about 15,000 years, which is considerably longer than the overall mixing time of deep-sea ocean waters. This could indicate that cadmium may perhaps be accumulated and transported in much larger amounts over long distances in the ocean than for example scavenge-type metals like lead. The oceanic reservoir of cadmium is believed to be large compared to current anthropogenic contributions of cadmium to surface waters.

106. Rivers are important transport media for cadmium and other heavy metals on a national and regional scale. For 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. Some large transboundary lakes may as well be important transport media for cadmium on a national and regional scale.

CHAPTER 8 - Prevention and control technologies and practices

107. 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 cadmium, including the use of suitable substitutes, where applicable.

108. Releases due to natural mobilisation of cadmium and remobilisation of anthropogenic cadmium previously deposited in soils, sediments and water bodies are not well understood and are largely beyond human control. Therefore, these are not addressed here.

109. Reducing or eliminating anthropogenic cadmium releases may require:

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

110. The specific methods for controlling cadmium releases from these sources fall generally under the following four groups described below:

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

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

111. Reducing the consumption of raw materials and products that include cadmium as an impurity is a potential preventive measure for reducing cadmium releases. This group of measures could potentially include the choice of an alternative raw material such as using natural gas for power generation instead of coal, but the reduction of cadmium emissions would most probably not be the main driver for such a shift.

112. As regards cadmium in fertilizers, the releases to the agricultural soils may be reduced by the use of phosphate rock naturally low in cadmium or to remove the cadmium in the manufacturing of phosphate fertilizers.

Substitution of products and processes containing or using cadmium

113. Substitution of products and processes containing cadmium with cadmium-free products and processes is a preventive measure which may influence the entire flow of cadmium through the economy and environment. It may substantially reduce cadmium in households, releases to the environment, the waste stream, incinerator emissions and landfills. However, it should be noted that cadmium is today extracted as a by-product to zinc production and the cadmium would be extracted from the ores or disposed with extraction residues regardless of whether cadmium would be used in products or not.

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

115. Major applications, for which alternatives have been introduced and are applied in some countries, include (with examples of alternatives in parentheses):

- NiCd batteries (nickel-metal hydride, lithium-ion-polymer, etc.);
- Plating (zinc, aluminium, tin, nickel, silver, gold plating, etc. depending on application);
- Silver-cadmium alloys for solders (several alternative solders exist, including Sn-Ag solders);
- Other alloys (many alternatives, depending on application);
- Thermal elements/low melting alloys (e.g. InSb and BiSn alloys; substitutes may not be available for all purposes);
- PVC stabilisers (alternatives for indoor purposes, calcium/zinc compounds; for outdoor purposes, stabilisers based on lead compounds or organic tin compounds);
- Pigments (many alternatives - bismuth vanadate and tin-zinc-titanate for demanding applications).

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

116. Controlling cadmium emissions through end-of-pipe techniques, such as exhaust gas filtering, may be especially appropriate to raw materials with trace cadmium content, including fossil-fuelled power plants, cement production, the extraction and processing of primary raw materials such as zinc and other non-ferrous metals and the processing of secondary raw materials such as iron and steel scrap. Existing control technologies that reduce SO_2, NO_x and particulate matter (PM) for coal-fired boilers, incinerators and other facilities also yield a high level of cadmium control due to particle retention. However, end-of-pipe control technologies, while mitigating the problem of atmospheric cadmium pollution, still result in cadmium-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 cadmium from these residues.

117. 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, the significance of fugitive emissions in many processes is very high, and fugitive emissions can be much greater than those that are captured and abated. 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 emissions, which is a very energy-consuming option.

118. The applied dust emission control systems are generally the same applied 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 cadmium
Municipal, medical and hazardous waste incineration	High-efficiency scrubbers	> 98%
	Electrostatic precipitator (3 fields)	80-90%
	Wet electrostatic precipitator (1 field)	95-99%
	Fabric filters	95-99%

Cadmium waste management

119. Cadmium wastes, including residues generated by end-of-pipe technologies, constitute a special category of cadmium releases, with the potential of affecting future populations. Most countries accept disposal of cadmium-containing products to ordinary landfills, except for a few product categories, e.g. nickel-cadmium (NiCd) batteries. Therefore those products containing cadmium that are not collected separately from the general waste stream, cadmium will end up in the municipal solid waste stream,

typically disposed of to landfills or by incineration. Some of the cadmium in these products may be released to the environment, the extent of which depends on the disposal method, control technologies applied and other factors. Collection and recycling of cadmium are possible and undertaken for some end-uses, primarily NiCd batteries, alloys and plating. As separate collection rates may be moderate even in countries with dedicated collection, in the global context significant quantities of cadmium may be disposed of with municipal solid waste. As metionned earlier, the environmental impact of the full life cycle of NiCd batteries is reported in the final EU risk assessment report on Cd and its compounds (EU, 2007).

120. A number of options exist for the treatment and disposal of solid wastes depending on the waste types in question and the characteristics of the waste. The dominant waste management practices relevant to cadmium-containing wastes include recycling, incineration, biological treatment, dumping/landfilling and waste water treatment. The overall input of heavy metals to waste streams in the society is indicated in Figure 7 below. It should be noted that in practice, each step on the figure may consist of several steps, and that steps related to the treatment of wastewater, for instance, are not indicated in the figure.

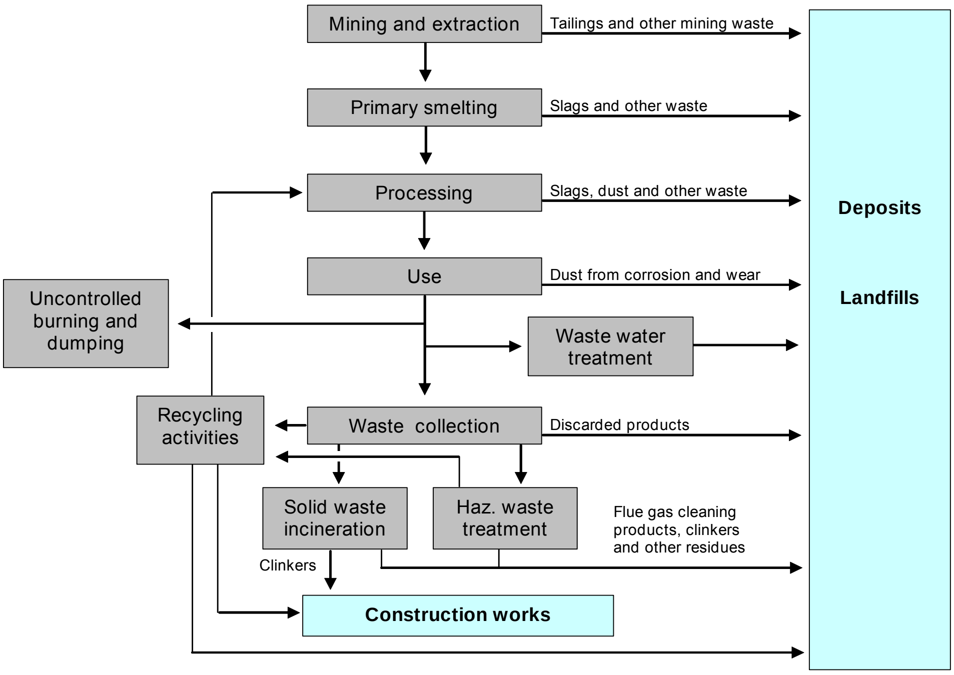


Figure 7 Schematic illustration of the overall flow of heavy metals to waste

121. **Separate collection and recycling -** NiCd batteries, accounting for the major part of the cadmium consumption, are in many countries separately collected for recycling. For the small batteries, which are easily disposed of with the general waste stream, experience shows that it is difficult to obtain higher collection rates than about 50 percent; the remaining part ends up in municipal solid waste or directly in the environment.

122. **Landfilling** is a waste management option that may 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. The main concern is that landfills can be considered a potential long-term source of releases of cadmium and other hazardous substances to the environment. Over time, landfills may 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.

123. **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 cadmium to air from modern incineration plants is usually around 1 percent of the cadmium in the waste. Cadmium is first collected with air cleaning residues and a small part ending in the clinker (bottom ash) which must be managed carefully to avoid future releases.

124. **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. Cadmium present in the waste (e.g. in pigment and stabilisers in plastics) is expected to a large extent to be released to the atmosphere by uncontrolled burning of waste, primarily attached to particle matter.

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

National initiatives

125. A number of countries have implemented national initiatives and actions, including legislation, to manage and control releases and limit use and exposure of cadmium within their territories.

126. The overall aims of existing initiatives on cadmium are to reduce or prevent the release of cadmium to the environment, and 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:

- Environmental quality standards, specifying maximum acceptable cadmium concentrations for different media such as drinking water, surface waters, air, soil, and for foodstuffs and feed;
- Environmental source actions and regulations that control cadmium 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;
- Product control actions and regulations for cadmium-containing products, such as phosphate fertilizers, pesticides, cosmetics, pigments and stabilizers in plastics, plating, vehicles, electrical and electronic equipment, etc.;
- Other standards, actions and programmes, such as regulations or guidance on exposures to cadmium in the workplace, requirements for information and reporting on use and releases of cadmium in industry, and consumer safety measures.

127. Table 2 gives an overview of types of implemented measures of importance to the management and control of cadmium, 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 cadmium products and processes from which cadmium is emitted.

Table 2 Overview of implemented measures of importance to cadmium, 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 cadmium from raw materials		
POINT SOURCES	Apply emission-control technologies to limit emissions of particulate matter (PM) and adhered pollutants (including cadmium) from combustion of fossil fuels and processing of mineral materials	Implemented in most countries
	Prevent or limit the release of heavy metals (including cadmium) from industrial processes to the wastewater treatment system	Implemented in many countries
	Require use of best available technology to reduce or prevent cadmium releases	Implemented in some countries, especially OECD countries
PRODUCTS	Prevent or limit products containing cadmium from being marketed nationally	General bans implemented in a few countries only. Bans or limits on specific products are more widespread, such as some types of pigments or cadmium plating
	Limit the allowable content of cadmium present as impurities in high-volume materials - for example phosphate fertilizers	Implemented in many countries - in particular OECD countries
	Limit the allowed contents of cadmium in commercial foodstuffs and feed.	Implemented in some countries, especially OECD countries. WHO guidelines used by some countries.
Disposal phase of life cycle		
Prevent cadmium in products and process waste from being released directly to the environment, by efficient waste collection		Implemented in many countries, especially OECD countries
Prevent cadmium 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, especially OECD countries
Prevent or limit cadmium releases to the environment from treatment of household waste, hazardous waste and medical waste by emission control technologies		Implemented or implementation ongoing in many countries.
Set limit values for allowable cadmium content in sewage sludge and other organic waste products used for land application		Implemented in many countries
Set limit values concerning cadmium regarding the use of solid incineration residues in road-building, construction and other applications		Implemented in a few OECD countries

International conventions and treaties

128. A number of international agreements have been established that enhance management and control of releases of cadmium to the environment and limit human and environmental exposure to cadmium. An overview of such international initiatives identified in this project and their main characteristics is given in Table 3. The individual agreement's relevance to cadmium are summarised in the review and more information can be found in the indicated sections. It should be noted that cadmium and cadmium compounds are not covered by the Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade.

Table 3 Overview of international agreements containing provisions relating to cadmium

Section	International agreement or instrument	Geographic coverage	Relevance to cadmium	Types of measures addressing cadmium
9.2.1	LRTAP Convention and its 1998 Aarhus Protocol on Heavy Metals	Europe, Canada, the United States of America , and Commonwealth of Independent States	Addresses cadmium and cadmium 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 cadmium and cadmium 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 of the Baltic Sea and catchment areas to these waters)	Addresses cadmium and cadmium compounds in releases, products, wastes, etc.	Goal definition, binding commitments on release reductions, recommendations, monitoring, information
9.2.4	The Convention on Cooperation for the Protection and Sustainable Use of the River Danube	Danube river basin	Addresses cadmium and cadmium 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 having cadmium as constituents or contaminants, excluding metal waste in massive form. Cadmium and its compounds are considered a hazardous waste and covered by specific provisions	Binding commitments regarding international transport of hazardous waste, procedure for information and approvals on import/export of hazardous waste

International organizations and programmes

129. A number of international organizations and programmes also have activities aimed at addressing the adverse impacts of cadmium 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 cadmium 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 the adverse impacts of cadmium on health and the environment

Section	International organization or programme	Geographic coverage	Organization or programme's relevance to cadmium	Types of activities addressing cadmium
9.3.1	International Agency for Research on Cancer (IARC)	Global	Addresses the evaluation of carcinogenic risk of chemicals, including cadmium, to humans	Evaluations on individual chemicals, information, guidelines
9.3.2	International Labour Organization (ILO)	Global	Addresses occupational health and safety issues linked with use of chemicals, including cadmium	Information, guidelines, capacity building
9.3.3	International Programme on Chemical Safety (IPCS)	Global	Addresses health and environmental aspects of heavy metals (including cadmium)	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 cadmium)	Information, guidelines, capacity building
9.3.5	Organization of Economic Cooperation and Development (OECD)	OECD member States	Addresses cadmium and cadmium 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 GPA	Global	Addresses heavy metals, including cadmium	Goal definition, guidelines
9.3.7	United Nations Industrial Development Organization (UNIDO)	Global	Addresses environmentally sustainable industrial activities,	Information, guidelines, capacity building
9.3.8	World Bank (WB)	Global	Addresses environmentally sustainable industrial activities	Information, capacity building, assistance

Sub-regional and regional initiatives

130. Finally, a number of governments have found it beneficial to cooperate across national borders in order to address the adverse impacts of cadmium 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 cadmium is given in Table 5. The individual initiative's specific relevance to cadmium are summarised in the review and more information can be found in the indicated sections. A number of initiatives that indirectly have relevance to cadmium may exist besides those listed in the table.

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

Section	**Sub-regional or regional initiative**	**Geographic coverage**	**Initiative's relevance to cadmium**	**Types of measures addressing cadmium set out in the initiative**
9.4.1	Arctic Council	Arctic region (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States of America)	Addresses heavy metals, including cadmium	Information, monitoring
9.4.2	Great Lakes Binational Toxics Strategy	Canada and the U.S.A	Addresses Cadmium and Cadmium compounds as Level II substances	For Level II substances, governments encourage stakeholders to undertake pollution prevention activities to reduce levels in the environment of those substances nominated jointly by both countries, and to conform to the laws and policies of each country, including pollution prevention, with respect to those substances nominated by only one country.
9.4.3	North Sea Conferences	North Sea (Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden, Switzerland, United Kingdom and European Commission)	Addresses heavy metals, including cadmium	Goal definition, information
9.4.4	South Asia Co-operative Environment Programme	South Asia (Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka)	Addresses trans-boundary air pollution	Goal definition, information, capacity building
9.4.5	International commissions for the protection of rivers	Different river basins e.g. the Elbe river and the Oder river basins	Addresses trans-boundary water pollution	Goal definition, information

CHAPTER 10 - Data and information gaps

National research and information gaps

131. A number of countries have in their submissions expressed the need for creating or improving their national data base on various aspects of cadmium 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 are summarised below:

- Development of exposure assessments, substance flow assessments (import, export, consumption etc.), and release inventories, especially for developing countries;
- Technical and financial assistance for - and implementation of - strategies for development of legislation, capacity building activities, awareness raising workshops, performing pilot projects 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.;
- Improvement of the information on the level of contamination of drinking water by cadmium as a result of leaching from landfills, especially in developing countries is needed.

Data gaps of a general, global character

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

- Updated global release inventories for cadmium for both natural and anthropogenic sources;
- More data on releases to the environment in developing countries are especially needed;
- Currently only regional atmospheric transport of cadmium is included in existing atmospheric transport models. Usable hemispheric models exist, but cadmium cannot be included in the models because adequate emission data are missing. Cadmium needs to be included in the models covering the Northern hemisphere based on suitable emission data. Also, there is a need to develop atmospheric transport models for the Southern hemisphere;
- Ocean transport of cadmium in general, and the significance of anthropogenic releases as source of cadmium subject to ocean transport, is poorly understood and seems to warrant more investigation as a means of long range environmental transport;
- More information on transport by rivers to marine environments on a global scale is needed;
- The release inventory database needs to be improved in the developed regions: Emission factors, contributions of natural sources and re-suspension of historical depositions, improved data quality of release inventories;
- Information to improve understanding of the inconsistencies between reported emissions and observed cadmium concentration and depositions is needed;
- Guidelines for monitoring activities (air, soil, precipitation, human blood etc.) are needed;
- The sources of cadmium to the waste are not well investigated (except for some data on NiCd batteries), and could warrant further investigation, especially in the developing regions;

- The toxicity of cadmium is well documented, but certain aspects of cadmium toxicity and exposure still need to be investigated: The possible effect of low doses of cadmium-oxide (CdO) on neurobehavioral performances, dermal exposure to cadmium metal from jewellery, the extent of risks to humans from exposure from cadmium in the global perspective;
- Monitoring and assessment of cadmium 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 cadmium is needed;
- Data regarding accidental spills from mine tailings on a global scale and the real extent of these events, especially in developing countries, are needed;
- Examination of the global flow of cadmium in products is needed.

1 Introduction

1.1 Background and mandate

133. 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.

134. 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..

135. 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[4] .

136. 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 Cadmium13 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"*

137. 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.

1.2 Process for developing the review

138. 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 cadmium.

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[4] 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 complete 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

139. The process initially involved, in May 2005 the establishment of a Working Group involving nomination of members by Governments, intergovernmental and non-governmental organizations as well as a call to these groups to submit information. 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. 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 cadmium 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 organisations.

140. 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.

141. 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.

142. 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.

143. A more detailed compilation of national initiatives, including legislation, in each individual country is contained in an Appendix to this review, entitled “Overview of existing and future national actions, including legislation, relevant to cadmium”. 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.

144. 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.

145. Because of the large volume of reports, articles, abstracts, etc. relating to cadmium 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 cadmium, especially from non-OECD countries, and information that might add to the general knowledge of the various issues linked to cadmium, based on the recently published authoritative reviews on such issues.

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

147. 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 cadmium –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 cadmium, which were presented for the information of the Governing Council in its 25th session on February 2009

148. 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 cadmium (and lead -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 cadmium (and lead), together with their relevant companion documents, were amended and circulated to the Working Group members. The present final reviews of scientific information on cadmium (and lead), 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.

149. 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.

150. 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 [5].

1.3 Scope and coverage in this review

151. The review responds to Governing Council Decision 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 cadmium, in order to inform future discussions of the Governing Council on the need for global action in relation to lead and cadmium.

152. It draws mainly on recently published authoritative reviews on the various topics relevant to cadmium, 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

153. During its meeting of 18 to 22 September, 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 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.

154. 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

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

information presented in that chapter should be reviewed by WHO and the chapter finalised after the meeting by WHO and UNEP.

155. 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.,

156. 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.

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

158. The final reviews of scientific information on cadmium (and lead), 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

159. Cadmium is a metallic element belonging to group II B of the Periodic Table (atomic number: 48, and relative atomic mass: 112.41). Cadmium in its elemental form is a soft, silver-white metal. It is not usually present in the environment as a pure metal. Cadmium is most often present in nature as complex oxides, sulphides, and carbonates in zinc, lead, and copper ores. It is rarely present in large quantities as chlorides and sulphates (ATSDR, 1999).

160. Cadmium is widely distributed in the Earth's crust. It is a relatively rare element with an average concentration of 0.1-0.2 mg Cd/kg (EC, 2001). Higher concentrations - with commercial interest - are found in association with zinc, lead and copper ores where cadmium is invariably recovered as a by-product, mainly from zinc-containing ores. Cadmium is not recovered as a principal product of any mine (OSPAR, 2002), but exclusively as a by-product of other non-ferrous metal extraction (notably zinc). Some rare cadmium minerals are, however, known, such as Greenockkite (CdS) and Hawlegite, Cadmoisite (CdSe), Monteponite (CdO) and Otavite ($CdCO_3$) (OSPAR, 2002). Sedimentary rocks and marine phosphates contain about 15 mg Cd/kg (EC, 2001). Based on data from (ECB, 2005), the cadmium concentrations in fertilizers used in Austria, Belgium, Denmark, Finland, Germany, Norway, Sweden and the UK in the period 1984-1995 ranged between 2.5-80 mg Cd/kg P. The current average cadmium content in phosphate fertilizers used in European countries is suggested to be 35 mg Cd/kg P_2O_5 or 79 mg Cd/kg P (ECB, 2005).

161. It should be noted that the amount of the cadmium compound identified analytically is not necessarily equivalent to the amount that is bioavailable (ATSDR, 1999). Cadmium can form a number of salts, and both its mobility in the environment and the effects on the ecosystem depend to a great extent on the nature of these salts in combination with other elements such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulphur (cadmium sulphide) (OSPAR, 2002). Metallic cadmium and CdO powder are less harmful in the environment than soluble Cd^{2+}. However, metallic cadmium and CdO powder transform in the environment to the bioavailable Cd^{2+} (ECB, 2005). Compounds with Cd^{2+} are all stable solids that do not evaporate, although cadmium is often found as part of small particles present in air (OSPAR, 2002).

162. Cadmium is not an element that is essential for animal or plant life (with the exception of certain ocean phytoplankton at element-depleted conditions, see section 7.2).

2.2 Cadmium in the atmosphere

163. The lifetime of cadmium in the atmosphere is relatively short compared to substances such as mercury or some POPs. Most of the cadmium in the air is bound to small-size particulate matter (below 1 μm) (EC, 2001). Cadmium is emitted to the atmosphere from anthropogenic sources as elemental cadmium and/or cadmium oxide and - from some sources - as sulphide or chloride (EC, 2001). From atmospheric combustion sources, cadmium may be emitted partly as elemental gaseous cadmium, but as it is cooled, this cadmium is also quickly bound to particulate matter.

164. In the atmosphere, the particulate matter increases in particle size due to interaction between particles of different sizes, and due to condensation of water vapour and other gases. Cadmium and many of its compounds have relatively low vapour pressure, and thus are not particularly volatile. However, high heat processes can volatilise cadmium and be emitted as a vapour. The cadmium vapours quickly condense on aerosols as they exit the stacks and enter the atmosphere (EC, 2001). Thus, most

cadmium in the atmosphere is in the form of particulate matter, which may consist of very small particles if it is produced by combustion processes (ATSDR, 1999).

165. According to a study on the occurrence of cadmium species in ambient aerosols based on measured size distributions and vapour pressure data, cadmium chloride, cadmium sulphate and cadmium oxide appear to be the predominant species in ambient air (EC, 2001). Atmospheric transport is governed by aerosol transport mechanism (see section 7.1).

2.3 Cadmium in aquatic environments

166. As to cadmium compounds found either in atmospheric dust or in effluents of principal sources, it can be stated that cadmium sulphate and cadmium chloride are quite soluble in water, whereas elemental cadmium, cadmium oxide and cadmium sulphide are almost insoluble (EC, 2001). Cadmium complexation with chloride ion increases with salinity until, in normal seawater, cadmium exists almost entirely as chloride species ($CdCl^+$, $CdCl_2$, $CdCl^{3-}$) with a minor portion as Cd^{2+} (NTP, 1991 as cited by ATSDR, 1999). The complexation of cadmium with chloride in seawater has been shown to greatly influence its bioavailability and hence toxicity to marine organisms. It is most probable that chloride complexation is responsible for the reduced cadmium accumulation and toxicity in a variety of organisms observed with increasing salinities (IPCS, 1992b).

167. Cadmium mobility in aquatic environments are enhanced by low pH, low hardness, low suspended matter levels, high redox potential and low salinity (Government of Canada, 1994). In natural water bioavailability of cadmium is reduced through sorption on suspended particles so that biological responses occur at higher cadmium levels (ECB, 2005). In aquatic systems, cadmium is most readily absorbed by organisms directly from the water in its free ionic form (AMAP, 1998).

168. IPCS (1992b) reports an average cadmium content of sea water of about 0.1 µg/L or less, which is supported by EC (2001) that reports concentrations of dissolved cadmium in surface waters of the open oceans of below 5 ng/L. River water contains dissolved cadmium at concentrations of between < 1 and 13.5 ng/L (IPCS, 1992b). See chapter 4 on concentrations in aquatic environments. High fractions of dissolved cadmium are found in acid waters, e.g. in Sweden (ECB, 2005). The concentrations of cadmium in EU freshwater have generally decreased since the end of the 1970's, though since 1990, the decrease in cadmium levels has generally been less pronounced (ECB, 2005).

2.4 Cadmium in soil

169. As with all cationic metals, the chemistry of cadmium in the soil environment is to a great extent controlled by pH. The U.S. EPA (1999) reports that under acidic conditions, cadmium solubility increases and very little adsorption of cadmium by soil colloids, hydrous oxides, and organic matter takes place. At pH values greater than 6 units, cadmium is adsorbed by the soil solid phase or is precipitated, and the concentrations of dissolved cadmium are greatly reduced. Cadmium forms soluble complexes with inorganic and organic ligands, in particular with chloride ions. The formation of these complexes will increase cadmium mobility in soils (McLean and Bledsoe, 1992, as cited by U.S. EPA, 1999). Adriano *et al.*, (2005) argue that in general, chloride can be expected to form a soluble complex with Cd^{2+} as $CdCl^+$, thereby decreasing the adsorption of Cd^{2+} to soil particles. In contrast to inorganic ligand ions, Cd^{2+} adsorption by kaolinite, a variable-charge mineral, could be enhanced by the presence of organic matter via the formation of an adsorbed organic layer on the clay surface (Adriano *et al.*, 2005).

170. Both toxicity and bioavailability of cadmium are influenced by soil characteristics (ECB, 2005). Soil characteristics influence cadmium sorption and therefore its bioavailability and toxicity (ECB, 2005). Cadmium mobility and bioavailability are higher in noncalcareous than in calcareous soils (Thornton 1992, as cited by ATSDR, 1999). Liming of soil raises the pH, increasing cadmium adsorption to the soil and reducing bioavailability (He and Singh 1994; Thornton 1992, as cited by ATSDR, 1999). A similar result was also obtained in a study jointly undertaken by the Polytechnic University of

Madrid and the Norwegian University of life sciences (Singh and Fernandes-Deschamps, 2008). The study concluded that the uptake of cadmium by oat plants was mainly dependent on the pH of the soil and the plant yield. A general trend emerges that toxicity increases in soil when mobility of cadmium is higher, i.e. soil toxicity increases as soil pH, or soil organic matter decrease. Exceptions to this rule have also been found (ECB, 2005).

171. Plants grown in a greenhouse or a container take up more cadmium than the same plants grown in soil with the same cadmium levels in the field. This is due to greater root development in a confined volume in containers and to the fact that all the roots are in contact with cadmium-contaminated soil. In the field, roots may grow down below the cadmium-contaminated level (Page and Chang, 1978; De Vries and Tiller, 1978, as cited by IPCS, 1992b).

172. Cadmium may be adsorbed by clay minerals, carbonates or hydrous oxides of iron and manganese or may be precipitated as cadmium carbonate, hydroxide, and phosphate (U.S. EPA, 1999). Evidence suggests that adsorption mechanisms may be the primary source of cadmium removal from soils. In soils and sediments polluted with metal wastes, the greatest percentage of total cadmium was associated with the exchangeable fraction. Cadmium concentrations have been shown to be limited by cadmium carbonate in neutral and alkaline soils (U.S. EPA, 1999).

173. Increasing soil zinc is known to reduce cadmium availability to plants (ECB, 2005) because Zn inhibits cadmium uptake and cadmium translocation from roots to shoots of plants (Chaney and Ryan, 1994).

174. Data on cadmium in different soils is illustrated in Figure 2-1. Further details and references to the data can be found in Annex 1 of this review.

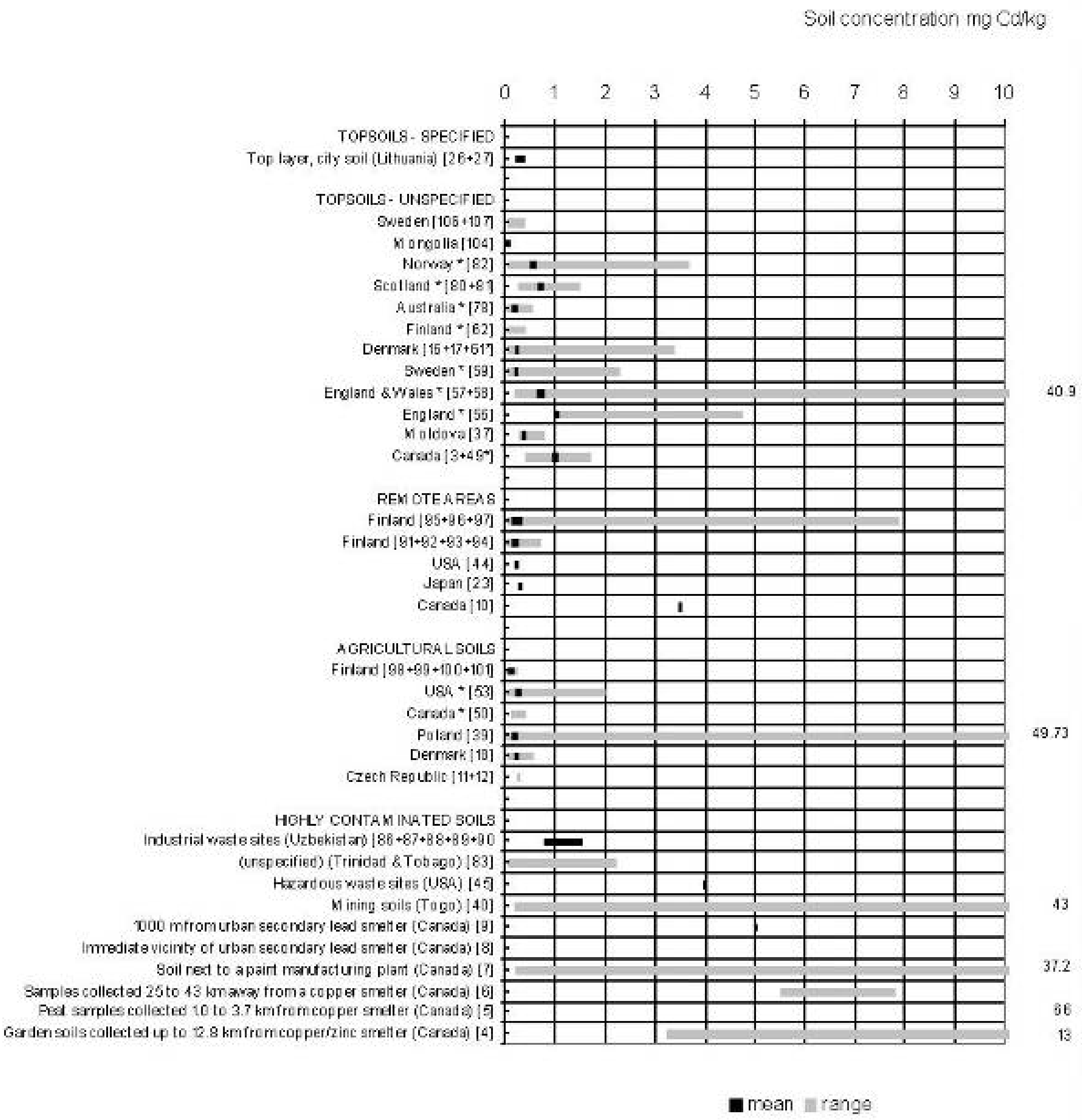

Figure 2-1 Cadmium in soils. More details and references to data sources can be found in Annex 1. The number in square brackets after the country name refers to the ID numbers in the table in Annex I. Concentrations out of scale are indicated to the right of the bars..

3 Human exposure and health effects

3.1 Human exposure

175. **Exposure of the general population** – Food is the main source of exposure to cadmium in the general population, providing over 90 percent of the total intake in non-smokers (WHO/UNECE, 2006). There are indications that the occurrence of cadmium in foodstuffs has increased over the past century as a result of contamination of the environment (WHO/EHG, 1994). In Japan the daily intake of cadmium per person is estimated at 3.59µg/person/day (2004). Additionally, the result was converted into weekly intake per body weight of 1kg for the comparison with provisional tolerable weekly intake settled by Joint Expert Committee on Food Additives. The result was 3.75µg/kg body weight/week, which is lower than the provisional tolerable weekly intake (7.0µg/kg bw/w) (Japan's submission, 2007). However, in some countries where cadmium emissions to air have been reduced, there has been a decrease in cadmium intake. Most cadmium in the human diet comes from agricultural products, as plants take up the metal from soil; cadmium reaches soil through deposition from the atmosphere and in certain fertilizers. In heavily contaminated areas, re-suspension of dust can cause a substantial proportion of crop contamination and human exposure via inhalation and ingestion (WHO/UNECE, 2006). Tobacco is an important source of cadmium for smokers, as tobacco plants, like other plants, accumulate cadmium from the soil. Cadmium exposure and accumulation may start early in life, as children are exposed through food intake, second-hand tobacco smoke and house dust. Toys may also constitute another route for children to get exposed to cadmium. In India, a study undertaken on 111 toys showed that the cadmium level in the toys ranged from 0.01 ppm to 188 ppm with an average of 15.7 ppm (Kumar and Pastore, 2007). Excretion from the body is limited, and cadmium accumulates in the kidneys, leading to nephrotoxicity and osteoporosis later in life (Schoeters *et al.*, 2006).

176. The average daily intake varies according to dietary habits: diets rich in fibre and shellfish are associated with high dietary cadmium intake (Järup *et al.*, 1998a). The concentrations of cadmium in most foods range from 0.01 to 0.05 mg/kg, but higher concentrations may be found in nuts and oil seed, molluscs, and offal, especially liver and kidney (WHO, 1988). An analysis of food intake and cadmium concentrations in food for the US population estimated a geometric mean intake of 18.9 µg/day (Choudhury *et al.*, 2001 as cited in U.S. CDC, 2005). Average daily intakes of cadmium from food in most countries are within the range 0.1–0.4 µg/kg of body weight. However, dietary cadmium intake is log-normally distributed, with a small fraction of the population ingesting more cadmium than the average. Further, within the population, children may have higher average intake per kg of body weight than adults. People with a high intake of meat and other products from marine mammals may have a particularly high intake of cadmium.

177. The Joint WHO/LRTAP Task Force on the Health Aspects of Air Pollution (WHO/UNECE, 2006) reported that geometric mean concentrations of urinary cadmium in non-smokers in various studies in Europe were generally between 0.15 and 0.7 µg/g of creatinine.[6] It reported, for example, 0.15–0.20 µg/g of creatinine in Sweden (Berglund *et al.*, 1994; Järup *et al.*, 1995)***;*** 0.69 µg/g of creatinine in Belgium (Roels *et al.*, 1993); 0.5–0.6 µg/g of creatinine in Poland (Jakubowski, 1995); and 0.15 µg/g of creatinine in Germany (WHO/UNECE, 2006). In a study of about 5000 people in the USA between 1999 and 2002, mean urine levels of cadmium were about 0.2 µg/g of creatinine, and the 95th percentile was 0.92 µg/g of creatinine (U.S. CDC, 2005). Cadmium levels in urine seem to increase with age. According to the data obtained in the USA, mean concentrations of urine cadmium in males were: 0.14

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[6] *Creatinine is a breakdown product of creatine phosphate in muscle, and is usually produced and excreted at a fairly constant rate. It is therefore used as the comparator for measurements of cadmium in urine.*

µg/g of creatinine in the age group 12–16 years; 0.18 µg/g at 20–39 years; 0.28 µg/g at 40–59 years; and 0.38 µg/g over 60 years. In females, the urine cadmium concentrations were higher: 0.19 µg/g at 12–16 years; 0.30 µg/g at 20–39 years; 0.66 µg/g at 40–59 years; and 0.81 µg/g at over 60 years (Choudhury *et al.*, 2001 as cited in WHO/UNECE 2006).

178. A study by the Centers for Disease Control and Prevention in the USA based on data from a random sample of 7970 people (National Health and Nutrition Examination Survey 1999-2002), found that the mean blood concentration of cadmium was 0.412 µg/litre (0.378-0.449) and the 95th percentile blood concentration was 1.3 µg/l (1.20-1.40) (U.S. CDC, 2005). According to other publications, the concentrations of cadmium in blood in normal populations range from about 0.4 to 1.0 µg/l for non-smokers and 1.4-4 µg/l for smokers (Elinder 1985; Sharma *et al.*, 1982). Environmental exposure can elevate blood cadmium concentration to above 10 µg/l (Shiwen *et al.*, 1990), and workers occupationally exposed to cadmium by inhalation may have blood cadmium levels ranging up to 50 µg/l (Roels *et al.*, 1981).

179. Low-level cadmium exposure has been associated with increased urinary calcium excretion and direct bone toxicity. Blood cadmium measurements generally reflect current or recent exposure, and are especially useful in cases where the exposure period has been short and little cadmium has accumulated in the kidneys (Järup *et al.*, 1998a); Lauwerys *et al.*, 1994). Both beta 2-microglobulin and alpha 1-microglobulin serve as organ-specific, early-effect biomarkers of tubular proteinuria, and thus play a role in identifying early signs of cadmium-induced renal damage in those who may have been exposed (Wittman and Hu, 2002).

180. **Occupational exposure –** Workers may be exposed to cadmium in the zinc, copper and steel industries, in the manufacture of nickel-cadmium batteries, solar cells, and jewellery, in metal plating, production of plastics and many other industrial activities. Acute cadmium poisoning is characterized by irritation of the respiratory tract, while in chronic poisoning the main target organ is the renal tubule (Nogue *et al.*, 2004). The main route of cadmium exposure in the occupational setting is via the respiratory tract. Air concentrations of cadmium fumes or dust vary considerably between different industries, such as smelters, pigment plants and battery factories (Järup *et al.*, 1998a). Workers exposed to high levels of cadmium may develop renal proximal tubular dysfunction, glomerular damage with progressive renal disease, and respiratory symptoms, including pneumonitis and emphysema, and acute respiratory distress syndromes (Barbee and Prince, 1999). In one estimate, workers with cumulative cadmium exposure equivalent to a blood concentration of 10 µg/L for 20 years would be expected to have a 14 percent incidence of renal dysfunction (Järup *et al.*, 1998a). Recent biological exposure index data from Japan show cadmium levels for workers exposed to cadmium at 5 µg/L in blood and 5 µg/g creatinine in urine (Japan’s submission, 2007). Changes in blood and urine cadmium in workers accompanying the change in atmospheric cadmium concentration in cadmium pigment factories over a four year period are approximately as follows: ambient concentration (mg/m3) 0.62 to 0.16; blood cadmium (µg/100g) 2.15 to 1.56; and urinary cadmium (µg/g creatinine) 14.2 to 7.8 (Kawasaki *et al.*, 2004 in Japan’s submission, 2007). To minimize risk exposure to Cd and its compounds at workplaces, the International Cadmium Association has submitted a guideline document entitled “Managing risks to workers exposed to chronic exposure to Cadmium and its compounds” that could be useful to workers directly exposed to these compounds (ICdA submission, 2006).

181. **Kinetics** – Data from experimental animals and from humans have shown that absorption via the lungs is higher than via the gastrointestinal tract (WHO, 1988). Up to 50 percent of inhaled cadmium may be absorbed. Gastrointestinal absorption is influenced by the type of diet and the person’s nutritional status (Jin *et al.*, 2002). On average, 5 percent of the total oral intake of cadmium is absorbed (IPCS, 1992a). A number of factors may increase absorption, such as low intake of vitamin D, calcium, and trace elements, e.g. zinc and copper (Godt *et al.*, 2006). A lack of iron also influences cadmium absorption: people with low iron supplies showed a 6 percent higher uptake of cadmium than those with a balanced iron stock (Flanagan *et al.*, 1979). This is the main reason for the higher cadmium resorption in people with anaemia and habitual iron deficit, such as children or menstruating women. Cadmium absorbed via the lungs or the gastrointestinal tract is stored mainly in the liver and kidneys, where more

than half of the body burden will be deposited. Highest concentrations are generally found in the renal cortex, but high exposures may lead to higher concentrations in the liver. Excretion is normally slow, and the biological half-life is very long (decades) in the muscles, kidneys, liver, and whole body. Cadmium concentrations in most tissues increase with age. In exposed people with renal damage, urinary excretion of cadmium increases and so the whole body half-life is shortened (IPCS, 1992a).

182. **Cadmium in the diet –** Cadmium occurs in all food types; in most countries, agricultural crops account for most of the intake of cadmium. In Japan in 2004, rice accounted on average for 44 percent of cadmium in the diet, followed by vegetables and seaweeds (16 percent), fish and shellfish (11 percent), and cereals, grains, nuts and seeds, and potatoes (10 percent) (Japan's submission, 2005). The former Food Agency in Japan conducted a nationwide survey of cadmium content in rice (brown rice) in 1997 and 1998, in the areas uncontaminated with cadmium. The results indicated that the cadmium content in 1kg of rice was 0.06 mg on average. Of 37,250 samples, only 1 sample contained more than 1mg/kg of cadmium, 94 samples contained more than 0.4mg/kg (0.2 percent) and 1,241 samples contained more than 0.2mg/kg (3.2 percent) (Japan’s submission, 2007). In the Finnish population, the most important sources of dietary cadmium intake are grain products (57 percent), vegetables, fruits and berries (23 percent), offal, e.g. kidneys and liver (4 percent), and seafood (5 percent). Other food sources contribute 11 percent (NFA, 2002). Daily human intake of cadmium from crops is related to the cadmium concentration in the agricultural soils. The rate of uptake of cadmium from soil varies considerably for different crops. It is also influenced by the presence of other elements, such as zinc, and by other factors, e.g. the acidity of the soil). Cadmium in soils mainly comes from atmospheric deposition, phosphate fertilizers, manure and sewage sludge.

183. Examples of daily intake of cadmium via food in different countries are shown in Table 3-1. Average daily intakes from food in most of the countries are within the range 0.1–0.4 µg per kg of body weight. Assuming an average body weight of 70 kg, this translates into 7–28 µg of cadmium per day. In areas of high exposure, intakes between 33 and 391 µg of cadmium per day have been reported (IPCS, 1992a). It has been estimated that 10 percent of the population consumes twice the average quantity of any particular food class, and that 2.5 percent consumes 3 times the average (IPCS, 1992a). In addition, children may have higher average intake per kg of body weight than adults, as reflected in the data from Australia (Table 3-1).

184. People with a high intake of products from marine mammals may have a particularly high intake of cadmium. AMAP (2003) estimated an intake for Inuit populations in Canada and Greenland of 1000 µg of cadmium per week. Estimates for the general population in Canada, Denmark and Finland ranged from 32 to 100 µg of cadmium per week. However, AMAP (2003) found that exposure to elevated levels of cadmium among Arctic people was principally attributable to cigarette smoking.

185. The joint WHO/LRTAP Task Force on the Health Aspects of Air Pollution concluded that the margin between the current daily intake of cadmium in diet and the intake that would have health effects is very narrow; for highly exposed subpopulations, there is even no margin. Population groups at risk include the elderly, people with diabetes and smokers. Women may be at increased risk because of their lower iron stores, which means they absorb more cadmium than men at the same level of exposure (WHO/UNECE, 2006).

186. **Cadmium intake via inhalation of ambient air and via drinking-water** – Cadmium intake via inhalation of ambient air and via drinking-water is in general small compared with dietary intake, accounting for less than 10 percent of total intake in the general population. In Finland, the average dietary intake of 10 µg/day is about 100 times the average exposure to cadmium via drinking-water and ambient air of 0.1 and 0.02 µg/day, respectively. Similarly, the intake via food was estimated to account for 97 percent of total intake in Japan and 94 percent in China (WHO/UNECE, 2006). The current standard set out in the national legislation for drinking water in the United Kingdom is 5 µg/L (United Kingdom’s submission, 2007). Levels registered in drinking water in Norway are in general well below the MAC for lead of 5 µg/L (Norway’s submission, 2007). In Niger, the limit fixed for cadmium in drinking water is 5 µg/L (Niger’s submission, 2007). According to the continuing monitoring conducted by the Ministry of Environment, environmental quality standards for cadmium in public water areas and

groundwater is generally achieved, being satisfied at 100 percent of the sampling points from years 2001 to 2005 at less than 0.01 mg/L (Japan's submission, 2007).

187. According to Hungarian rules the quality of drinking water shall comply with the requirements stipulated in the Government Decree No. 201/2001. (X.25.). The suppliers of the drinking water are obliged to regularly analyse their water according to different parameters, including cadmium. The limit values appearing in the decree mentioned above are identical with those published in the European Directive 98/83/EGK. The limit for cadmium is 5 µg/L. Of 376 samples undertaken in 2004 only one sample was over the limit (Hungary's submission, 2007).

188. According to the WHO Air Quality Guidelines, assuming a daily inhalation of 20 m^3 of air and indoor concentrations similar to those outdoors, the average amount of cadmium inhaled daily by humans in rural, urban and industrialized areas should not exceed 0.01, 0.2 and 0.4 µg, respectively. Deposition of inhaled cadmium in the lungs varies between 10 percent and 50 percent depending on the size of airborne particles. Absorption of cadmium in the lung depends on the chemical nature of the particles deposited (around 50 percent for cadmium oxide but considerably less for insoluble salts such as cadmium sulfide. (WHO, 2000).

189. **Cadmium intake via smoking** – Tobacco is an important source of cadmium uptake in smokers. In non-polluted areas, cadmium intake from heavy smoking may equal that from food (IPCS, 1992a). Cigarette smoking may represent an additional source of cadmium which may equal or exceed that from food. Depending on the brand (i.e. mainly on the origin of the tobacco), cigarettes produced in Europe or the United States of America contain different cadmium concentrations, of which 10 percent can be absorbed (WHO, 2000). According to other publications, the human lung resorbs 40–60 percent of the cadmium in tobacco smoke (Elinder *et al.*, 1976). On average, a 50-year-old non-smoker has a cadmium body burden of 15 mg, while a comparable lifelong smoker has 30 mg. Smokers generally have cadmium blood levels 4–5 times those of non-smokers (Järup *et al.*, 1998a). The cadmium concentration varies in different brands of cigarettes, and may range from 0.19 to 3.0 micrograms per gram (of dry weight) (Elinder *et al.*, 1983) The amount of cadmium inhaled from smoking one cigarette containing about 1.7 microgram cadmium was estimated to be 0.14 to 0.19 microgram, corresponding to about 10 percent of the total cadmium content in the cigarette (Elinder *et al.*, 1983).

190. **Trends in cadmium exposure** – The concentration of cadmium in blood generally reflects current exposure. Different trends in blood cadmium have been reported from different countries. In Belgium, in a group of men not occupationally exposed to cadmium, who were examined annually between 1984 and 1988, the mean blood cadmium concentration decreased from 2.25 µg/l to 0.79 µg/l (a 14 percent annual decrease). A similar decline (about 10 percent per year) was suggested by data reported from Germany, which showed a decrease in blood cadmium from 1.19 µg/l in 1979 to 0.39 µg/l in 1986 (Ducoffre *et al.*, 1992). In Japan between 1980 and 1990, the geometric mean concentration of blood cadmium decreased from 3.8 µg/l to 1.79 µg/l in men, and from 3.57 µg/l to 1.84 µg/l in women (Watanabe *et al.*, 1993). In Sweden, the concentration of cadmium in erythrocytes was determined in a total of 600 men and women aged 25–74 years in 1990, 1994, and 1999. A decline was seen only for smokers, indicating that cadmium exposure from tobacco decreased while other environmental sources of cadmium did not change significantly (Wennberg *et al.*, 2006). In spite of decreasing cadmium emissions, ambient air concentrations, and deposition, recently published data do not show a reduction in cadmium body burdens in non-smokers in the past decade (WHO/UNECE, 2006). Studies of cadmium balance in the top layers of arable soil indicate that the deposition of cadmium still exceeds removal. As a result, cadmium is accumulating in certain soils, increasing the likelihood of future exposure through food. The Scientific Committee on Toxicity, Ecotoxicity and Environment, of the European Union, found no conclusive evidence of a decreasing trend in cadmium exposure in Europe (CSTEE, 2004). Data on trends in exposure to cadmium in developing counties are not available; trends in these countries may be significantly different from those reported in the industrialized countries. Some data on residential exposure to cadmium in China were reported by Wang and Tian, 2004 (United States' submission, 2007).

3.2 Health effects in humans

191. Cadmium is not essential for biological function in humans. The kidney is considered the critical target organ, for both the general population and occupationally exposed populations. Several studies over the past decade have indicated that renal tubular damage occurs at lower levels of cadmium body burden than previously observed. Smokers and people with low body levels of iron are at particular risk. Skeletal damage is another critical effect of cadmium exposure, either as a secondary response to kidney damage or as a result of the direct action of cadmium on bone cells. Some studies have suggested that cadmium alters calcium metabolism, contributing to osteoporosis (Järup *et al.*, 1998b). An increased risk of lung cancer has been reported following inhalation exposure in occupational settings, but there is no evidence that cadmium is a carcinogen by the oral route of exposure (WHO Chemical Fact Sheet, 2006).

192. The first description of the health effects of cadmium referred to lung damage after acute inhalation in the 1930's (Nordberg, 2004). After the Second World War, bone effects and proteinuria were reported from Japan, in descriptions of a bone disease (*itai-itai* disease), with fractures and severe pain, linked to cadmium exposure and related to a low-calcium diet. International warnings of the health risks from cadmium pollution were issued in the 1970’s, and in 1992 WHO identified renal dysfunction as the critical effect. In the 1990’s, population groups in China exposed to cadmium in rice were studied, and new information was obtained on the skeletal, renal and reproductive toxicity of cadmium (ChinaCad project) (Nordberg, 2004). Proximal tubular disease, due to high cadmium absorption, has been reported in many Asian countries, where the population has for many decades consumed rice grown on cadmium-contaminated soils (Tsukahara *et al.*, 2003; Ikeda *et al.*, 2006; Cheng *et al.*, 2006; Simmons *et al.*, 2005). The ingestion and inhalation of low levels of cadmium over a long period of time (years) can lead to a build-up of cadmium in the kidneys and if cumulative exposure is high enough, induce kidney damage and bone fragility (ATSDR, 1999). An increased risk of lung cancer has been reported following inhalation exposure in occupational settings (WHO/UNECE, 2006; ATSDR, 1999).

Table 3-1 Daily intake of cadmium via food: country examples

Country	Type of consumption data/intake study	Average dietary intake (µg of cadmium per kg body weight per day)	Population group	Information source
Submission to this assessment				
Australia	Total diet study by Food Standards Australia New Zealand 2002	0.08–0.24	Males 25–34 years	Australia's submission, 2005
		0.07–0.22	Females 25–34 years	
		0.11–0.29	Boys 12 years	
		0.09–0.22	Girls 12 years	
		0.18–0.57	Toddler 2 years	
		0.13–0.68	Infant 9 months	
Burkina Faso	Total diet study Calculated from average total daily intake assuming an average weight of 60 kg	0.28		Burkina Faso's submission, 2005
Finland	Calculated from average total daily intake assuming an average weight of 60 kg	0.17		NFA, 2002 (submitted by Finland)
Japan	Total diet studies in 10 locations	0.43		Japan's submission, 2005
Mexico	Calculated from average total daily intake assuming an average weight of 60 kg	4.88	Population of Mezquital Valley in Hidalgo	Mexico's submission, 2005
Reported previously (based on WHO, 2004a)				
Austria	Disappearance	0.15		European Commission, 1996b
Belgium	Household purchases, 24-h records, FAO food balance sheets	0.39		European Commission, 1996b
Canada	Total diet study	0.22		Dabeka and McKenzie, 1995
China	Total diet studies	0.21–0.51	Adult males	Yang *et al.*, 1994; Chen and Gao, 1993; 1997a; 1997b
		0.13	Adult females	
Czech Republic	Total diet study	0.26		National Institute of Public Health Prague, 1996 [Reference missing in WHO 2004]
Denmark	National consumption survey	0.28		European Commission, 1996b
France	Household consumption survey	0.22		European Commission, 1996b
Germany	Total diet study	0.18		Mueller *et al.*, 1998 [reference missing in WHO 2004]
	National consumption survey	0.19	Males	European Commission, 1996b
		0.16	Females	

Table 3-1 Continued

Country	Type of consumption data/intake study	Average dietary intake (µg of cadmium per kg body weight per day)	Population group	Information source
Greece	Total diet study	0.74		Tsoumbaris and Tsoukali-Papadopoulou, 1994
	Not specified	0.94		European Commission, 1996b
Italy	National consumption survey	0.33		European Commission, 1996b
Japan	Duplicate diet study	0.36	Adult males	Watanabe *et al.*, 1992
		0.31	Adult females	
Netherlands	National consumption survey	0.33–0.40	Males aged 16–70 years	Kreis *et al.*, 1992
		0.31–0.38	Females aged 16–70 years	
New Zealand	Total diet study	0.40/0.24	Young males	Vanoort *et al.*, 2000
		0.33/0.19	Adult males	
		0.33/0.16	Females	
		0.24	Female vegetarians	
Norway	Not specified	0.14		European Commission, 1996b
Portugal	National consumption survey, household budget survey	0.26		European Commission, 1996b
Spain	Not specified	0.30		European Commission, 1996b
Sweden	Not specified	0.12	Males	European Commission, 1996b
		0.13	Females	
United Kingdom	Total diet study	0.17		[Reference missing in WHO 2004]
	National consumption survey	0.20		[Reference missing in WHO 2004]
United States	Total diet study	0.14–0.15	Adult males	United States Food and Drug Administration [Reference missing in WHO 2004]
		0.13–0.14	Adult females	

193. **Kidney effects –** The accumulation of cadmium in the renal cortex leads to kidney dysfunction with impaired reabsorption of, for instance, proteins, glucose, and amino acids (IPCS, 1992a). The concentration of cadmium in the kidneys – reflecting cumulative exposure – can be assessed by measuring cadmium levels in urine. The first sign of cadmium-induced renal lesions is tubular proteinuria, that results from the damage to the proximal tubular cells and is usually detected as an increase in low molecular weight proteins in the urine (Järup *et al.*, 2000). However, both glomerular and tubular damage may be observed (Åkesson *et al.*, 2005). The primary markers of kidney damage are the urinarily excreted β2-microglobulin, N-acetyl-α-D-glucosaminidase (NAG), and also retinol-binding protein (RBP). A study in China found significantly higher values for urinary β2-microglobulin and RBP in people with high blood cadmium concentrations than in people with normal values (Jin *et al.*, 2002). Tubular damage is generally thought to be irreversible (Godt *et al.*, 2006).

194. Data from several studies indicate that a urinary cadmium excretion of about 2.5 µg/g of creatinine is associated with an excess prevalence of renal tubular damage of 4 percent. An average urinary excretion of 2.5 µg/g of creatinine corresponds to an average concentration of cadmium in renal cortex of 50 µg/g, which would be the result of long-term (decades) intake of 50 micrograms per day

(Järup *et al.*, 1998a). If the average daily intake of cadmium would increase to 30 micrograms/day, about 1 percent of the entire population would have cadmium-induced tubular damage. In risk groups, for example, women with low iron stores, the percentage would be higher, up to 5 percent (Jarup *et al*, 1998a). However, some data suggest that effects may occur even at lower levels in some populations. For example, in Sweden, it has been estimated that 1 percent of women who smoke and who have low body iron levels may experience adverse kidney effects at a cadmium intake of about 15 µg/day (Järup *et al.*, 1998a). Dose–response relationships at low-level exposure have been established only recently. In 1992, WHO estimated that a urinary excretion of 10 nmol/mmol of creatinine could constitute a "critical limit", below which kidney damage would not occur. However, cadmium-induced kidney dysfunction in the general population was demonstrated at urinary cadmium levels around 2–3 nmol/mmol of creatinine, and a negative dose-effect relationship was found between cadmium dose and bone mineral density in people at the age of 60 or older (Jarup and Alfven, 2004). Because of the potential public health consequences of chronic low-level cadmium exposure, the authors recommend that measures should be taken to reduce cadmium exposure to an absolute minimum (Järup and Alfven, 2004).

195. In workers, an increased prevalence of low molecular weight proteinuria has been reported after 10–20 years of exposure to airborne cadmium levels of 20–50 µg/m^3 (IPCS, 1998a). In polluted areas, where the general population has an estimated cadmium intake of 140–260 µg/day, increased low molecular weight proteinuria has been seen in some individuals following long-term exposure (IPCS, 1992a). Several studies over the past ten years have found renal tubular damage due to exposure to cadmium at lower levels of cadmium body burden than previously observed, and – more importantly – glomerular effects. Although the effects are minimal, they represent early signs of damage, affecting large segments of the population; individuals with diabetes may be at increased risk (Åkesson *et al.*, 2005).

196. A study of 1021 people in Sweden, occupationally or environmentally exposed to low concentrations of cadmium, found an increased prevalence of tubular proteinuria (10 percent compared with a background prevalence of 5 percent) at a urinary cadmium concentration of 1.0 µg/g of creatinine. In most populations, the normal level of cadmium in urine is between 0.1 and 0.6 µg/g of creatinine (Järup *et al.*, 2000). Increased urinary excretion of early biomarkers of kidney dysfunction has also been reported at cadmium levels of about 2.0 µg/g of creatinine (Noonan *et al.*, 2002; Trzcinka-Ochocka *et al.*, 2004 (as cited by WHO/UNECE, 2006)).

197. An evaluation of 15 studies of diverse exposures examined the level of cadmium in the renal cortex that was associated with a 10 percent prevalence of low molecular weight proteinuria. The lower confidence limit (CI 95 percent) of the renal cortex dose was found to be 84 µg/g of cortex, corresponding to a chronic cadmium intake of 1 µg per kg of body weight per day in females, and 2.2 µg/kg of body weight per day in males. Additional exposure from smoking approximately 20 cigarettes a day (3 g of cadmium inhaled per day) was predicted to increase the renal cortex concentration by 45–70 percent. The author indicates that, for most of the US population, dietary-derived risks are likely to be negligible, in the absence of exposures from other sources (Diamond *et al.*, 2003).

198. The Cadmium Dietary Exposure Model, developed by Choudhury *et al.* (2001), predicts a mean peak concentration of cadmium in the renal cortex of 15 µg/g wet cortex in males and 29 µg/g wet cortex in females, with a cadmium intake of about 21.5 µg/day. Predicted kidney cadmium levels in females were higher than in males, in agreement with empirical estimates based on the NHANES III (U.S. National Health and Nutrition Examination Survey III), when females were predicted and observed to excrete approximately twice as much cadmium in urine as males. Females may absorb a larger fraction of ingested cadmium than males, possibly as a result of lower body stores of iron. This suggests that females may be at greater risk of cadmium toxicity than males (Choudhoury *et al.*, 2001)

199. A study of 820 women aged 53–64 years in Sweden (1999-2000) showed cadmium levels in blood to be significantly associated with effects on renal tubules (as indicated by increased levels of human complex-forming protein and N-acetyl-beta-D-glucosaminidase in urine), even among women with low exposure who had never smoked. The study also found associations with markers of glomerular effects (glomerular filtration rate and creatinine clearance). The tubular renal effects occurred at

lower cadmium levels than previously demonstrated, as significant effects were seen at a mean urinary level as low as 0.8 µg/g of creatinine, and glomerular effects were also observed. (Åkesson *et al.*, 2005).

200. **Skeletal damage** – Studies in humans and animals have indicated that exposure to cadmium can cause skeletal damage. Cadmium is associated with low bone mineralization, a high rate of fractures, increased osteoporosis, and intense bone pain. These were features of *itai-itai* disease, first described in Japan in the 1940's among people who had eaten rice grown on fields irrigated with cadmium-polluted water (Godt *et al.*, 2006). Classic *itai-itai* disease resulted from a combination of low-calcium diet and high cadmium exposure, which caused kidney disease and, subsequently, bone disease. A great deal of epidemiological data has been produced from studies in polluted areas of Japan, especially in the basin of the Jinzu river, which runs through the central part of Toyama Prefecture in west central Japan (the major source of cadmium pollution in the area was a mine 50 km upstream of the endemic area) IPCS, 1992a). Most of the patients were postmenopausal women, and underlying osteoporosis, possibly enhanced by cadmium poisoning, was suggested to be the actual reason for the observed symptoms (Kazantzis, 2004; Nogawa *et al.*, 2004). Further evidence of skeletal effects of high cadmium exposure has been provided by other studies (Honda *et al.*, 2003; Jarup *et al.*, 1998b, 2000) In some European studies, urinary cadmium was significantly lower than among the Japanese *itai-itai* patients: participants in one study had a urinary cadmium level of only 1 µg/g of creatinine, while *itai-itai* patients were excreting approximately 30 µg/g of creatinine (Staessen *et al.*, 1999).

201. A recent joint WHO/UNECE Task Force (WHO/UNECE, 2006) suggested two possible mechanisms for the skeletal effects of cadmium. The first is that, as cadmium accumulates in the proximal tubular cells, it depresses cellular functions, which may result in reduced conversion between two forms of vitamin D3. This is likely to lead to a decrease in calcium absorption and bone mineralization, which in turn may produce osteomalacia (IPCS, 1992a). Alternatively, cadmium may act directly on bone cells, enhancing bone resorption (Miyahara *et al.*, 2001; Regunathan *et al.*, 2003) and decreasing bone formation (Blumenthal *et al.*, 1995; Dohi *et al.*, 1993; Long, 1997; Miyahara *et al.*, 1988). Several investigators have demonstrated skeletal injury due to cadmium at exposure levels that do not impair kidney function (Honda *et al.*, 2003; Sacco-Gibson *et al.*, 1992; Wang and Bhattacharyya, 1993) suggesting that cadmium acts directly on bone.

202. However, the exact mechanism of action is not clear, especially for low long-term exposures. Experimental animal studies have indicated that even a relatively low exposure to cadmium during the period of intensive skeletal development in the first months of life disturbs the accumulation of bone mass. Depending on the exposure level, this can lead to osteopenia or more advanced disorders of bone mineral status. If exposure continues until skeletal maturity, the effect is intensified (Brzóska and Moniuszko-Jakoniuk, 2005). Cadmium causes low bone turnover at the stage of intensive skeletal development; conversely, it induces high bone turnover, linked to enhanced resorption, at the stage of consolidation of bone mass.

203. Studies in Japan on 1380 female farmers did not confirm the European opinion that exposure to low-dose cadmium would increase the risk of osteoporosis (WHO/UNECE, 2006). Cadmium exposure at a level insufficient to induce renal dysfunction was found to have no effect on bone mineral density or urinary calcium excretion. Adverse effect on bone occurred only after the appearance of adverse effects on kidney (Horiguchi *et al.*, 2005).

204. **Cancer –** IARC has classified cadmium and cadmium compounds as group 1 human carcinogens, having concluded that there was sufficient evidence that cadmium can produce lung cancers in humans and animals exposed by inhalation. However, because of the identified and controversial influence of concomitant exposure to arsenic in the epidemiological studies, no reliable unit risk can be derived to estimate the excess lifetime risk for lung cancer (WHO, 2000). The International Agency for Research on Cancer (IARC) classifies cadmium in Group 1: carcinogenic to humans (IARC, 1993), and the US Environmental Protection Agency (EPA) has determined that cadmium is a probable human carcinogen by inhalation (ATSDR, 1999) and (U.S.EPA, 1992). Some publications have suggested a link between cadmium and renal cancer in humans (Il'yasova and Schwartz, 2005), prostate cancer (Verougstraete *et al.*, 2003) and breast cancer (McElroy *et al.*, 2006), but results are inconclusive. The

association between environmental exposure to cadmium and cancer (lung and other) in a population living near zinc smelters has been reported in a Belgian study (Nawrot *et al.*, 2006). An increased risk of lung cancer has been reported following inhalation exposure in occupational settings WHO/UNECE, 2006). According to a review by Waalkes (2000), the epidemiological data linking cadmium to lung cancer are much stronger than for prostate cancer and evidence of an association between cadmium and cancer in liver, kidney and stomach is considered equivocal (Waalkes, 2003). Although the molecular mechanisms of cadmium-induced carcinogenesis are not yet understood, several factors may contribute to it, including perturbance of mitogenic signalling, the DNA repair mechanism and apoptotic resistance, as well as effects on E-cadherin and its role in cell–cell adhesions, especially in epidermal cells (Goyer *et al.*, 2004; Prozialeck *et al.*, 2003)**.**

205. **Reproductive effects –** In animal experiments, cadmium appeared to interfere with the ovarian production of steroids, with the production of progesterone and testosterone, precipitated mammarian development, and increased uterine weight (Piasek and Laskey, 1999; Johnson *et al.*, 2003). Maternal exposure to cadmium is associated with low birth weight and spontaneous abortion (Frery *et al.*, 1993; Shiverick and Salafia, 1999). Data from studies in vitro and in animals suggest that cadmium has effects on the hypothalamus-pituitary axis and the endocrine systems (Schoeters *et al.*, 2006).

206. **Sensitive subgroups** – The population at highest risk consists on women with low iron stores or nutritional deficiencies, people with kidney disorders and fetuses and children. Smokers, people eating a cadmium-rich diet, and those living in the vicinity of industrial plants that emit cadmium (e.g. nonferrous metal extraction plants) represent population groups at high risk of exposure (WHO/UNECE, 2006). Studies in children and pregnant women are still limited, but there is some evidence that elevated cadmium exposure *in utero* can affect motor skills and perception, and that high cadmium levels in the urine of school children are associated with immunosuppressive effects. (Schoeters *et al.*, 2006). More studies are needed to confirm these results. Two recent small epidemiologic studies have noted a positive association between maternal exposure to cadmium and early delivery (Nishijo *et al.*, 2002) and cadmium levels in cord blood and lower birth height (Zhang *et al.*, 2004). People with kidney damage unrelated to cadmium exposure, such as that resulting from diabetes, some drugs and chemicals, and the natural age-related decline in kidney function, could be expected to exhibit nephrotoxicity at lower cadmium exposures. People with depleted stores of calcium, iron, or other dietary components, as a result of multiple pregnancies or dietary deficiencies could be expected to have increased cadmium absorption from the gastrointestinal tract.

3.3 Reference levels

207. **Provisional tolerable weekly intake** – The Joint FAO/WHO Expert Committee on Food Additives has established a provisional tolerable weekly intake (PWTI) of 7 µg/kg of body weight, corresponding to 1 µg/kg of body weight per day. Thus, for a 70-kg person, the tolerable daily intake is 70 µg of cadmium. Although there is some indication that a proportion of the general population might be at an increased risk of tubular dysfunction at the current PTWI, the Joint Expert Committee, at its fifty-fifth meeting, maintained the PTWI at this value because of a lack of precision in the risk estimates (WHO, 2004a). However, the results of a new study undertaken by the Scientific Panel on Contaminants in the Food Chain (CONTAM Panel) of the European Food and Safety Authority (EFSA) indicates that in order not to exceed the cut-off level for adverse health effects (increased excretion of beta-2-microglobulin) of 1 µg Cd/creatinine in urine, the intake should not exceed 2.5 µg Cd/kg body weight per week (Sweden and Switzerland submissions, 2009).

208. The U.S. EPA has established reference doses (or RfDs) for cadmium of 0.0005 mg/kg/day for exposures through water, and 0.003 mg/kg/day for exposures through food. In general, the RfD is defined as “an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime (U.S.EPA, 1992)

209. WHO recognizes that the margin between the PTWI and the actual weekly intake of cadmium in the general population is small (less than 10-fold) and may be even smaller in smokers (WHO, 2004b). Further research is needed to assess the potential public health impact of such exposures.

210. **Codex Alimentarius maximum levels** –Table 3-2 summarizes the Codex Alimentarius maximum levels for cadmium.

Table 3-2 Codex Alimentarius maximum levels for cadmium (Codex Alimentarius, 2005)

Code no.	Food	Maximum level (mg/kg)	Remarks
GC 0654	Wheat grain	0.2	
VR 0589	Potato	0.1	Peeled
VR 0075 VS 0078	Stem and root vegetables	0.1	Excluding celeriac and potato
VL 0053	Leafy vegetables	0.2	
VA 0035 VB 0040 VC 0045 VO 0050	Other vegetables	0.05	Excluding fungi and tomatoes

211. **Drinking-water guideline** – A drinking-water guideline value for cadmium of 0.003 mg/l has been established by WHO, based on an allocation of 10 percent of the PTWI to drinking-water and an average water consumption of 2 l/day (WHO, 2004b).

212. The EPA regulation for drinking water (also known as the Maximum Contaminant Level [or MCL]) limits cadmium in drinking water to 0.005 milligrams per litre (mg/L), and the EPA MCL Goal (or MCLG) is also 0.005 mg/L (U.S. EPA, 2008b)

213. **Cadmium in soil** - In order to prevent any further increase of cadmium in agricultural soils likely to increase the dietary intake of future generations, a guideline of 5 ng/m^3 in ambient air has been established by WHO (WHO, 2000).

4 Impacts on the environment

4.1 Environmental behaviour and toxicology

214. Cadmium is not an element that is essential for animal or plant life (with the exception of certain ocean phytoplankton at element-depleted conditions, see section 7.2).

215. Cadmium mobility in aquatic environments is enhanced by low pH, low hardness, low suspended matter levels, high redox potential and low salinity. In soil, the mobility and potential accumulation by biota is enhanced by low pH, low organic matter content, large soil particle size, and high soil moisture (Government of Canada, 1994).

216. Thus, in Canada, concentrations of dissolved cadmium in acidic lakes (pH 5.0 to 6.5) were found to be consistently higher than those in more neutral systems. At that time, in Canadian freshwater systems like the St. Lawrence River and Lake Erie, 60-90 percent of total cadmium may occur in the "dissolved" phase (i.e. dissolved and in particles of <0.45 μm) (Government of Canada, 1994).

217. In Europe, the dissolved fraction of cadmium ranges from 10-40 percent of total cadmium in the rivers Rhine, Meuse and Schelde, to about 50 percent in the rivers Rhine and Arno, and 30-40 percent in Tiber and Elbe rivers. In lakes Constance and Zürich (Switzerland), the percentage of dissolved cadmium is 80 and 84 percent, respectively. High-dissolved fractions are found in acid waters in which total concentrations are also elevated (ECB, 2005).

218. Cadmium is readily accumulated by many organisms, particularly by micro-organisms and molluscs in which bioaccumulation factors are in the order of thousands. Soil invertebrates also concentrate cadmium markedly in their tissue. Most organisms show low to moderate concentration factors of less than 100 (IPCS, 1992b).

219. In animals, cadmium concentrates in the internal organs like kidney and liver rather than in muscle or fat. Cadmium levels usually increase with age (IPCS, 1992b).

220. Available data indicate that cadmium bioaccumulates in all levels of the food chain. Cadmium accumulation has been reported in grasses and food crops, and in earthworms, poultry, cattle, horses, and wildlife. In plants, cadmium generally accumulates in the leaves of plants. It has been shown that for plants grown in the same soil, accumulation of cadmium decreases in this order: leafy vegetables > root vegetables > grain crops (ATSDR, 1999).

221. As cadmium mainly accumulates in the liver and kidneys of vertebrates, and the intestinal absorption of the metal is low, biomagnification through the food chain may not be significant. There exist data which indicate increased cadmium concentrations in some top predators, but overall the data on biomagnification of cadmium are found to be inconclusive (ATSDR, 1999). A recent study by Croteau *et al.* (2005) found that cadmium was progressively enriched among trophic levels in discrete epiphyte-based food webs composed of macrophyte-dwelling invertebrates (the first link being epiphytic algae) and fishes (the first link being gobies). Cadmium concentrations were biomagnified 15 times within the scope of two trophic links in both food webs.

222. Chronic cadmium exposure produces a wide variety of acute and chronic effects in mammals similar to those seen in humans. Kidney damage and lung emphysema are the primary effects of high cadmium in the body. Certain marine vertebrates contain markedly elevated cadmium concentrations in the kidney, which, although considered to be of natural origin, have been linked to signs of kidney damage in the organisms concerned (IPCS, 1992a).

223. Mammals can tolerate low levels of cadmium exposure by binding the metal to a special protein that renders it harmless. In this form, the cadmium accumulates in the kidney and liver. Higher levels of exposure, however, lead to kidney damage, disturbed calcium and vitamin D metabolism, and bone loss. The body takes decades to remove cadmium from its tissues and organs (IPCS, 1992a).

224. **Toxicity in relation to the marine environment** - Recent studies have focused on the affects of Cd on the biochemistry of various marine organisms. Toxic metals, including cadmium and lead, can generate reactive oxygen species that are highly toxic to marine organism. Exposure to Cd can cause both reversible and irreversible changes in proteins including ubiquitination and carbonylation (Chora *et al., 2008*). It has been suggested that this could be used as a biomaker for oxidative stress in marine bivalves. Cadmium-induced oxidative stress has also been reported in the green alga *Ulva lactuca* (Kumar *et al.*, 2010) and in the marine fish *Salaria basilisca* (Messaoudi *et al.*, 2009). Although survival rate and growth were not affected when farmed fish were fed a Cd-rich diet or exposed to waterborne Cd, induction of metallothioneins (metal-binding proteins involved in metal detoxification) occurred (Dang and Wang, 2009). Similarly, the synthesis of phytochelatin in three species of marine phytoplankton was enhanced by exposure to Cd^{2+}, although the effectiveness of phytochelatins as a detoxification pathway was found to be species-dependent (Wang and Wang, 2009). Sensitivity of mitochondrial ADP-stimulated respiration to Cd inhibition was found to increase with increased ambient temperature in wild oysters (*Crassostrea virginica)* from three parts of the United States (subtropical Texas, warm temperate North Caroline and cold temperate Washington) (Cherkasov *et al.*, 2010). This has the important implication that regulatory standards for water pollution derived in one area may not offer adequate protection in other (warmer) climates.

225. **Transformation to more- or less-toxic compounds -** In water, the availability of cadmium for bioaccumulation by marine organisms depends on the chemical species present: chelating agents such as dithiocarbamates and xanthates increase the uptake of cadmium by marine organisms; increase in temperature increases cadmium uptake and makes it more toxic whereas the higher the salinity and degree of hardness of the water, the lower the cadmium bioconcentration. The bioconcentration of cadmium at an increased temperature and decrease in salinity implies that cadmium could be more toxic in estuarine species rather than marine species. (Delmotte *et al.*, 2007). In sediments, the mobility of PTE depends on their speciation, pH, temperature, dissolved oxygen content, grainsize, and the availability of a wide variety of metal binding sites on the components of the solid phase. For example, the concentration and distribution of trace metals in salt marsh sediments were recently found to be correlated with organic carbon content, but not with other sediment properties (grain size, iron-oxyhydroxide content, acid volatile sulfides and pyrite content) that are known to be capable of playing a major role in trace metal partitioning (Roychoudhury 2007). The phosphorite deposits of southern Togo are substantially enriched in Cd (by a factor of 157 compared with shale), and the main Cd-carrying species appears to be apatite (Gnandi *et al.*, 2009). This is significant because it means that the processing of phosphorite by wet sieving using seawater and dumping of the tailings into the coastal waters of Togo could be a major local source of marine pollution with Cd.

226. Evidence has been reported of the biomethylation of Hg and Cd, at depth, by bacteria in the polar oceans (Pongratz and Heumann*, 1999*). Further work is required to determine the magnitude of the atmospheric flux of toxic species generated and to asses whether ice algae are also capable of methylating metals in the Arctic and Antarctic.

4.2 Environmental exposure

227. In this section, examples are given of ambient cadmium levels in countries and regions. The choice of examples does not imply that these places are to be considered as special, or at special risk, compared to many other places. The examples only serve to illustrate possible cadmium levels in the environment. Note also that some data are relatively old and may not necessarily represent the current situation at the locations in question. A wider range of examples could be beneficial for the presentation; it has however been beyond the limits of this review to describe them here.

228. **Terrestrial environments -** In European soils, measured concentrations (mainly from the northern part of Europe) of cadmium in areas away from point sources range between 0.05-14 mg/kg dw, and most concentrations are found in the range 0.1-1.8 mg/kg dw. The average of all survey means, medians or geometric means is 0.33 mg/kg dw, and the average of the 90th percentiles is 0.67 mg/kg dw. In northern Europe, the levels are largely below 0.25 mg/kg dw (ECB, 2005). The bioavailability of the cadmium in the soils is, apart from the concentration of cadmium in the soils, influenced by a number of physical and chemical properties of the soils as discussed in section 2.4.

229. In Japan, the level of cadmium in supposedly non-contaminated domestic soils is stated to be "several hundred ppb dry weight". The environmental quality standard (EQS) for cadmium in soils - 0.01 mg/L in leachate - was exceeded in 8-22 percent of the samples from the period 1998-2002, while the EQS in groundwater (0.01 mg/L) was not exceeded at all from 1999-2003 (Japan's submission, 2005).

230. Concentrations of cadmium measured in different media at different sites in 2006 in Norway show annual mean ranges of 0.016 to 0.063 ng/m^3 in air, 0.016 to 0.163 µg/L in precipitation and 7.1 to 64.4 µg/m2 atmospheric deposition, the lowest levels being in northern Norway; the annual range for levels in terrestrial mosses in Norway in 2005 was 0.017 to 2.5 µg/g and reflect deposition patterns; concentrations in sediment in 102 lakes sampled in 1995 showed a range of 0.0954 to 179 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.

231. Typical values of cadmium found in moss in Switzerland resulting from deposition of air particulates shows a downward trend from 1990 to 2000 with median values of 0.36 to 0.19 µg/g respectively. Levels in the Central Alps with low precipitation were just under half those from Southern Switzerland with high precipitation values (Switzerland's submission, 2007).

232. In an Australian environmental study, scat from red kangaroo (*Macropus rufus*) and western grey kangaroo (*Macropus fuliginosus*) were sampled with a 5-km spacing across large parts of western New South Wales and analysed for the content of, among others, cadmium and other metals. High contents were found in the scat sampled in the vicinity of Broken Hill in New South Wales and near a mine west of Broken Hill (Australia's submission, 2005). The results, reflecting that a high content of cadmium must be present in the top soil and vegetation on or near Broken Hill, are illustrated on Figure 4-1 below.

233. Moose and reindeer samples were collected annually as part of a national residue control programme in Finland. The cadmium levels in muscle tissue had decreased in all studied animals and were currently near the limit of quantification, 0.001 mg/kg wet weight. The cadmium levels in liver and kidney moose samples had decreased during the monitoring period and varied from 0.71 to 1.28 mg/.kg wet weight and 4.95 to 6.18 mg/kg wet weight respectively. In a corresponding study cadmium levels in Mountain hares were higher than in European hares and kidney cadmium levels in Mountain hares were statistically significantly higher than the kidney cadmium levels in moose. The kidney cadmium levels exceed the maximum level in theEU (1.0 mg/kg) in almost all adult reindeer samples and also in some calves (Venäläinen, 2007 in Finland's submission, 2007).

234. 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 cadmium 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 cadmium concentrations in PM10 particulate matter in atmospheric precipitation and in surface waters. A preliminary air quality assessment of cadmium content in PM10 particulate matter will be available in 2008 (Poland's submission, 2007).

235. In Armenia, the average cadmium content in air in industrial towns reached 0.0195µg/m3. Near the outlets in waste water of industrial enterprises the concentration of cadmium ranged from 1-5 mg/L; in soils near the Alaverdi mining and metallurgy combine cadmium levels exceeded control levels by 2-5fold, while in plants from the area cadmium levels exceeded the maximum allowable concentration of 0.03mg/kg 50 fold (Armenia's submission, 2007).

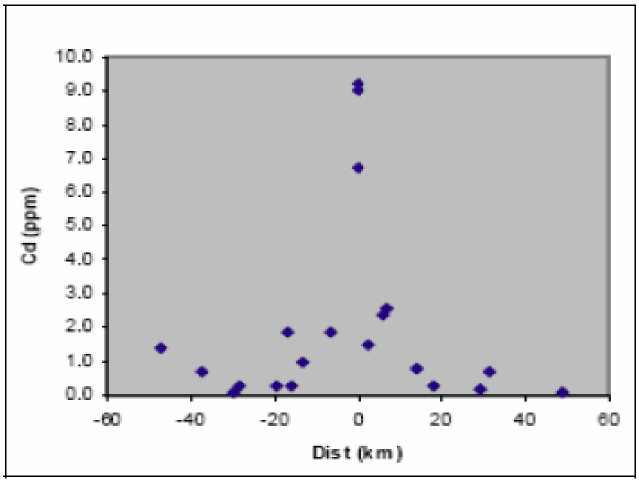


Figure 4-1 Levels of cadmium in kangaroo scat along East-West transect centred at Broken Hill, New South Wales, Australia (original figure from Australia's submission, 2005)

236. In Hungary concentration of cadmium in the environmental air is not regularly measured. Sampling and measurement campaigns have however been conducted from time to time. The last one was performed in 2005 by the network of environment authority. Samples taken in many towns and countrysides were analysed for As, Ni, Cd, Pb and benzo(a)pyrene in the PM10 fraction of dust. Figure 4-2 (Yearly average concentration of cadmium in PM10 from sampling points in the PM10 campaign) is drawn from those results (Hungary's submission, 2007).

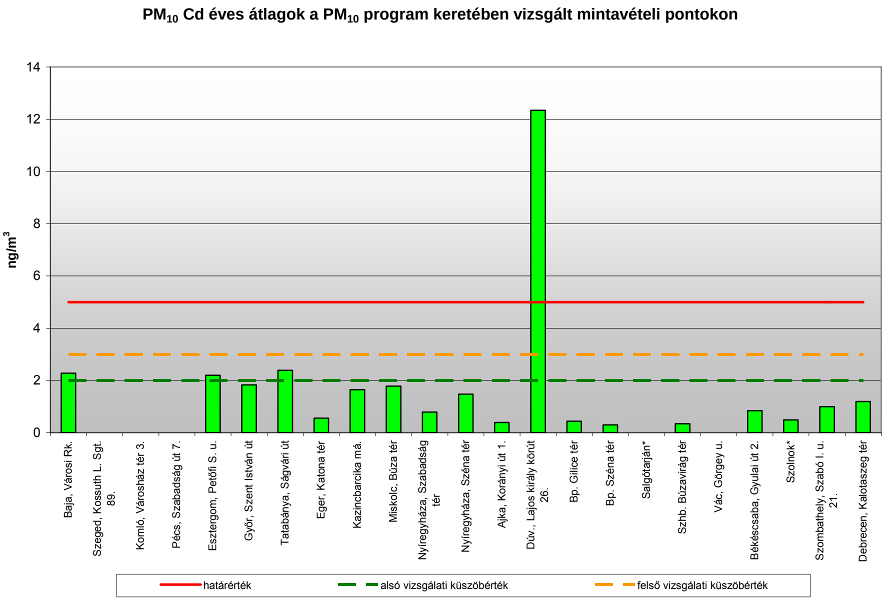


Figure 4-2 Yearly average concentration of cadmium in PM10 from sampling points of PM10

237. Cadmium levels determined in plants and soil samples of mafic and ultramafic rocks in the Mingora and Kabla areas, Swat, Pakistan were found be in the range of 0.04 to 0.09 mg/kg and 2.0 to

4.0 mg/kg respectively. It has also been reported that in major cities of Pakistan, raw effluents, currently being used for irrigation, had levels of cadmium greater than 0.01 ppm. In another study carried out in winter 2006 in Lahore, Pakistan, airborne $PM_{2.5}$ particulate matters were found to contain an average 7.02 ng/m^3 of Cd with a range varying from 0.34 to 27.7 ng/m^3. The study noted that airborne pollutants exhibited higher mass distribution in the winter season as compared to summer (Pakistan's submission, 2010).

238. **Aquatic environments -** Water characteristics affect cadmium toxicity. Toxicity of cadmium generally increases with reducing water hardness, reducing concentrations of dissolved organic matter and increasing solution pH. Effects of dissolved organic matter on cadmium toxicity cannot be described using the tests that are reviewed here since most tests did not report this water characteristic (ECB, 2005). Toxicity of Cd2+ in solution is lower in more acid conditions because of H^+/Cd^{2+} competition at the membrane (e.g. data on *Lemna paucicostata* (Nasu and Kugimoto, 1981 as cited by ECB, 2005)). Acidification leads to higher cadmium emissions from catchments into water, but this is an effect on exposure, not on ecotoxicology of soluble cadmium. In the presence of soluble cadmium complexes (cadmium complexed by dissolved organic matter), the situation is more complex because pH has effects on affinity of Cd^{2+} for the membrane and for the dissolved organic matter (ECB, 2005).

239. The complexation of cadmium with chloride in seawater has been shown to greatly influence its bioavailability and hence toxicity to marine organisms. It is most probable that chloride complexation is responsible for the reduced cadmium accumulation and toxicity in a variety of organisms observed with increasing salinities (IPCS, 1992b).

240. The concentrations of cadmium in EU freshwater have generally decreased since the end of the 1970's. In the lower course of the river Rhine, the largest drop in the concentration of dissolved cadmium occurred between 1977 and 1984, while in another study of great Dutch rivers, the cadmium concentrations (total dissolved and on suspended matter) decreased 4-fold from 1983 to 1986 (ECB, 2005).

241. Figure 4-3 shows monitoring data on levels of cadmium in Canadian marine and freshwaters in comparison to levels known to induce adverse effects in fish, invertebrates, amphibians and aquatic plants (Government of Canada, 1994). It appears from the figure that in Canadian marine waters, cadmium levels were largely below the lowest effect levels, while freshwater concentrations at or above effect thresholds were observed near point sources such as base metal smelters. It should be noted, though, that the monitoring data are almost all from before 1990 and, thus, the levels may well be lower today.

242. In Canadian marine and freshwater sediments cadmium levels in sediments were for the majority of sites below threshold effect levels, but the concentrations at the most highly contaminated locations near industrial and urban areas (means 5-40 mg/kg) were in the range that could cause effects (Government of Canada 1994).

243. Monitoring data on the content of dissolved cadmium in European freshwaters (mainly rivers) are summarised in Figure 4-4 . Observations near point sources are excluded from the data. The mean of the means is 0.11 µg/L, while the mean of the 90th percentiles is only slightly higher; 0.12 µg/L. Practically all the values lie within the interval 0.01-1.0 µg/L. For the EU risk assessment of cadmium, a level of 0.05 µg/L (dissolved fraction) was chosen as the natural background level in freshwaters, while for sediment the background level was chosen to be 2 mg/kg dry weight (dw). The natural background in sediments is probably lower; a level of 0.1-0.8 mg/kg dry weight has been suggested (ECB, 2005).

244. Levels of cadmium in water in Moldova are shown in Table 4-1. Additional data on cadmium levels in aquatic sediments and soil were also provided in the submission from Moldova and are available on the UNEP Chemicals website.

Table 4-1 Levels of cadmium 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
Cd µg/l	Total	Dissolved	Total	Dissolved	Total	Dissolved	Dissolved	Dissolved	Dissolved	Dissolved
2002	1.379	<0.5	1.483	0.5	1.475	0.5				
2003	0.5	0.5	0.5	0.5	0.5	0.5				
2004	0.5	0.5	0.5	0.5	0.5	0.5				
2005	0.37	0.5	1.22	0.33	2.25	0.3				
2006	0.21	0.08	0.16	0.12	0.29	0.0	<0.5	<0.5	<0.5	<0.5

Maximum permissible concentration (MPC) (dissolved) 1.0 µg/l for surface water of potable purposes;
5.0 µg/l for reservoirs of fish-breeding purpose

245. The cadmium concentration of rivers in Hungary is regularly analysed. Based on these data the influx of dissolved cadmium of the major rivers entering Hungary, and similarly, the amount of cadmium in the rivers leaving the country is estimated in values of 27 tonnes of cadmium input to the rivers Duna, TIsza and Drava and 9 tonnes cadmium output. Industrial enterprises as well as municipalities are obliged to analyze the cadmium concentration of discharge waters. An estimated 57.8 kg/year was discharged from industry and 298.6 kg/year from municipalities (Hungary's submission, 2007).

246. Concentrations of cadmium in marine organisms in Norway gave annual median ranges of 0.788 to 13.8 ppm dry weight in blue mussel (*Mytillus edulis*) soft body tissue, 0.019 to 0.414 ppm dry weight in cod (*Gadus morhua*) liver tissue and 0.014 to 1.31 ppm dry weight in other fish species liver tissue (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 (Norway's submission, 2007).

247. Concentrations of cadmium in mussels (both *M. edulis* and *M. galloprovindalis*) during the period 1995 to 1999 (2001 for the Black Sea) indicate that levels were elevated in the estuaries of large rivers in areas with point source discharges and in some harbours. No high concentrations (above EU food stuff limit values were found for any fish. At seven locations, different from the observed hot spots, increasing trends in cadmium concentrations of mussels and fish were observed. A total of 283 temporal trends have been analysed statistically on a station-by-station basis, of which only 27 were statistically significant: 20 downwards and seven upwards (Green *et al*., 2003 in Finland's submission).

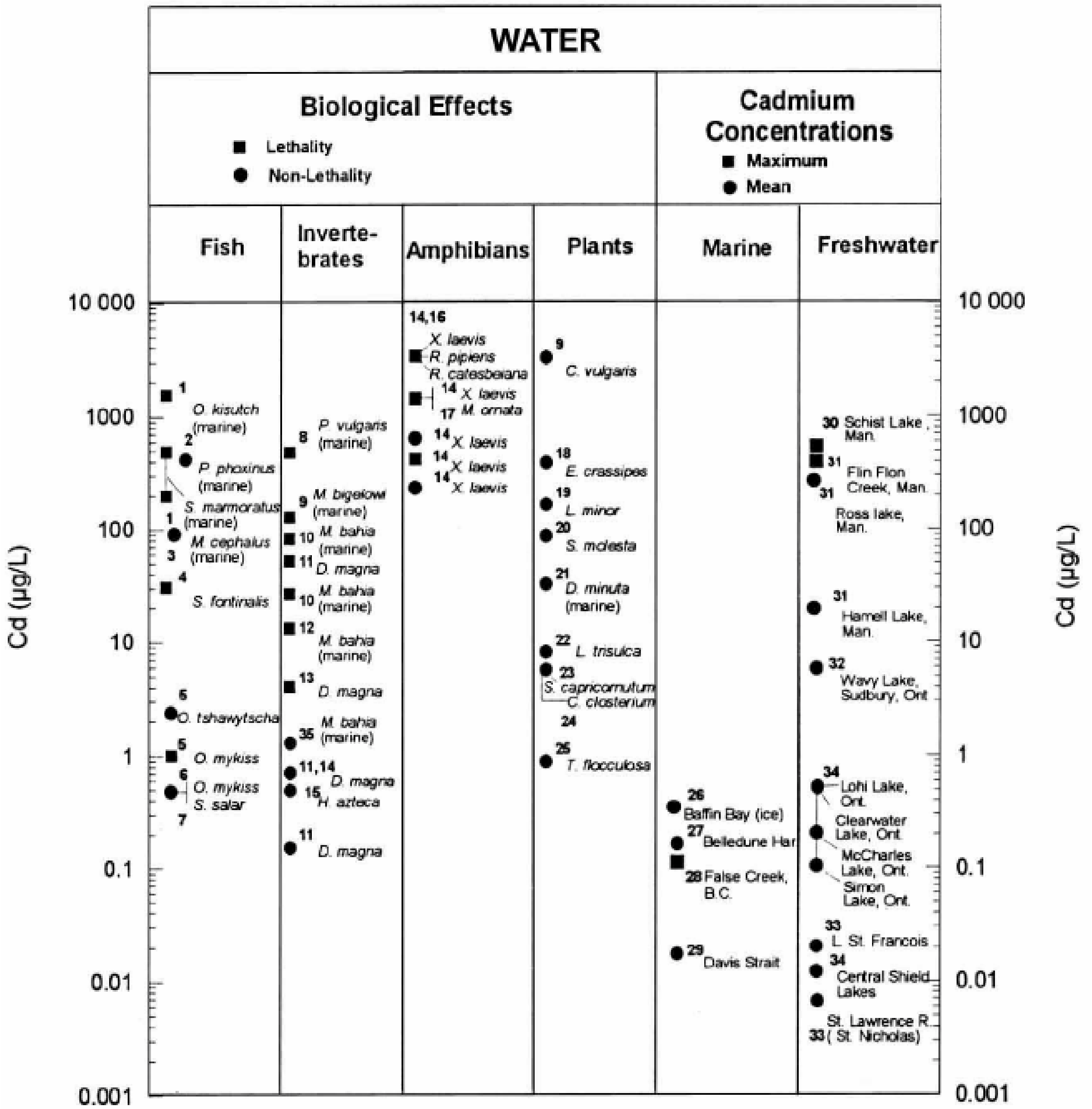


Figure 4-3 *Monitoring data on levels of cadmium in Canadian marine and fresh waters in comparison to levels known to induce adverse effects on fish, invertebrates, amphibians and aquatic plants. Note logarithmic scale (original figure Government of Canada, 1994)*

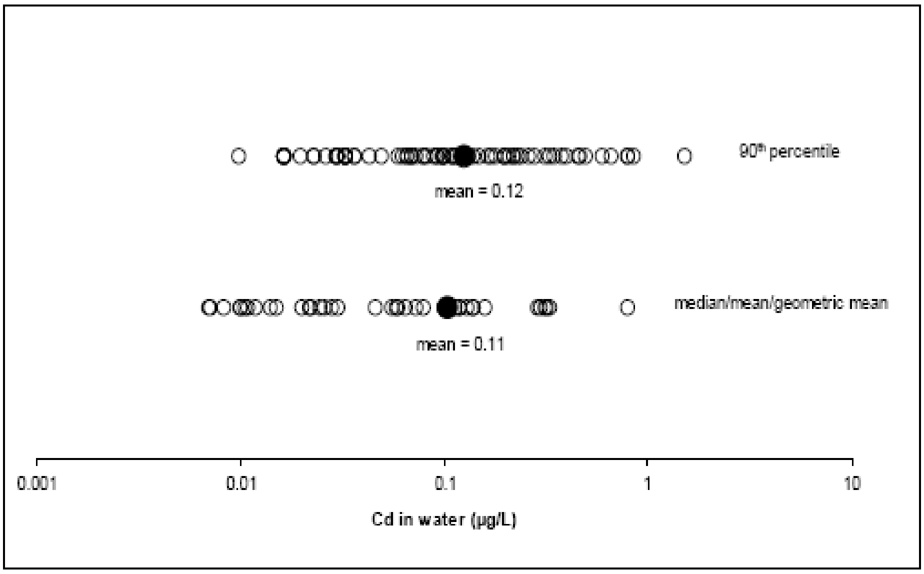


Figure 4-4 Summary of measured concentrations of dissolved cadmium in European freshwaters (mean values and 90th percentiles) (original figure from ECB, 2005)

248. Japanese monitoring data from 1997 and later (Japan's submission, 2005) for cadmium residues in some aquatic organisms are shown in Table 4-2 below. The results clearly demonstrate that cadmium is bioconcentrated in the liver and kidney of both fish and marine mammals. Data from a number of analysed birds of prey exhibit the same pattern, however, at much lower concentration levels than the marine species monitored (Japan's submission, 2005).

Table 4-2 Cadmium levels in tissue and organs of some marine species in Japan (Japan's submission, 2005)

Species	**Analyzed part**	**Mean concentration (ppm, dw)**	**Note**
Skipjack	liver	18.1 - 42.5	Average value range in the researches in 1997
	muscle	0.1 - 5.4	
Bluefin tuna	liver	1.2 - 40.0	Average value range in the researches in 1999-2000
Sagittated calamary	liver	35 - 67	Average value range in the researches in 1997
		38	Average value in the researches in 1999
		34	Average value in the research in 2000
		10 - 142	Range of average value in the research in 2001
Mussel (small size)	soft tissue	0.14 - 0.77	Range of average value in the research in 1998 - 1999
Mussel (large size)	soft tissue	0.50 - 1.25	

Table 4-2 Continued

Species	Location & period	Sample	Part	Concentration (µg/g dry) mean ±SD(range)	Ref.
Northern fur seal *Callorhinus ursinus*	off Sanriku 1997 and 1998	m=3, f=20	liver	47.5 ±29.5 (11.1-136)	(Ikemoto *et al.*, 2004)
			kidney	209 ±88 (86.0-497)	
			muscle	0.539 ±0.286 (0.142-1.16)	
			hair	0.635 ±0.245 (0.373-1.368)	
Dall's porpoises *Phocoenoides dalli*	off Sanriku coast March-April 1999 January-April 2000	n=45 (m=25, f=20)	skin	all: 0.026 ±0.026(0.003-0.13) m: 0.027 ±0.028(0.004-0.13) f: 0.024 ±0.023(0.003-0.11)	(Yang *et al.*, 2002)
	inshore area of Sea of Japan in Hokkaido May-June 1999	n=31 (m=17, f=14)	skin	all: 0.40 ±0.33(0.017-1.6) m: 0.43 ±0.37(0.065-1.6) f: 0.35 ±0.27(0.017-0.91)	

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

249. **Arctic environments -** The concentration of cadmium and other hazardous substances in the Arctic environment and biota and the possible environmental and health effects of the substances are monitored by the Arctic Monitoring and Assessment Programme (AMAP) and reported in the Arctic Assessment reports prepared by AMAP. In general, the levels of cadmium that have been measured in Arctic marine species do not appear to be above toxicity thresholds (UNECE, 2006b). Some seabird species may exceed thresholds for terrestrial birds, however, seabirds are known to be adapted to higher levels of cadmium found naturally in the marine environment and are therefore not considered to be as sensitive as terrestrial birds (UNECE, 2006b). Similarly, some marine mammals approach and even exceed the threshold for terrestrial mammals, however, they are generally an order of magnitude below thresholds derived for marine mammals (Figure 4-5). Ringed seals from Greenland that display relatively high concentrations of cadmium in their kidneys did not display any signs of related adverse effects (AMAP, 1998 as cited by UNECE, 2006b). UNECE (2006b) notes that the overwhelming majority of cadmium in the world's oceans is naturally occurring.

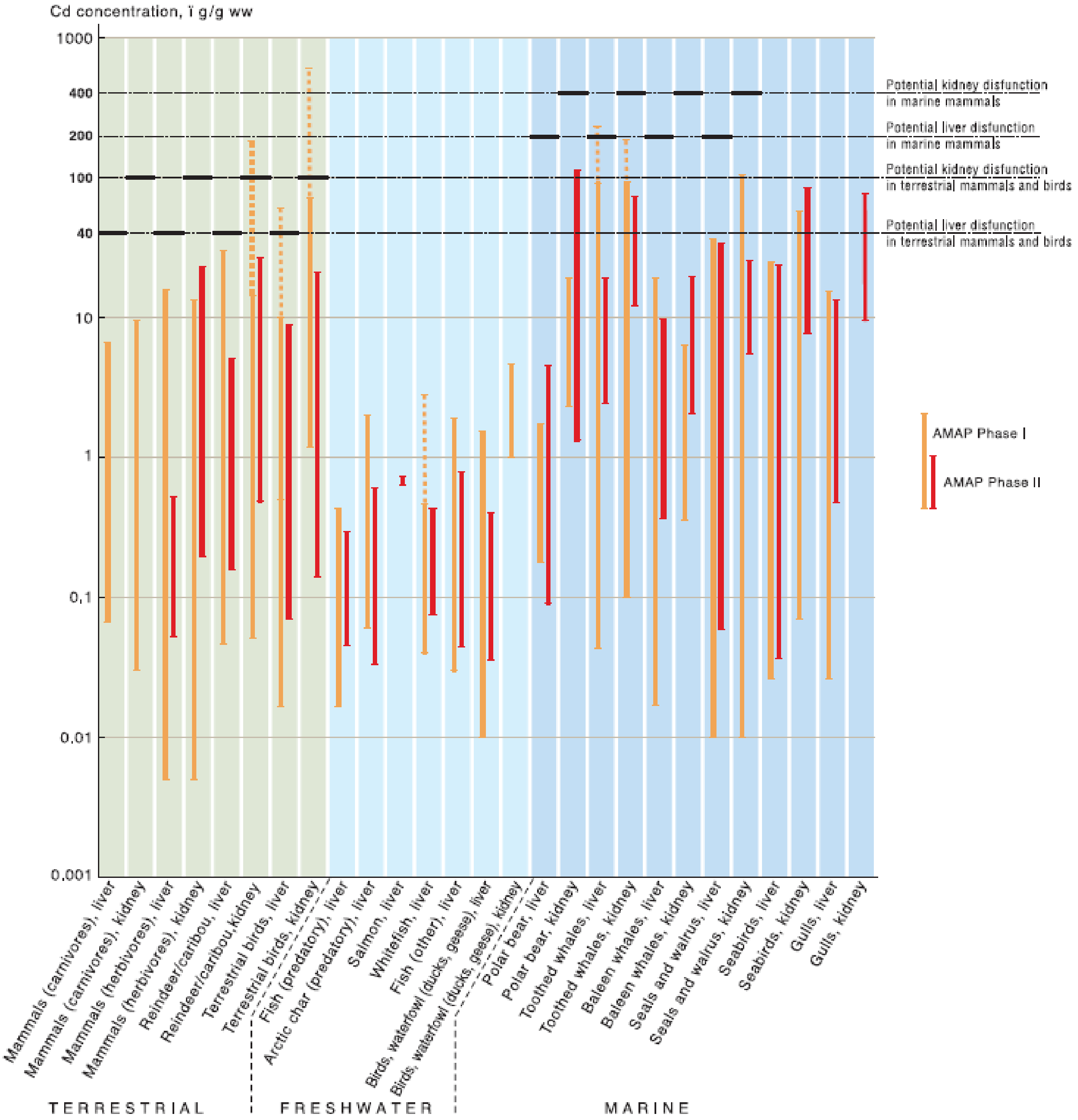


Figure 4-5 Ranges in cadmium concentrations that were reported during the last two AMAP assessments are displayed as vertical bars and compared to toxicity thresholds represented by horizontal lines. Toxicity thresholds are taken from ecotoxicology literature and reviewed in (AMAP, 2005)

250. The concentration of cadmium in different environmental matrices and environmental quality objectives in Trinidad and Tobago is shown in Table 4-3. The data illustrates the wide ranges found in the concentration of cadmium in the media.

Table 4-3 Concentration of cadmium 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)	<0.07	-	100
Water (µg/L)			
- Seawater	<0.04-59.5	0.4	40
- Freshwater	<1.0-300	-	2.0
- Groundwater	<0.01	<0.01	5
Soil and Sediment (µg/g)	<0.06-2.24	<0.5	0.7

4.3 Effects on organisms and ecosystems

4.3.1 Birds and terrestrial mammals

251. Kidney damage has been reported in wild colonies of pelagic sea birds having cadmium levels of 60-480 µg/g in the kidney (IPCS, 1992b). Seabirds and marine mammals in Greenland have high levels of cadmium, but researchers have found no evidence of effects in a study of ringed seal specimens with very high cadmium levels in their kidneys (AMAP, 2002). AMAP (2005) concludes that based on existing toxicity thresholds for non-Arctic species, cadmium levels in some Arctic seabirds are high enough to cause kidney damage. However, monitoring data on cadmium in the abiotic and biotic environment to date provide no conclusive evidence of trends or effects.

252. Cadmium levels in some reindeer/caribou, moose (*Alces alces*), and ptarmigan (*Lagopus mutus*) from the Yukon Territory (Canada) as well as those in seabirds and marine mammals from northwest Greenland and the Faroe Islands may be high enough to cause kidney damage (AMAP, 2005). Pathological investigations on ringed seal, beluga and bowhead whale (*Balaena mysticetus*), including examinations of animals with cadmium levels above expected effects thresholds, have not identified cadmium related effects (AMAP, 2005).

253. Cadmium concentration in liver, kidney, and fur of Japanese black bear was investigated. Three samples showed concentration of 1 µg/g or higher in liver. Concentration is higher in kidney than in liver, the maximum value in liver being 3.2 µg/g while it is 20.5 µg/g in kidney. Cadmium concentration was higher in the kidney than in the liver and muscle in Stellar's sea eagles and white-tailes sea eagles sampled in Hokkaido and Golden eagle in Iwate in Japan. Common kestrel samples in the neighbourhood of Haneda Airport near landfill disposal sites or industrial areas showed higher cadmium concentration in the liver and kidney (Japan's submission, 2007).

254. In some Arctic locations cadmium concentrations measured in liver of terrestrial wildlife, e.g. caribou from Yukon, Canada, approach the threshold for adverse effects on liver (40 µg/g ww). The cases of high exposure, like that of Yukon caribou, however, were all attributed to natural conditions, not deposition from long-range atmospheric transport (AMAP 2005 as cited by UNECE, 2006b).

255. The risk of secondary poisoning of fish-eating birds by cadmium is assessed to be smaller than the direct effects in the freshwater environment. In contrast, nephrotoxic lesions ascribed to cadmium have been observed in sea birds from relatively uncontaminated areas and where natural cadmium may be the source (ECB, 2005).

256. For the terrestrial environment, the risk of secondary poisoning in the soil-worm-bird/mammal system is predicted to be far more critical than the risk of soil cadmium affecting plants, invertebrates or micro-organisms (ECB, 2005).

257. No Observed Effect Concentrations (NOECs) for oral exposure to cadmium via ingestion of food have been calculated by the assessment factor method (AFM) to be 0.30 mg/kg food (fresh weight) for mammals and 0.16 mg/kg food for birds (ECB, 2005). The latter value, which is the NOEC for feeding studies of mallard ducks, is used by the EU as $PNEC_{oral}$ (Predicted No Effect Concentration) in the risk assessment for mammals and birds (ECB, 2005).

258. Based on a number of Australian studies it was concluded that bioaccumulation of cadmium in animals had been identified in close proximity to smelters or near major mineral ore bodies, and that in most cases, bioaccumulation in animals and plants was at its greatest within close proximity to these smelters and ore bodies. In the case of grazing ruminants, concentrations of cadmium were attributed to the consumption of soil treated with superphosphate fertilizer (Australia's submission, 2005).

4.3.2 Other terrestrial species including micro-organisms and plants

259. Cadmium is toxic to a wide range of micro-organisms as demonstrated by laboratory experiments. However, in the presence of sediment, high concentrations of dissolved salts or organic matter in the test vessels all reduce the toxic impact. The main effects are on growth and reproduction. The most affected soil micro-organisms are fungi, some species being eliminated after exposure to cadmium in soil. Selection exists for resistant strains of micro-organisms after low exposure to the metal in soil (IPCS, 1992a).

260. In Canada, it was concluded that a wide range of laboratory and field effects studies with soil invertebrates, micro-organisms, metabolic processes, and vascular plants consistently support an effects threshold in soil of 2.0 mg/kg (d.w.) (total cadmium) (Government of Canada, 1994). Effects associated with this threshold soil concentration range from physiological impairment in individual organisms (e.g., growth, reproduction) to impacts on soil community structure (e.g., altered microbial populations) and function (e.g., nitrogen fixation, CO_2 evolution).

261. The toxicity of cadmium for soil micro-organisms generally decreases with increasing clay content, pH and organic matter content. The data behind the effects values in Table 4-4 indicate that nitrogen-fixation is probably the most sensitive soil microbial process. Toxic effects on nitrogen-fixation have been found with moderate cadmium pollution, both in metal salt-applied soils as in sludge-treated soils (ECB, 2005). The LOEC values on yield of clover or on population of *Rhizobium leguminosarum* biovar *trifolii* was 0.8 µg/g, 1.0 µg/g and 6.0 µg/g cadmium in three European long-term sludge treated plots). The Zn levels on these sites was 130 µg/g, 200 µg/g and 180 µg/g, respectively (ECB, 2005).

262. Cadmium affects the growth of plants in experimental studies, although no field effects have been reported. Stomatal opening, transpiration, and photosynthesis have been reported to be affected by cadmium in nutrient solutions, but the metal is taken up into plants more readily from nutrient solutions than from soil. Terrestrial plants may accumulate cadmium in the roots, and cadmium is found bound to the cell walls (AMAP, 1998).

263. In Table 4-4 a summary of the NOECs, LOECs and EC_{50}s determined as part of the EU risk assessment of cadmium (ECB, 2005) for soil micro-organisms, soil fauna and higher terrestrial plants is presented. The NOEC (No Observed Effect Concentration), LOEC (Lowest Observed Effect Concentration) and EC_{50} (concentration at which 50 percent are affected) values determined for soil fauna are based on standard tests with the earthworm *Eisenia fetida* and the collembolan *Folsomia candida*. The compilation of data indicates that soil fauna are less sensitive to cadmium than soil micro-organisms and plants. The LOEC values obtained with soil fauna are all higher than or equal to 5 mg/kg, whereas cadmium toxicity to soil microbial processes or plants has been shown at lower concentrations (ECB, 2005).

264. A total $PNEC_{soil}$ of 1.15-2.3 mg/kg soil has been proposed. The country averages for soils in European countries range from 0.21 to 0.54 mg/kg. Data on soil concentration in a range of countries are further shown in Figure 2-1.

Table 4-4 Summary of the NOECs, LOECs and EC_{50}s determined as part of the EU risk assessment of cadmium (ECB, 2005) for soil micro-organisms, soil fauna and higher terrestrial plants.

	NOEC (mg/kg)			
	min	**median**	**max**	**n**
Microflora	3.6	50	3000	21
Higher plants	1.8	10	80	41
Soil fauna	5	32	320	13
	LOEC (mg/kg)			
	min	**median**	**max**	**n**
Microflora	7.1	100	8000	21
Higher plants	2.5	40	160	44
Soil fauna	5	59	326	12
	E-$LC_{x\geq50}$ (mg/kg)			
	min	**median**	**max**	**n**
Microflora	7.1	283	5264	20
Higher plants	2.8	100	320	34
Soil fauna	27	102	3680	28

The minimum, the 5th percentile, median and maximum values of the NOEC, LOEC and EC_{50}/LC_{50} concentrations of terrestrial effect tests found in the literature are shown, as well as the number of studies included for each category of organisms and endpoints. All concentrations in mg/kg
n: number of studies

4.3.3 Terrestrial ecosystems

265. 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 to evaluate the loads within Europe (EMEP area). 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 beyond the limits of this review to describe them here.

266. Preliminary critical load levels for cadmium 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). Figure 4-6 below shows the areas in which the critical load level for cadmium, i.e. the level above which terrestrial ecosystems are considered to be at risk, were exceeded in 1990 and 2000, respectively. As indicated in the table, the areas in which the atmospheric deposition exceeded the critical load levels (as defined by the methodology) for cadmium.

267. These calculations are based only on atmospheric cadmium loads and do not take into account other major anthropogenic cadmium loads to soil such as from fertilizers, manure and sewage sludge. Note that the "critical load" approach used in work under the UNECE LRTAP Convention (see Section 9.2.1) is one option for assessing the risk of impacts from pollutants. Other approaches exist; it has however been beyond the limits of this review to describe them here.

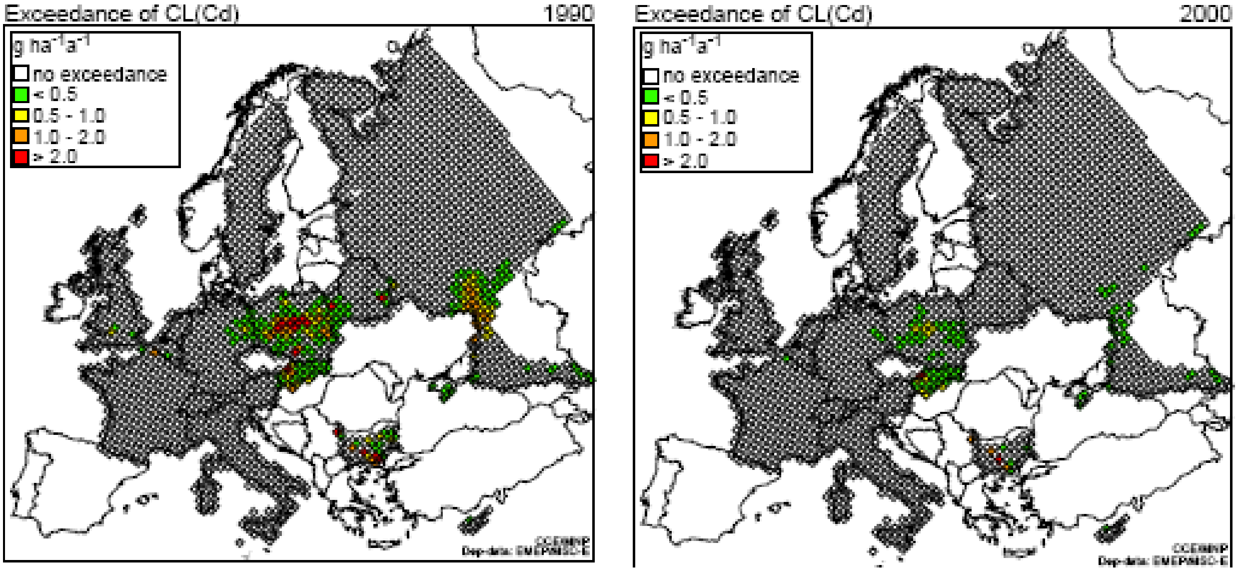


Figure 4-6 Areas in which the critical load level for cadmium, i.e. the level above which terrestrial ecosystems are considered to be at risk, were exceeded in 1990 and 2000, respectively, due to atmospheric emissions only (Slootweg et al., 2005). White grid cells indicate non-exceedance, whereas white areas without grid indicate no data.

4.3.4 Aquatic organisms

268. In aquatic systems, cadmium is most readily absorbed by organisms directly from the water in its free ionic form (AMAP, 1998). The acute toxicity of cadmium to aquatic organisms is variable, even between closely related species, and is related to the free ionic concentration of the metal. Cadmium interacts with the calcium metabolism, and in fish it causes abnormally low calcium levels (hypocalcaemia), probably by inhibiting calcium uptake from the water. However, high calcium concentrations in the water protect fish from cadmium uptake by competing at uptake sites. Effects of long-term exposure can include larval mortality and temporary reduction in growth (AMAP, 1998).

269. Zinc increases the toxicity of cadmium to aquatic invertebrates. Sublethal effects have been reported on the growth and reproduction of aquatic invertebrates; there are structural effects on invertebrate gills. There is evidence of the selection of resistant strains of aquatic invertebrates after exposure to cadmium in the field. The toxicity is variable in fish, salmonoids being particularly susceptible to cadmium. Sublethal effects in fish, notably malformation of the spine, have been reported. The most susceptible life-stages are the embryo and early larva, while eggs are the least susceptible (IPCS, 1992b).

270. The toxicity of cadmium to aquatic plant, invertebrate and vertebrate species has been studied extensively. Planktonic and benthic (bottom living) invertebrates appear to be the most sensitive biota in freshwaters, with laboratory-derived LOECs (reproductive impairment) reported as low as 0.17 µg Cd/L (48.5 mg $CaCO_3$/L) for the zooplankton *Daphnia magna*. This laboratory threshold was supported by *in situ* field experiments in Ontario, Canada demonstrating growth inhibition in two Cladocerans *(Daphnia galeata mendotae* and *Holopedium gibberum)* at 0.2 µg Cd/L. The effects threshold of 0.17 µg Cd/L for freshwater was exceeded by total mean concentrations reported in waters from four lakes in the vicinity of known sources (e.g. metal smelters) in Ontario (Government of Canada, 1994).

271. Invertebrates are also considered to be among the most sensitive biota tested in marine water. The lowest-observed-effect concentration identified was 1.2 µg Cd/L, based on reduced survival and reproduction of the zooplankton, *Mysidopsis bahia* (Government of Canada, 1994).

272. In a survey in selected Ontario lakes, community structure changes (absence of 5 percent of the species) occurred in sediments with cadmium concentrations > 0.6 mg/kg dry weight (dw). Major community structure changes (absence of 95 percent of the species) were observed in sediments with concentrations of cadmium > 9.5 mg/kg dw (Government of Canada, 1994).

273. For marine benthic biota, the most sensitive effects reported were mortality (40 percent) and behavioural effects (44 percent) for the amphipod *Rhepoxynius abronius* at 5.6 mg/kg dw following a 72-hour exposure period. Concentrations associated with lethality following acute exposure, and with various sublethal effects following chronic exposure, range from 6.5 to 11.5 mg/kg dw for *R. abronius* and two other infaunal amphipods, *Eohaustorius sencillus* and *Pontoporeia affinis* (Government of Canada, 1994).

274. The survival and behaviour of the water hyacinth *Eichhornia crassipes* was studied in Egypt (Soltan and Rashed, 2001) under varying heavy metal concentrations in different aquatic media e.g. Nile water and wastewater. The results showed that water hyacinth can survive in a mixture of heavy metal concentrations up to 3 mg/L, whereas higher concentrations of metals as mixtures and 100 mg Cd/L led to rapid fading of the plants.

275. In Japan, the biological monitoring research results in Table 4-5 allow for the provision of information on bioaccumulation. In loggerhead turtles and green turtles, cadmium is detected in higher concentrations in the liver, kidney and pancreas. Cadmium concentration is lower in egg and reproductive organs indicating that cadmium release at egg-laying is not so significant. The concentration in the carapace is also low. In green turtles and hawksbill turtles, cadmium tends to be more accumulated in kidney rather than in liver or muscle. (Japan’s submission, 2007).

Table 4-5 Research on monitoring methodology using index species （1997～2001）

Species	Analyzed part	Mean concentration (ppm, dw)	Note
skipjack	liver	18.1～42.5	Average value range in the research in 1997.
	muscle	0.1～5.4	
bluefine tuna	liver	1.2～40.0	Average value range in the research in 1999-2000.
sagittated calamary	liver	35～67	Average value range in the research in 1997.
		38	Average values in the research in 1999.
		34	Average values in the research in2000.
		10～142	Range of average values in the research in 2001.
mussel(small size)	soft tissue	0.14～0.77	Range of average values in the research in 1998-1999.
mussel(large size)	soft tissue	0.50～1.25	

276. In Table 4-6 below, a summary of the NOECs, LOECs and EC_{50}s determined for aquatic fish, amphibians, invertebrates and primary producers in the EU risk assessment of cadmium (ECB, 2005) is presented. A total $PNEC_{water}$ of 0.19 μg/L has been proposed in the risk assessment, while the proposed PNEC for benthic organisms ($PNEC_{sediment}$) is 2.3 mg/kg dw. The levels in European waters away from point sources are, on average, below this level, but higher levels do occur.

Table 4-6 Summary of the NOECs, LOECs and EC$_{50}$s determined for aquatic fish, amphibians, invertebrates and primary producers in the EU risk assessment of cadmium (ECB, 2005)

	NOEC (chronic tests only) (µg/L)			
	min	**median**	**max**	**n**
Fish/amphibians	0.47	4.2	62	19
Aquatic invertebrates	0.16	2.0	11	22
Primary producers	0.85	6.9	31	8
	LOEC (chronic tests only) (µg/L)			
	min	**median**	**max**	**n**
Fish/amphibians	0.78	11	132	20
Aquatic invertebrates	0.28	1.9	25	19
Primary producers	1.9	18	100	9
	E-LC$_{x\geq50}$ (chronic tests only) (µg/L)			
	min	**median**	**max**	**n**
Fish/amphibians	3.4	20	650	7
Aquatic invertebrates	1	5	32	14
Primary producers	6.1	59	1000	12
	E-LC$_{x\geq50}$ (acute tests only) (µg/L)			
	min	**median**	**max**	**n**
Fish/amphibians	0.9	1500	40,200	31
Aquatic invertebrates	7	166	74,000	61

n = Number of samples

277. The following main conclusions were drawn in the EU risk assessment of cadmium (ECB, 2005) based on the extensive review of literature on effects on aquatic organisms at different trophic levels:

- For fish (and amphibians), it was concluded that the lowest effect concentrations for fish were found at 0.8 µg/L. Toxicity is most pronounced in soft water. One reliable EC$_{50}$ and one LOEC value were found below 1 µg/L. These values refer to tests performed at water hardness < 50 mg $CaCO_3$/L. Reproduction parameters are most sensitively affected by cadmium.

- Primary aquatic consumers (invertebrates) can be affected by cadmium in the µg/L range and below. Reproduction was found to be the most sensitive endpoint. Different effect data lower than 1 µg/L were found. However, several of those values are considered unreliable because they were obtained by extrapolation, or because they are expressed as nominal concentrations without information on background cadmium concentration in the test medium;

- Cadmium can affect primary producers (mainly algae) in the 1-10 µg/L range, but no tests showed toxicity below 1 µg/L. At nutrient-limiting conditions and low cell density, species are likely to be most sensitive to cadmium. With one exception, all tests were performed in artificial media, some of which had very similar composition as freshwater samples;

- The summary of selected data from chronic tests reveals that sensitivity to cadmium decreases as follows: aquatic invertebrates > fish/amphibians> primary producers.

278. In Togo cadmium levels have been recorded in crustacean as follows: 0.24 ppm in Penaeus duorarum, 0.14 ppm in Callinectes pallidus and 0.16 ppm in Cardisoma armatum (Togo's submission, 2007).Table 4-7 provides data on cadmium concentration in dried fish in Togo.

Table 4-7 Concentration of cadmium (ppm) dry weight of dried fish (Togo's submission, 2007)

Species name	**Concentration of cadmium (ppm)**			
	Agbodrafo	**Kpeme**	**Goumou-Kope**	**Aného**
1*Chloroscombrus chrysurus*	0,25	0,36	1,68	0,12
2 *Sardinella aurita*	0,24	0,24	1,00	0,12
3 *Ilisha africana*	0,38	0,38	0,46	0,13
4 *Galeoides decadactylus*	0,25	0,46	1,06	0,12
5 *Caranx latus*		0,37	0,58	0,12
6 *Sphyraena barracuda*		0,37	0,25	0,20
7 *Selene dorsalis*		0,23	0,25	0,13
8 *Caranx crysos*		0,10	0,12	
9 *Pellonula leonensis*		0,37	0,20	
10 *Trichiusus lepturus*		0,25	0,12	

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

4.3.5 Summary of PNECs for all environmental compartments

279. The predicted no-effect concentrations (PNECs) derived for the various environmental compartments and groups of organisms in the EU risk assessment of cadmium (ECB, 2005) are summarised in Table 4-8 below.

Table 4-8 The predicted no-effect concentrations (PNECs) derived for the various environmental compartments and groups of organisms in the EU risk assessment of cadmium (ECB, 2005)

	Value	**Units**	**Remark**
PNEC $_{water}$	0.19	µg Cd/L	dissolved fraction
PNEC $_{water}$	$0.09^{*}(H/50)^{0.7409}$	µg Cd/L	for refined risk characterisation if hardness is known (section 3.2.1.6.4); dissolved fraction; not to be used below H=40
PNEC $_{soil}$	1.15 – 2.3	µg Cd/kg dw	based on ecotoxicity
PNEC $_{soil}$	0.9 (selected)	µg Cd/kg dw	based on secondary poisoning to mammals (local and regional)
PNEC $_{sediment}$	2.3	µg Cd/kg dw	AVS and oc based normalisation could be used for regional as well as site-specific risk characterisation
PNEC $_{micr-organisms}$	20	µg Cd/kg	dissolved fraction only
PNEC $_{oral}$	0.16	mg Cd/kg $_{diet\ fw}$	birds/mammals

AVS: acid-volatile sulphides, oc: organic carbon content

5 Sources and releases to the environment

280. The important releases of cadmium to the biosphere can be grouped in the following categories:

- Natural sources - releases due to natural mobilisation of cadmium from the Earth's crust and mantle, such as volcanic activity including hydrothermal vents and weathering of rocks;
- Current anthropogenic (associated with human activity) releases from the mobilisation of cadmium impurities in raw materials such as phosphate minerals, fossil fuels and other extracted, treated and recycled materials - particularly zinc and copper;
- Current anthropogenic releases resulting from cadmium used intentionally in products and processes, due to releases by manufacturing, use, disposal or incineration of products;

281. Besides these categories, remobilisation of historic anthropogenic cadmium releases previously deposited in soils, sediments, landfills and waste/tailings piles may be considered.

282. The recipients of cadmium releases to the environment include: the atmosphere, aquatic environments (fresh and salt water environments) and terrestrial environment (soil and biota). Within the environment, cadmium will flux between these compartments. Cadmium released to the atmosphere will be redirected to the terrestrial and aquatic environments as atmospheric deposition, whereas some cadmium released to soil over time will be washed out to the aquatic environments. It is also important to assess the bioavailability of cadmium in soils or sediments. For example, complexed to organic substances or bound to sulphides, cadmium may not be bioavailable. Other parameters like high soil pH values will also render cadmium less bioavailable as reported in chapter 2.

5.1 Natural sources

283. Natural sources of cadmium to the biosphere include volcanic activity, and the weathering of rocks and minerals. In addition, insignificant amounts of cadmium enter the biosphere through meteoritic dust.

284. The atmospheric emission from volcanoes in 1983 is estimated at 140-1,500 tonnes (Nriagu, 1989). In a newer study (Richardson *et al.,* 2001), the releases are estimated at 380 - 3,800 tonnes (see Table 5-1). Hydrothermal vents (undersea volcanic activity) may be a direct natural source of cadmium to the oceans. Most of the vents are along the Mid-Ocean Ridge. Vents are also found along some subduction zones (Bruland and Lohan, 2004). Vents can also occur on land. Two of the most famous are the hot springs and geysers in Yellowstone National Park in the USA and on the North Island f New Zealand (Bruland and Lohan, 2004).

285. As cadmium is an element that is naturally present in many minerals, cadmium will be present in rocks and soils in low concentrations. The concentration of cadmium in the continental crust ranges from 0.008 to 0.1 mg/kg cadmium (Rudnick, 2004 as quoted by Australia's submission, 2005), while cadmium concentration in common rock types and soils ranges from 0.001-0.60 mg/kg for igneous rocks to 0.05-500 mg/kg for sedimentary rocks (Adriano, 2001, as quoted by Australia's submission, 2005). In Togo natural sources of cadmium are mainly veins of sedimentary phosphate from Hahotoé-Kpogamé (Southern Togo) with mean levels of 49 ppm for raw minerals and 58 ppm for commercial minerals (Togo’s submission, 2007).

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

287. Weathering and erosion result in the transport by rivers of large quantities of cadmium to the world's oceans; an annual gross input of 15,000 tonnes has been estimated (IPCS, 1992 b)

288. Within the biosphere, cadmium 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. Very different estimates of total releases of cadmium to the atmosphere by natural processes have been reported

289. Two different estimates of total emission to the atmosphere from natural sources are shown in Table 5-1. Nriagu (1989) estimated the total emission in 1983 at 150 - 2,600 tonnes/year. These estimates are still frequently cited. In a new study by Richardson *et al.* (2001), total emissions from natural sources are estimated at 15,000-88,000 tonnes/year. The large difference is mainly due to very different estimates of the significance of the releases of soil particles to the atmosphere and cadmium releases from natural fires. 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 south-central U.S.A. The soil particle flux for each ecoregion (region with similar ecosystems: scrubland, desert, rainforest, etc.) is estimated on the basis of frequency of dust storms of each ecoregion in comparison to scrubland. Due to the high frequency of dust storms in deserts (6 times the frequency in scrubland and 27 times the frequency in grassland), the desert ecoregion (19 percent of the global land area) accounts for the major part 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 Two examples of estimated global emission of cadmium to the atmosphere from natural sources

Source category	**Cadmium emission in tonnes/year**			
	Richardson *et al.*, 2001		**Nriagu, 1989**	
	Mean	**5-95th percentile**	**Mean**	**Range**
Release of soil particles during dust storms etc.	24,000	3,000 - 69,000	210	10 - 400
Sea salt spray	2,000	103 - 6,700	60	0 - 110
Volcanic emissions	1,600	380 - 3,800	820	140 - 1,500
Natural fires	13,000	4,400 - 30,000	110	0 - 220
Vegetation, pollen and spores	-	-	190	0 - 1,530
Meteoritic dust	0,0002	0.00004-0.0004	50	0 - 100
Total	**41,000**	**15,000-88,000** 1)	**1,300**	**150 - 2,600** 2)

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

2) Sum as reported by Nriagu, 1989.

290. These figures may be compared to an estimated total global anthropogenic air emission in 1995 of approximately 3,000 tonnes. The releases of cadmium by natural processes, as estimated by Richardson *et al.* (2001), seem to exceed anthropogenic releases. However, differences in particle size may make the natural releases less significant for the long-range transport of cadmium (reference is made to chapter 7).

291. The significance of anthropogenic versus natural emissions causing contamination in remote locations due to long-range transport is indicated by ice core records from the Greenland ice sheet. Based on the ice core samples, cadmium deposition peaked in the 1960's and 1970's, when deposition levels were eight times higher than in pre-industrial times (AMAP, 2002). This indicates that industrial emissions at that time were more important as a source of cadmium deposition on Greenland, and per-

haps also other arctic areas, than natural emissions. However, it should be noted that data indicate that cadmium deposition levels have steadily declined since the 1970's (AMAP, 2005).

292. Due to deposition, cadmium concentrations have increased in the mor layer of Scandinavian soils during the twentieth century (Johansson *et al.,* 2001, Steinnes *et al.*, 1997).

293. According to Boutron (1995) quoting Wolf and Peel (1994) and Görlach and Boutron (1992) no significant increasing trend was seen in Antarctica.

5.2 Anthropogenic sources in a global perspective

294. Data on anthropogenic sources of cadmium mainly address emissions to air, whereas data on releases of cadmium to water and soil and quantities directed to landfills are scarce.

295. In a number of developing countries including countries in Sub-Saharan Africa, Latin America and small developing island states, cadmium-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. 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).

296. The European region is developing a European Pollutant Release and Transfer Register (PRTR). This European PRTR is a European-wide register of industrial and non-industrial releases including releases of cadmium into air, water, land and off-site transfers of waste water and waste. The website also gives information from point and diffuse sources. According to Article 8 of the European PRTR Regulation the register shall contain information on releases from diffuse sources where such information exists and has already been reported by the Member States. This website gives access to information on the annual releases from diffuse source sectors from all 25 EU Member States as far as data are available - mostly for the year 2003. The European PRTR site can be accessed at the following link: http://www.oecd.org/env_prtr_data/

297. Anthropogenic sources of cadmium are investigated and assessed in Hungary and information regarding emissions by industry is compiled from reports and submitted by the enterprises to the environmental authority in compliance with Government decree No. 21/2001. (II.14.). The major component of cadmium emission to air is due to pyrogenic emission which involves burning of fossil solid and liquid fuels in boilers, internal combustion engines, turbines, etc. The quantity of air pollutant is estimated from the consumption data of the various fuels by using adopted emission coefficients. The consumption data is available in the form of energy statistics for the past and as energy prognoses for the future. By this method approximately 95-98 percent of all anthropogenic emissions are taken into account. The annual emissions between 1980 and 2005, which were calculated by the above mentioned method, as can be seen in Table 5-2 (Hungary's submission, 2007).

Table 5-2 Emission of cadmium to the air, tonnes per year

	1980	**1985**	**1990**	**1995**	**2000**	**2005**
From fossil fuels	5,35	5,19	4,17	3,16	2,44	2,25
From other technology	2,28	1,78	1,35	0,60	0,68	0,61
Total	7,63	6,97	5,52	3,76	3,12	2,85

5.2.1 Emission of cadmium to air

298. The most comprehensive assessment of the global anthropogenic cadmium emission dates back to 1983. From 1983 to the mid-1990's, the total anthropogenic emissions of cadmium to air decreased from about 7,600 tonnes (medium estimates of Nriagu and Pacyna, 1988) to 3,000 tonnes (see Table 5-3). According to the assessment, the major source of cadmium emission to the air is non-ferrous metal production.

299. The estimates should, however, be treated with caution, as some sources may be significantly underestimated due to the methodology of the inventories. In particular, waste incineration may be underestimated (AMAP, 2002). It must be recognised that in countries or regions with less developed waste disposal systems, unorganised burning of waste frequently takes place and may contribute significantly to the total emissions (further discussed in section 8.4).

Table 5-3 Estimated global emission of cadmium to air in the mid-1990s (Pacyna and Pacyna, 2001)

Economic sector	**Air emission (tonnes)**	**Percent of total**
Non-ferrous metal production	2,171	73
Iron and steel production	64	2.1
Stationary fossil fuel combustion	691	23
Cement production	17	0.6
Waste disposal (incineration)	40	1.3
Total	**2,983**	
Total, 1983 emission	**7,570**	

300. All emission inventories are subject to uncertainty. In Table 5-4, three inventories of atmospheric emission of cadmium in Europe in 2000 are presented. The basis for all three inventories is data submitted by the 44 counties 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 Party to the UNECE Convention on Long-Range Transboundary Air Pollution (LRTAP Convention). The official data are, for the different source categories, typically either estimated from actual measurements in the country, or by multiplication of activity rates by default emission factors from the EMEP/CORINAIR guidebook (EMEP/CORINAIR, 2005). The official submitted data are in some instances subject to 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 and accurate inventory, the data can be critically reviewed and improved by inventory experts. Table 5-4 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.

301. According to the revised estimates by TNO, emissions to air are mainly caused by "Industrial Combustion and Processes" (in Table 5-4 indicated as a common figure for cement production, iron and steel production and non-ferrous metal production), which in this context in particular cover primary zinc and copper production and the iron and steel industry (especially sinter production). Another important source is power plants, which in this context in particular, covers combustion of hard and brown coal and heavy fuel oil in heat/power plants (Dernier van der Gon *et al.,* 2005).

Table 5-4 Atmospheric emission of cadmium 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 Cd/year	**Percentage** [5)]	**Tonnes Cd/year**	**Percentage** [5)]	**Tonnes Cd/year**	**Percentage** [5)]
Power plants	60	22	116	20	99	26.3
Residential and commercial boilers	59	22	251	43	49	13.0
Cement production	0	0	64	11	214	56.8
Iron and steel production	37	14	46	8		
Non-ferrous metal production	52	19	52	9		
Waste disposal	9	3	9	2	9	2.3
Road transport					6	1.4
Other sources	52	19	52	9	0.7	0.2
Total	**269**	**100**	**589**	**100**	**377**	**100**

1) Europe is in this context defined as the 44 European countries that are partners to the UNECE Convention on Long-Range Transboundary Air Pollution (LRTAP Convention) (Includes 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 with experts from the Netherlands' Organisation for Applied Scientific Research (TNO) and national experts (Denier van der Gon *et al.*, 2005).

5) Indicates the percentage of the total releases from the various sources included in the inventory.

302. Examples of other country emission data which have been submitted for this review are presented in Table 5-5. The weight of the different sources are dependent on the industry structure of the countries. In countries with extensive non-ferrous metal production, such as Canada and Australia, this sector is the main source of atmospheric cadmium emission, whereas fossil fuel combustion is the main source in the U.S.A.

Table 5-5 Country data on emission of cadmium to air - examples

	Atmospheric emission (tonnes/year)			
Source category	**Australia 2003/4 1)**	**Canada 2004 2)**	**U.S.A, 2002 3)**	**Japan 2003 4)**
Energy production				
Stationary fuel consumption	0.75	1.5	144	
Industrial processes				
Mining	4.8	0.0		
Oil and gas extraction	1.1	0.1		
Non-ferrous metal production	10	29	6.9	1.62
Iron and steel production		0.7	not assessed	
Waste incineration		0.0	7.5	<0.09 - < 1.9
Mobile sources		0.1	3.0	
Other sources		1.2	25.9	0.05
Total (rounded)	**16.8**	**32.7**	**82**	**1.7 - <4.9**

1) (Australia's submission, 2005) - industrial emissions data from national pollution inventory (NPI).

2) (Canada's submission, 2006).

3) U.S. EPA (2008). National Emissions Inventory (NEI) for year 2002. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards.

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 on waste disposal is included in the range of the total. The table in the submission mistakenly has interchanged "non-ferrous industry" with "plastics industry".

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

Table 5-6 Anthropogenic cadmium emissions to the atmosphere in the Republic of Moldova Units: tonnes per year (Moldova's submission, 2007)

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**
Republic of Moldova	3.08	3.49	1.69	1.42	0.82	0.59	0.66	0.36

	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Republic of Moldova	0.33	0.15	0.17	0.11	0.23	0.12	0.14	0.145

Trends in atmospheric emissions

304. In general, the atmospheric emission has decreased significantly in industrialised countries during the last 15 years, due to improved emission control. The trends in atmospheric cadmium emission in Canada and Europe (EMEP area) are shown in Figure 5-1. In Europe the emission in 2003 was at approximately half of the 1990 level, whereas in Canada the emission in 2003 was one at third of the 1990

level. In the United States, cadmium emissions decreased from about 182 tonnes in 1990 down to about 82 tonnes in 2002 (about 55 percent reduction) (U.S.EPA 2008)

305. Data on the trends in atmospheric cadmium 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 cadmium.

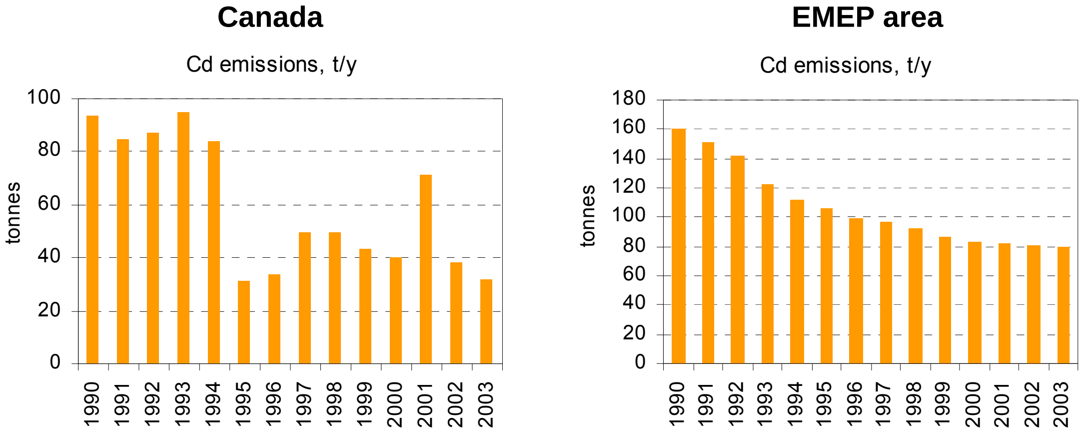


Figure 5-1 Trends in atmospheric emission of cadmium in Canada and the EMEP area (24 countries in Europe) 1990- 2003(UNECE, 2006a)

306. Within the EMEP area, the most complete datasets on lead, cadmium and mercury emissions by source sectors (in EMEP nomenclature codes) for both 1990 and 2003 were reported by 8 European countries: Austria, Belgium, France, the Netherlands, Norway, Spain, Sweden, and the United Kingdom (UNECE, 2006a).

307. Table 5-7 shows estimates of cadmium emission by sector in 1990 and 2003 from the eight countries. The total reduction of the emission from all sectors was 47 percent. The reduction ranged by sector from 95 percent for road transport to -23 percent for chemical industry (corresponding to an increase of 23 percent). The significant decrease in air emissions is mainly caused by improved flue gas cleaning. A consequence of this improvement is that increasing quantities of cadmium is collected with fly ash and other residues, which has partly changed the problem of direct release to the environment to an issue of disposal of residues.

308. 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 *Trends in atmospheric emission of cadmium by sector in 1990 and 2003 in 8 European countries [1)] (Based on UNECE, 2006a)*

Sectors	**1990**		**2003**		**Reduction**	
	Tonnes Cd	**Percentage**	**Tonnes Cd**	**Percentage**	**Tonnes Cd**	**Percentage**
Road Transportation	14.5	19.9	0.8	2.0	13.7	95
Metal Production	12.3	16.8	10.0	25.9	2.3	19
Waste Incineration	11.9	16.3	5.8	15.1	6.0	51
Iron and Steel	10.1	13.8	4.6	11.9	5.5	54
Public Electricity and Heat Production	4.9	6.7	3.3	8.7	1.6	32
Non-ferrous Metals	4.0	5.5	1.4	3.7	2.6	64
Other, Manufacturing Industries and Construction	3.7	5.1	3.8	9.8	-0.1	-1.4
Chemical Industry	3.4	4.6	4.1	10.6	-0.8	-23
Residential	1.6	2.3	1.4	3.6	0.2	15
Other sectors	6.6	9.0	3.4	8.7	3.2	49
Total emission (rounded)	**73**	**100**	**39**	**100**	**34**	**47**

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

309. In Hungary, information on cadmium emissions and trends is periodically updated on the framework of the European Pollutant Emission Register (EPER, website: http://www.eper.cec.eu.int/eper/default.asp). EPER, the publicly accessible register, provides environmental information on emission data of major industrial activities' emission data. Data is provided through the compulsory report by all EU Member States. After the reporting period of 2007, EPER will be replaced by the European Pollutant Release and Transfer Register (E-PRTR, website: http://ec.europa.eu/environment/air/legis.htm#stationary). Detailed data on Hungarian cadmium emission as it appears in EPER, are summarized in Table 5-8 below (Hungary's submission, 2007).

Table 5-8 *Trends of cadmium emission in 2001 and 2004, as it appears on EPER*

	Cd release to air [kg/2001]	**Cd release to air [kg/2004]**	**Trend +/- [kg]**
Facility 1	51		n.a.
Facility 2	57	113	+ 56
Facility 3	106		n.a.
Facility 4		38	n.a.

310. Emission factors for combustion processes, and metal, cement and glass production have been proposed by Czech Republic (2009 submission). As seen in Table 5.8a, 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 5.8b), the emission factors are given with respect to each tonne of product manufactured.

Table 5.8a: Emission factors for combustion processes (Czech's submission, 2010)

Capacity of facility	Fuel	Emission factors (mg Cd/GJ)
> 5MW	Brown coal	0.04 to 1.10
	Hard coal	0.01 to 0.52
	Heavy oil	3.0 to 9.62
	Other liquid fuels	3.0 to 9.62
0.2 – 5 MW	Brown coal	6.00
	Hard coal	0.23
	Coke	20.80
	Liquid fuel	126.0
< 0.2 MW	Brown coal	6.00
	Hard coal	0.23
	Coke	20.80
	Liquid fuel	50.0

Table 5.8b: Emission factors for metal, cement and glass production (Czech's submission, 2009)

Type of facility	NFR	Emission factors (mg Cd/tonne of product)
Sinter and pelletizing plants	1A2a	59.0
Gray iron foundries	1A2a	4.0
Secondary Pb production	1A2b	300.0
Secondary Zn production	1A2b	14000.0
Secondary Cu production	1A2b	2,000
Secondary Al production	1A2b	7.0
Cement production	1A2f	8.0
Glass production	1A2f	150.0
Lead glass production	1A2f	150.0
Coke production	1B1b	10.0
Pig iron tapping	2C1	0.2
Steel production	2C2	173.2

5.2.2 Release of cadmium to waste and soil

311. The only comprehensive assessment of global cadmium releases to soil and landfills dates back to 1983 (see Table 5-9). According to the inventory, the total releases to the soil approach 5,600-38,000 tonnes per year, with atmospheric deposition as the dominating source, whereas an extra 4,300-7,400 tonnes per year are estimated to be directed to landfills and various deposits in form of discarded products and production waste. The distinction between releases to soil and waste in the table is not quite clear, e.g. coal fly ash is probably released to landfills and not to soil.

312. The single major source of cadmium directed to landfills with municipal solid waste is nickel-cadmium batteries (NiCd batteries). The long-term fate of the cadmium accumulating in the landfills is uncertain, and may represent a future source of cadmium releases to the environment. In that context, a full targeted risk assessment of NiCd batteries including the reviewing of the environmental impact of the full life cycle of NiCd batteries is reported in the final EU risk assessment on Cd and its compounds (EU, 2007).

313. It should be noted that the estimated input by fertilizers of 30-250 tonnes seems very low considering that one country (Australia) reports an input of 32 tonnes per year, and that the content of cadmium in fertilizers was previously significantly higher (Australia's submission, 2005). 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, cadmium. The main inorganic pollutants monitored are a result 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 cadmium measured in excess of guidance values in remote alpine and pre-alpine regions were attributed to geogenic sources or to low pH values of the soil. Typical values of cadmium found in Swiss soil in the NABO monitoring campaign 1995-1999 show median lowest and highest values of 0.147 to 0.350 mg cadmium/kg soil and average lowest and highest values of 0.237 to 0.503 mg cadmium/kg soil (Switzerland’s submission, 2007).

Table 5-9 Estimated global cadmium releases to soil and waste in 1983 (derived from Nriagu and Pacyna, 1988)

Source category	**Release to land Tonnes Cd/year**	**Percent of discharge to land**
Agricultural and food wastes	0-3,000	6
Animal wastes, manure	200-1,200	3
Logging and other wood wastes	0-2,200	4
Urban refuse	880-7,500	15
Municipal sewage sludge	20-340	0.7
Miscellaneous organic wastes including excreta	0-10	0.0
Solid wastes, metal manufacturing	0-80	0.1
Coal fly ash, bottom fly ash	1,500-13,000	26
Fertilizer	30-250	0.5
Peat (agricultural and fuel use)	0-110	0.2
Wastage of commercial products	780-1,600	4
Atmospheric fall-out	2,200-8,400	19
Total to soil	**5,600-38,000**	
Mine tailings	2,700-4,100	12
Smelter slags and wastes	1,600-3,300	9
Total discharge on land	**9,900-45,000**	

314. Country examples of sources of cadmium to land submitted for this review are presented in Table 5-10. For most countries, only data for industrial sources have been reported. In a study undertaken in Kenya at the Dandora Municipal Dumping Site in Nairobi, soil samples around the dumpsite had cadmium levels eight times higher than 5.0 ppm. High concentrations were found in both surface and sub-surface soils (Kimani, 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 cadmium contents of 14 ppm (Togo's submission, 2007).

315. Use of fertilizer is the major source of direct releases to soil in Australia and Denmark. Cadmium input to agricultural soils with fertilizers has been of concern in many countries and is discussed further in the section titled "particular on cadmium in agricultural soils". In Denmark, the cadmium input with agricultural chalk was notably of the same magnitude as the input with fertilizers (Table 5-10).

Table 5-10 Sources of cadmium releases to soil and landfills in different countries - examples

Source category	**Sources of cadmium to soil and landfills (tonnes Cd/year)**			
	Australia 2003/4 1)	**Canada 1994** 2)	**Denmark 1996**3)	**Japan 2003** 4)
Industrial releases				
Metal ore mining	0.14			
Mining - other	1.1			
Non-ferrous base metal manufacturing	0.31	340 5)		114.1
Other industry sources	0.15			32
Use of products				
Use of fertilizers	32		1.2	
Agricultural chalk			0.6 - 1.2	
Corrosion of hot-dip galvanised products			0.1-0.5	
Other			<0.2	
Waste disposal				
Land application of compost based on municipal solid waste			0.1-0.2	
Residues from waste incineration			8.7 - 18	
Solid waste - landfilled			3.3 - 6.1	
Sewage sludge - land application and landfilled			0.21	
Hazardous waste - landfilled			0.4 - 0.5	
Tire disposal		0.1		
Other			0.01	
Total	**33.7**	**340.1**	**14.2 - 28.5**	**146**

1) (Australia's submission, 2005). Includes only direct releases to land and not transfer to landfills and waste deposits:

2) (Government of Canada, 1994) submitted by Canada. All other sources are indicated as "no data were identified or available."

3) (Drivsholm *et al.,* 2000 submitted by Denmark)

4) (Japan's submission, 2005). Includes total releases to landfills. The direct releases to soil are reported as 0.

5) Stated in the reference as slag and solid waste residue or sludge from base metal smelters and refineries

316. A more recent estimate addressing sources of cadmium to waste disposal in Europe is presented in Table 5-11. The main sources of cadmium directed to landfills and waste deposits were municipal waste, cadmium processing, non-ferrous metal processing and cement production. Both industrial and

municipal wastes are important sources of cadmium for landfilling (see Table 5-11). In some densely populated countries, e.g. Denmark and the Netherlands, waste incineration residues, and in particular clinker, are frequently used for road construction purposes and other civil works, thereby increasing the possibility that cadmium may be spread into the environment through construction and later reconstruction activities. The fate of cadmium in landfills and other deposits is addressed in section 8.4 on waste management practices.

Table 5-11 Sources of cadmium to waste disposal in the EU about 2000 [1)] (derived from Scoullos et al., 2001)

	Tonnes/year [2)]	**Percent of total**
Cadmium processing	400 (approx.)	16
Coal ash	113	4
Sewage sludge	70	3
Phosphate processing	60	2
Iron and steel processing	230	9
Cement production	280	11
Non-ferrous metals processing	419	17
Total industrial sources	**1,572**	**62**
Municipal waste or mixed, direct input to landfills	800	32
MSWI ashes	150	6
Total municipal waste or mixed	**950**	**38**
Total to land	2,522	100

1) The table text in the report designates the geographic area “Europe”, but the figures refer, according to the report text, only to the EU15.

2) Only average values are indicated. The report contains uncertainty ranges for only a few of the sources, indicating the total figures to be more precise than judged by the authors of this review.

317. The major media of release and transfer for cadmium and its compounds are landfill and waste, respectively. Releases as landfill within the industry is 120-160 tonnes/year, accounting for 95 percent of the total amount of cadmium release. The transfer of cadmium outside of the industry as waste is approximately 60 to 140 tonnes per year, which would cover most of cadmium transfer amount. It should be noted that the ratio of cadmium released as landfill within the industry and of cadmium released as waste outside the industry, in proportion to total release and transfer amount, are 45-66 percent and 31-53 percent respectively, which account for the ratio of 2 to 1 (Japan’s submission, 2007).

318. The main issue regarding releases to soil, is the input of cadmium to agricultural soils. While some contamination of soil occurs apart from agricultural soils - e.g. by corrosion of hot-dip galvanised items along roads in which cadmium is present as contaminant of the zinc - the available information does not indicate this to be a key issue, and it will not be further addressed here. Cadmium in phosphate fertilizers is further discussed in section 5.4 on cadmium in agricultural soils.

5.2.3 Releases of cadmium to aquatic environments

319. In 1983, the total anthropogenic releases to aquatic environments, exclusive of atmospheric deposition, was estimated at 1,200-13,400 tonnes (Nriagu and Pacyna, 1988). To this amount added an input to aquatic environments by atmospheric deposition at estimated 900-3,600 tonnes. The major sources were: domestic wastewater, non-ferrous metal smelting and refining, and manufacturing of chemicals and metals. Data available for some countries are presented in Table 5-12. It is noted that

mostly data for industrial sources have been reported, whereas some diffuse sources and municipal wastewater may not be included. The countries apply different source categories, and the data are not readily comparable across countries.

320. As mentioned above it has been estimated that weathering of rocks and soil erosion resulted in an annual gross input to aquatic environments of estimated 15,000 tonnes cadmium per year.

321. HELCOM identifies the following pathways as being important routes for cadmium to the marine environment in the Baltic Sea Area (HELCOM, 2002):

- Atmospheric deposition (originating from industrial sources, fuel combustion and waste incineration of NiCd batteries and other cadmium-containing waste);
- Direct discharges from industry and other human activity; which is supported by COBSEA (Coordinating Body on the Seas of East Asia) report of regional workshop on identification of pollution hot spots in East Asia Seas region; Indonesia (COBSEA, 2002a) and Thailand (COBSEA, 2002b).
- Sacrificial anodes on fixed and mobile steel structures including shipping for preventing electrochemical corrosion of the structures(direct input to the marine environment);
- Loss of recyclable NiCd batteries through the waste disposal system with consequent release of cadmium to the environment;
- Run-off, containing cadmium from a number of diffuse sources (for example, galvanized guttering);
- Run-off from agricultural areas treated with phosphate fertilizers.

322. Additional information on the atmospheric deposition of cadmium to the marine environments is available (Migon *et al.*, 1991). The input of cadmium through rainfall and dry deposition to the Ligurian Sea, France was measured for two years (1986 and 1987). The total flux was 174 x 10^{-3} kg km^{-2} $year^{-1}$ corresponding to an input of 9.2 tonne $year^{-1}$. The dry deposition contribution of Cd was only 2%.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 80% of the Cd enters from waterborne species (i.e. from rivers or as direct discharges) (HELCOM, 2005).

323. Morocco reports that the total releases of cadmium to the marine environment discharged by the main discharge pipe in four hot spots - Tangier, Tétouan, Al Hoceima and Nador - amounted to 1.42 tonnes/year (Morocco's submission, 2005).

324. 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).

Table 5-12 Sources of cadmium to aquatic environments - examples

Source category	**Releases to aquatic environments (tonnes/year)**				
	Australia 1)	**Canada 2) 1994**	**Japan 3)**	**Denmark 4) 1996**	**EU-16 6)**
Metal ore mining	1.2				>1.1
Mining – other	0.06				
Non-ferrous metal manufacturing	1.5	10 5)	1.2		10.9
Iron and steel manufacturing		1	4.2		>15.6
Cd plating and battery production and recycling					0.3
Phosphate processing					9.1
Sacrificial anodes				0.6	
Oil/coal combustion and traffic					>0.1
Other industry sources	0.44	1	0.3		
Municipal waste water and storm water				0.3 - 1.4	>1.2 7)
Municipal incineration					0.5
Landfills and municipal solid waste operation				<0.003	0.5
Total	**4.2**	**12**	**5.7**	**0.9 - 2**	**>39.2**

1) (Australia's submission, 2005).
2) (Government of Canada, 1994) submitted by Canada.
3) (Drivsholm *et al.,* 2000) submitted by Denmark.
4) (Japan's submission, 2005).
5) Indicated in (Government of Canada, 1994) as slag and solid waste residue or sludge from base metal smelters and refineries.
6) Data compiled for the EU Risk Assessment of cadmium for EU-15 and Norway (EBC, 2005). The main part of the underlying data concerns the late 1990's.
7) The dataset includes as regards releases with municipal waste water and chemical industry data for two countries only.

5.3 Remobilisation of historic anthropogenic cadmium releases

325. Remobilization of historic anthropogenic cadmium releases denote the effect that cadmium 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 cadmium; a more comprehensive description has not been possible within the frames of the development of this review. As indicated in the introduction to Chapter 5, remobilization in the environment of historic anthropogenic cadmium releases embraces several somewhat different phenomena:

- Remobilization of cadmium previously deposited from the atmosphere via re-allocation of cadmium-bearing dust particles by wind and precipitation (cadmium originating from anthropogenic as well as natural sources). Quantitative data on this phenomenon are scarce.

- Remobilization of cadmium 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 cadmium 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 cadmium 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 cadmium extraction 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 cadmium 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).

326. 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 cadmium. 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).

327. Another example of heavy metal contamination, specifically cadmium, is cited in Romania where two tailings dam failures (January and March 2000) resulted in the release of 200,000 m^3 of contaminated water and 40,000 tonnes of tailings into tributaries of the Tisa River reaching the Ukraine and Hungarian borders, reaching the Danube (Macklin *et al.*, 2003; UNEP, 2000).

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

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

5.4 Particulars on cadmium in agricultural soils

330. The application of fertilizers and atmospheric deposition are significant sources of cadmium input to agricultural soils. These sources may cause enhanced soil and crop cadmium levels, which in turn may lead to increases in dietary cadmium exposure (see section 3.1 on human exposure).

Cadmium input to agricultural soils

331. Country examples of cadmium input to agricultural soils are shown in Table 5-13 The main sources are atmospheric deposition, commercial phosphate (P_2O_5) fertilizers and livestock manure. The input with phosphate fertilizers vary by country, and may be a result of the use of fertilizers with varying cadmium content. For example the input with phosphate fertilizers is e.g. relatively low in Finland due to the use of fertilizers with low cadmium content (Louekari *et al.*, 2000). The total input of cadmium to agricultural soils from phosphate fertilizers in the EU15 + Norway is in the EU Risk Assessment for cadmium estimated at 231 tonnes while the cadmium input with sewage sludge is estimated at >13.6 tonnes (ECB, 2005). The data used for these estimates are mainly from the 1990's. The use of phosphate fertilizers in the EU has been declining steadily from a level around 6 million tonnes P_2O_5 per year in the early 1980's, to 3.7 million tonnes per year in the mid 1990's and 2.9 million tonnes in 2003-2004 (UNIFA, 2006). The total cadmium content in 2.9 million tonnes P_2O_5 is estimated at 116 tonnes (EFMA, 2003).

332. Contrary to the situation in many European countries, fertilizers provide the bulk of the cadmium inputs to agricultural soils in Australia (Australia's submission, 2005). Furthermore, most Australian agricultural soils are naturally low in cadmium compared to soils in Europe and North America. Historical imports of cadmium via phosphate fertilizers show in Australia an increasing trend up until the 1970’s followed in the 1980’s and 1990’s by a sharp downward movement to levels of 56 tonnes cadmium in 1995. This decline was due to increased imports of phosphate fertilizers with low cadmium concentrations and to the switch from imports of high to low-cadmium phosphate rock (Australia's submission, 2005). More information regarding fertilizer as a source of cadmium in OECD countries can be obtained from the OECD Proceedings of Fertilizer Workshop- Fertilizer as a Source of Cadmium (OECD,1995)

333. Information on cadmium input to agricultural soils in developing countries has not been available.

Table 5-13 Input of cadmium to agricultural soils - examples

Source	**Input to agricultural soils (g Cd/ha/year)**				
	Austria 1) **1998**	**Belgium 2)** **late 1990's**	**Greece 3)** **late 1990's**	**Czech Rep. 4)** **around 2000**	**Finland, 5)** **2004**
Atmospheric deposition	2.1	9.8	0.031 - 0.045	1.3	0.19
Mineral fertilizer	0.8	1.0	0.44 - 1.14	0.71	<0.071
Livestock manure	0.46	1.4	0.01 - 0.14	-	0.148
Sewage sludge	0.04	~0	0	0.1	-
Other organic waste	0.04	0	-	0	
Substrate weathering				0.02	
Pesticides	-	-	0.01	-	-
Agricultural chalk	-	-	0.05 - 1.2	-	0.030
Total	**3.2**	**12.21'**	**0.6 - 1.3**	**2.2**	**<0.44**

1) Estimated average from (Zethner and Goodchild, 2000).

2) Reported averages for Belgium (Guns and Pussemier, 2000).

3) Examples (Greece, 2000).

4) (Zapletal *et al.*, 2002 as cited by Tocoen, 2005). Reported averages.

5) (Finland's submission, 2006).

334. **Cadmium accumulation** - By the continued application of phosphate fertilizers cadmium may accumulate in the soil. The significance of cadmium accumulating in agricultural top soils is supported by risks assessments related to cadmium in phosphate fertilizers undertaken by several European countries. The predicted cadmium concentration by the use of scenarios of different fertilizer cadmium contents is shown in Table 5-14 In a number of European countries, the present European average content of cadmium in fertilizers would cause the content of cadmium in top soil to increase (Hutton and de Meeûs , 2001). In order to track the actual trends in cadmium concentrations in the agricultural soils some countries (e.g. France and Switzerland) has launched programmes for monitoring the cadmium concentrations in soils (UNIFA, 2006). The cadmium in agricultural soil will be recycled through uptake in plant for feeding and successively excreted in livestock manure, which is applied for fertilizing. It cannot be excluded that the cadmium taken up by the livestock in this process has a potential for increasing animal exposure.

335. As an example, in Austria the mean concentration of cadmium in the porewater of the agricultural soil would over a 100 year period increase by an estimated 43 percent using fertilizers with the current average of 25 mg Cd/kg P_2O_5 whereas the increase would be 74 percent if the fertilizer cadmium content was 90 mg Cd/kg P_2O_5 (Table 5-14).

Table 5-14 Predicted cadmium accumulation in agricultural soils based on the risk assessments undertaken by a number of European countries, reported fertilizer cadmium content and country average cadmium in soils (Hutton and de Meeûs, 2001)

County	**Scenario fertilizer Cd content mg/kg P_2O_5**	**Percentage accumulation in soil**		**Reported fertilizer Cd content mg/kg P_2O_5**	**County average Cd in soils (mg/kg dry matter)**
		+60 year	**+ 100 year**		
Austria	• 25 • 90		+43 +74	25	0.24
Belgium	• 32.6	-70 to +120		32	-
Denmark	• 15 • 45 • 60		+8 to +28 +40 to +54 +53 to +125	15	0.18
Finland	• 1 • 21 • 60		-31 to +9 +5 to +43 +40 to +125	1	0.21
Greece	• 18		+7	18	0.29-0.41
Ireland	• 58.6		+7	58	0.54
Norway	• 2.3 • 60		-20 to 0 +15 to +127	-	0.24
Sweden	• 0 • 7 • 60		-? to +? -75 to +11 +10 to +50	7	0.23
United Kingdom	• 15 • 30.6 • 50 • 100		+4 +20 +39 +9	30 (15) 1)	0.32

1) It is reported that, in the United Kingdom, the weighted average is probably lower than the median of just over 30 and may be less than 20. A value of 15 was used in the United Kingdom Risk Assessment

336. Since crops to a large extent are trade internationally, dietary cadmium exposure may take place in areas far away from production sites, even on other continents.

337. **Cadmium in phosphate rock -** Cadmium occurs naturally as a contaminant in all phosphate (P_2O_5) rock, but the concentrations vary considerably, depending on the origin of the material. Igneous rock or apatite (found in the former Soviet Union, Finland, South Africa and South America) has low concentrations of cadmium (often less than 1 mg per kg P_2O_5). Sedimentary rock, which accounts for some 85-90 percent of world phosphate production, contains cadmium in concentrations ranging from less than 20 to more than 200 mg per kg P_2O_5 (see Table 5-15).

338. The phosphate rock and phosphate fertilizers with varying cadmium contents are transported on a global scale due to international trade.

Table 5-15 Cadmium content of main commercial phosphate rocks according to the different information sources (Oosterhuis et al., 2000)

Origin	**Cadmium content (mg per kg P_2O_5)**		
	(1)	**(2)**	**(3)**
Igneous			
Kola (Russia)	< 13	0.3	0.25
Phalaborwa (South Africa)	< 13	0.1	0.38
Sedimentary			
Florida (U.S.A.)	23	19.8 – 32.7	24
Jordan	< 30	12.1 – 28	18
Khouribga (Morocco)	46	17 – 63	55
Syria	52	13 – 46	22
Algeria	60	42 – 62.6	
Egypt	74		
Bu_Cra (Morocco)	100	101 – 115	97
Nahal Zin (Israel)	100	81 – 112	61
Youssoufia (Morocco)	121	164.7	120
Gafsa (Tunisia)	137	94	173
Togo	162	164 – 179	147
North Carolina (U.S.A.)	166	125	120
Taiba (Senegal)	203	165 – 180.6	221
Nauru	243		

Sources: (1) Davister (1996); (2) Botschek and Van Balken (1999); (3) Demandt (1999).

339. **Releases of cadmium by mining of phosphate rock -** The processing of phosphate rock may as well result in local or regional contamination of soil and waters. As an example, in Togo the processing of phosphates is done through sifting, by separating the fraction rich in phosphate from the waste (Togo's submission, 2005). The phosphate rock in Togo contains, as indicated in Table 5-12, about 147-179 mg cadmium per kg P_2O_5. The mining wastes account for approximately 40 percent or the raw ore and 3.5 million tonnes of muddy wastes have every year been discharged into the sea since 1963 (Togo's submission, 2005). With the phosphate mining wastes significant quantities of cadmium is discharged into the sea around Togo and neighbouring countries such as Benin and Nigeria. Studies have demonstrated elevated cadmium concentrations in sediments and biota. The remainder of the mining wastes (the solid fraction) is discharged around the factory.

340. The IPCS monograph on cadmium (IPCS, 1992a) reports that the manufacture of phosphate fertilizer results in a redistribution of the cadmium in the rock phosphate between the phosphoric acid product and the gypsum waste. In many cases, the gypsum is disposed of by dumping in coastal waters, which leads to considerable cadmium inputs. Some countries, however, recover the gypsum for use as a construction material and thus have negligible cadmium discharges.

Leaching of cadmium from agricultural soils

341. The cadmium applied to soil will ultimately be removed from the soils by leaching either to the groundwater or to surface waters (Kemi, 2000). A Finnish assessment of risk to health and the environment from cadmium in fertilizer concludes that there is a risk for aquatic environments for all calculated scenarios, both at the present time and in the future (Loukari *et al.*, 2000). In practice this means that no margin of safety can be established, and any increase in the natural background concentrations is likely to present a risk for the aquatic environment (Loukari *et al.*, 2000). A similar Swedish assessment report that there are no clear indications that cadmium from fertilizers are affecting Swedish surface waters at present, but scenarios indicate that, in certain cases, cadmium concentration in streams

close to agricultural fields can be affected by certain soils. Contributing factors are i) high solubility of cadmium, i.e. at low pH, ii) highly permeable soils; and iii) extensive surface runoff (Kemi, 2000). Danish measurements demonstrate significantly higher cadmium concentrations in streams located in the western part of the country, with sandy soils, compared to streams located in areas with clay soils (Lassen *et al.,* 1998). Considering the high amounts released from the sandy soils, the difference was explained by differences in the soils' capacities for adsorption of cadmium supplied through fertilizers and atmospheric deposition.

342. In Hungary, sewage sludge may be applied to the agricultural fields if the rules of Government Decree No 5/2001 (IV.3.) Korm. and the conditions set in the permit are complied with. According to the the authority' database, the yearly amount of cadmium applied to the soil is estimated at 53 kg on 7.350 acres (2004), 60 kg on 7.069 acres (2005) and 45 kg on 6.406 acres (2006) (Hungary's submission, 2007).

6 Production, use and trade patterns

6.1 Global production and raw material consumption

343. Cadmium is produced mainly as a by-product from mining, smelting and refining of zinc, (from sulphide ore) and to a lesser degree, lead and copper. Cadmium minerals do not occur in concentrations and quantities sufficient to justify mining them in their own right. As it is a by-product of zinc, the production of cadmium is more dependent on zinc refining than on market demand (OECD, 1994). The percentage of cadmium in zinc concentrates varies from mine to mine, ranging from 0.07 to 0.83 percent, with an average of 0.23 percent.

344. Compared with the high of 20,000 t in 1997, the latest World Bureau of Metal Statistics figures for primary cadmium metal production from zinc producers continue to show decreases in 2005, 2006 and 2007. The decreases have occurred mainly in Europe, where there are now only a few zinc producers who continue to produce by-product cadmium. Most European zinc producers have largely shut down, curtailed or otherwise eliminated their cadmium by-product output from zinc-refining operations. Asia and the Americas, on the other hand, continue to increase their primary cadmium production with respect to European production. African cadmium production really no longer exists and Australian cadmium production continues at a constant but somewhat lower level than in the past. Secondary cadmium production from the recycling of nickel-cadmium (NiCd) batteries continues to increase. Consumption of primary cadmium has decreased dramatically and yet total cadmium supply during the year has been short, indicating that a sufficient amount of secondary cadmium may not have been forthcoming to meet the continuing demand. The cadmium price, as a result, has jumped substantially during the past year, moving rapidly from US$1.40/lb in October 2006 for the high purity 99.99% grade, to US$6.20/lb in July 2007. The strength of the cadmium market and price appear to be due to continuing demand from the Chinese nickel-cadmium battery industry, decreasing primary cadmium production by primary zinc producers, and insufficient secondary cadmium production to meet the total cadmium demand (ICdA’s submission, 2007).

345. Total global production of refined cadmium for the period from 1950 to 1990 is shown in Figure 6-1. The production figures for the period 1970’s to the 1990’s do not include the Eastern European countries, China and North Korea, and the total global production have been higher in this period than indicated in the figure (ICdA, 2006), however, this is not indicated in the original source of information for the figure (U.S.GS, 2002). From 1996 to 2006, the primary production has decreased about 25 percent which is, however, compensated by an increase of production of recycled cadmium so the total consumption has been rather stable (Figure 6-2). In Japan, production of cadmium ingot has stayed at about 2,200-2,600 tonnes since 1995, whereas import rapidly decreased from 6,000 tonnes (1995) to 3,500 tonnes (1998), changing from 2,500 to 3,900 thereafter. (Japan’s submission, 2007).

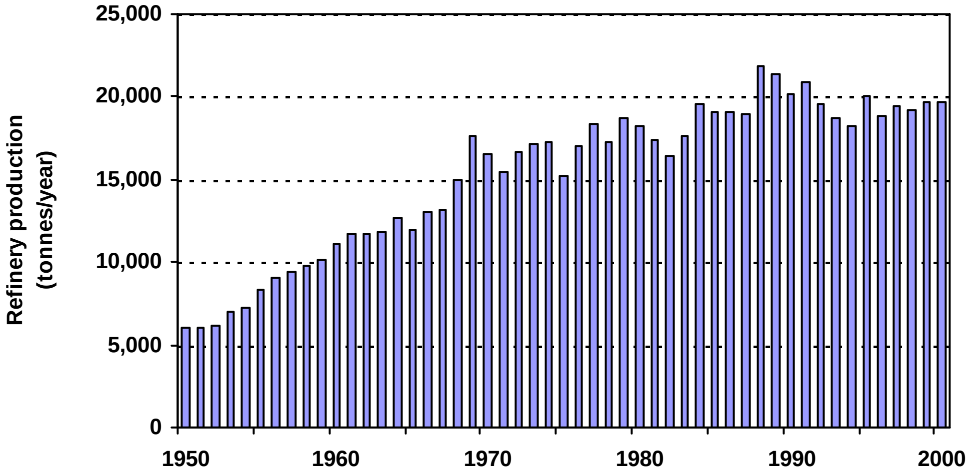


Figure 6-1 Global production of refined cadmium 1950-2000 (U.S.GS, 2002)

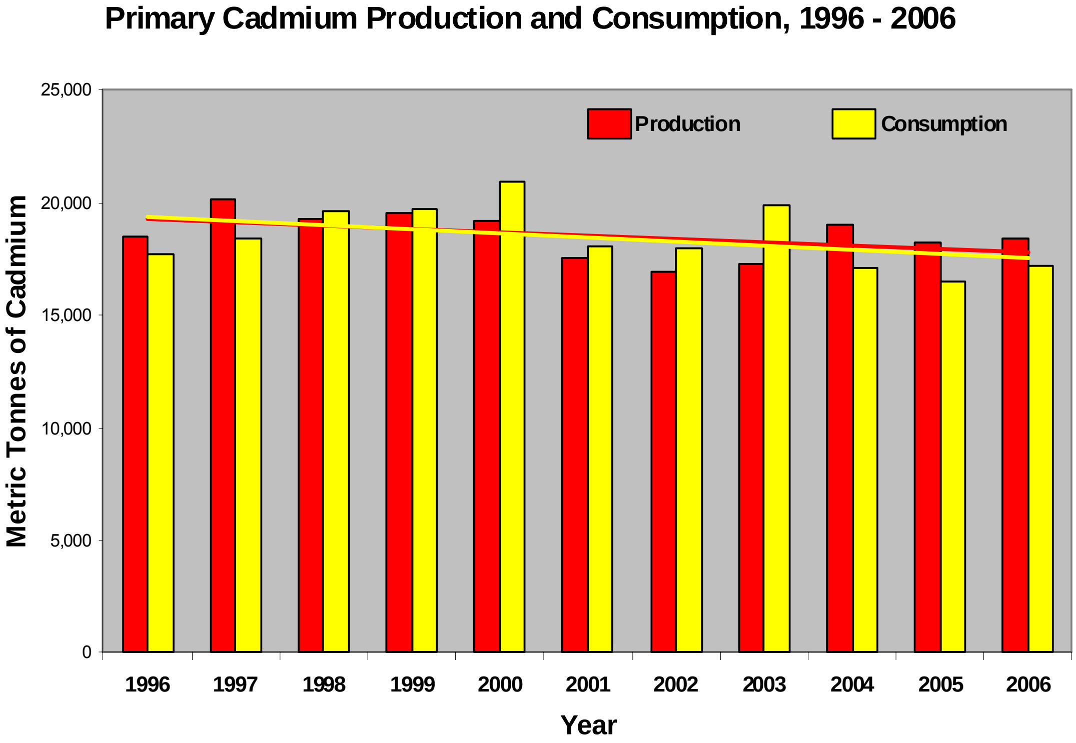


Figure 6-2 World primary production and consumption of primary cadmium metal 1996-2006 (original figure submitted by ICdA, 2007)

346. Whereas total primary cadmium production has only decreased slightly over the last 10 years, major geographical changes are prominent. In 1997, primary production in Asia, Europe and the Americas was nearly equal. During the period from 1995 to 2005, primary production in Asia increased steeply, and the production in Europe decreased correspondingly. As a result, primary production in Asia in 2004 was 5 times the production in Europe. It should be noted that an increasing part of the primary cadmium production takes place in countries for which data on releases are not available.

347. Worldwide primary cadmium metal production appears to have settled into a pattern of approximately 60 percent being produced in Asia, roughly 25 percent in the Americas, 12.5 percent in Europe and 2.5 percent in Australia as can be seen in Figure 6-3. The leading producers are given in Table 6-1. The expected trend is that less and less primary cadmium will be produced in Europe while more and more will come from Asia. What is more difficult to gauge is future trends in secondary or recycled cadmium. The amount of secondary cadmium production will continue to increase, but good statistics in this area are difficult to obtain because much of the secondary cadmium production occurs as a result of proprietary tolling arrangements between recyclers and NiCd battery manufacturers (ICdA's submission, 2007).

Table 6-1 Leading producers of primary cadmium metal (tonnes) (ICdA, 2007)

Country	**2003**	**2004**	**2005**	**2006**	**2007***
Korea	2,379	2,633	2,782	3,450	3,704
China	2,705	2,900	3,000	3,000	3,000
Japan	2,496	2,222	2,297	2,287	1,724
Canada	1,759	1,881	1,727	2,094	1,557
Mexico	1,606	1,590	1,627	1,397	1,526
Kazakhstan	930	2,358	1,624	1,140	996
United States	700	1,010	1,070	892	892
Russia	650	650	650	650	650
Germany	640	640	640	640	640
Netherlands	495	572	570	570	570
India	477	489	409	457	534
Peru	529	532	481	416	432
Australia	673	469	429	425	425

*Estimated

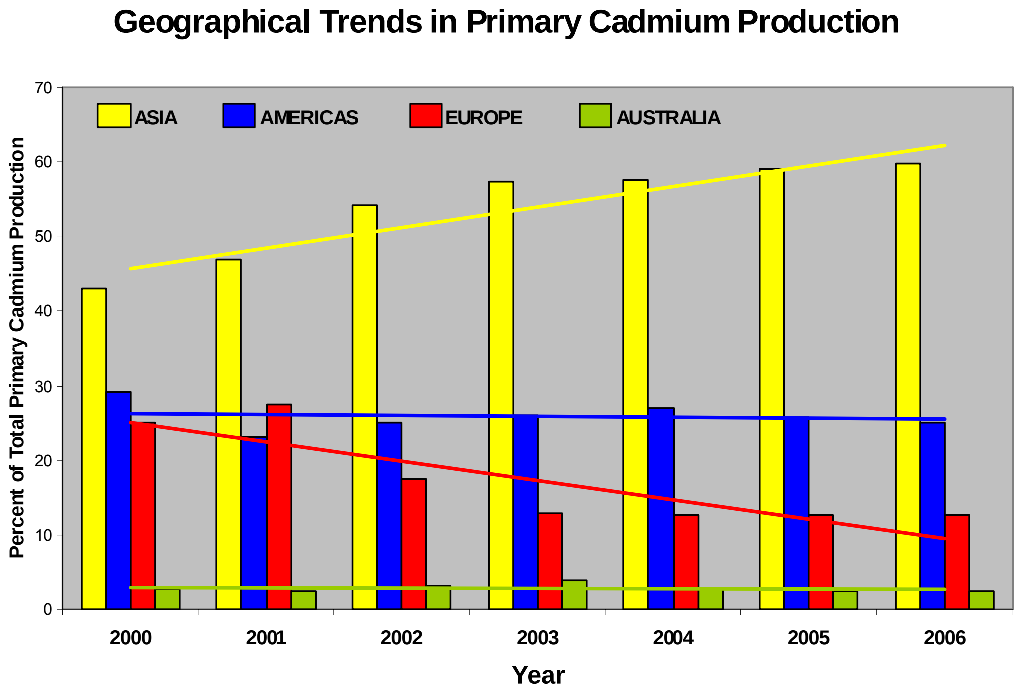


Figure 6-3 Geographical trends in primary cadmium metal production 2000-2006 (original figure submitted by ICdA, 2007)

348. The production and consumption of cadmium, cadmium compounds and cadmium-containing products is carried out on a global scale. Cadmium-containing concentrates are extracted all over the world, mainly a as by-products to zinc. World refinery production and reserves by country are shown in Table 6-2. The reserves (the amount that can be economically extracted with today technology) are estimated at 600,000 tonnes, equalling 30 years of production at today's level. The geographical trends in primary production from 1997 to 2004 are illustrated in Figure 6-3. As illustrated, production decreased in Europe and increased in Asia in recent years. Estimated world total resources (including resources that cannot be economically extracted with today's technology) of cadmium were about 6 million tonnes based on zinc resources containing about 0.3 percent cadmium. Zinc-bearing coals also contain large sub-economic resources of cadmium (U.S.GS, 2006). World cadmium consumption figures in 2006 are provided in Table 6-3 (ICdA, 2007).

Table 6-2 World refinery production of cadmium and reserves by country, 2004/2005 (U.S.GS, 2006)

Country	**Refinery production 2004 Tonnes cadmium**	**Reserves [1] 2005 Tonnes cadmium**
China	2.800	90,000
Japan	2.233	10,000
Korea, Republic of	2.100	-
Kazakhstan	1.900	50,000
Canada	1.888	55,000
Mexico	1.600	35,000
Russia	950	16,000
Germany	620	6,000
United States	550	90,000
Peru	532	12,000
India	489	3,000
Australia	350	110,000
Belgium	120	-
Other countries	2.650	120,000
World (rounded)	**18.800**	**600,000**

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

Table 6-3 World cadmium consumption in 2006 (ICdA, 2007)

Country	**Status**	**MT Cadmium**	**Notes**
China	Developing	5,407	Production of NiCd Batteries
Belgium	Developed	3,682	Conversion of Cd to CdO
Japan	Developed	2,053	Production of NiCd Batteries
United States	Developed	1,250	Production of Cadmium Products
Germany	Developed	647	Production of Cadmium Products
United Kingdom	Developed	598	Production of Cadmium Products
India	Developing	480	Production of Cadmium Products
Sweden	Developed	302	Production of NiCd Batteries
France	Developed	268	Production of NiCd Batteries
Canada	Developed	233	Production of Cadmium Products
Brazil	Developing	176	Production of Cadmium Products

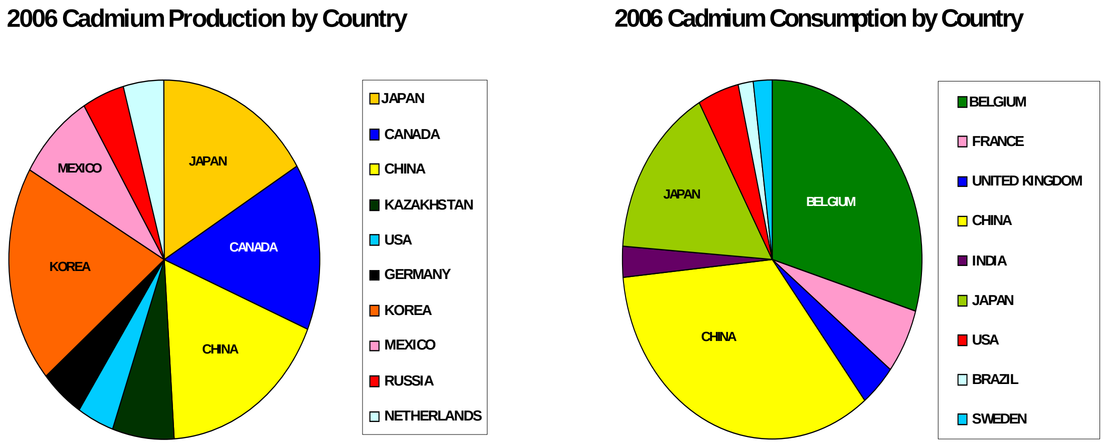
Mexico	Developing	140	Production of Cadmium Products
Asia - All Other Countries	Developing	119	Production of Cadmium Products
Italy	Developed	105	Production of Cadmium Products
South Korea	Developing	100	Production of Cadmium Products
Americas - All Other Countries	Developing	72	Production of Cadmium Products
Poland	Developing	71	Production of Cadmium Products
Europe - All Other Countries	Developed	40	Production of Cadmium Products
Yugoslavia	Developing	30	Production of Cadmium Products
Australia	Developed	24	Production of Cadmium Products
Africa - All Countries	Developing	20	Production of Cadmium Products
Taiwan	Developing	0	Production of Cadmium Products

*** Source - August 2007 World Bureau of Metal Statistics**

349. The melting and refinement of cadmium from concentrates takes to a large extent place in a number of countries with China, Japan, Korea, Canada and Mexico as the major producers of primary cadmium metal

350. Primary cadmium production and consumption by country is shown below. The main part of the cadmium metal is converted into cadmium oxide for production of batteries. Cadmium metal is converted into cadmium oxide mainly in China, Belgium and Japan. Belgium and China are major importers of cadmium metal and Belgium further export the cadmium oxide to producers of NiCd batteries in other countries. NiCd batteries are manufactured in a global manner in that raw materials originate in one country, the batteries are produced in another, incorporated into a product in yet another, and sold into a final market and used by the consumer in yet another. The main producers of portable batteries are China and Japan, whereas Sweden and France are the major producers of industrial NiCd batteries (ICdA, 2006).

351. Cadmium pigments, on the contrary, are produced in only a few countries, but may be sold to users in many countries normally for incorporation into products and direct use in the same country. Stabilizers, coating and alloys tend to be more national in their productions, use and disposal



Production of primary cadmium metal

Consumption of primary cadmium metal

Figure 6-4 Production and consumption of cadmium by country in 2006 (ICdA, 2007)

352. **Recycling** - Cadmium is recovered from spent NiCd batteries, copper-cadmium alloys and other non-ferrous alloys, as well as cadmium-containing dust from the recycling of iron and steel scrap (U.S.GS, 2006). It is estimated that recycled (secondary) cadmium in 2004 accounted for 3,500 tonnes, corresponding to about 17.5 percent of a total global supply of about 20,000 tonnes (ICdA, 2005).

Cadmium is now estimated at 4,000 tonnes per year or 19 percent of total supply (ICdA, 2006). The size of recycled production was earlier estimated at about 10-15 percent of the supply (OECD, 1994).

353. Countries with significant production of recycled cadmium include the U.S.A, Sweden, France, Germany and Japan, but detailed data on recycling are not available (ICdA, 2006). The International Cadmium Association estimate that 90 percent of the recycled cadmium goes back into NiCd battery production in France, Sweden, USA, Mexico, Japan and China (ICdA, 2006)

354. **Market price fluctuations** - The world market price of cadmium is fluctuating, which illustrates the varying relations between supply and demand. Price development from 1993 to 2006 is illustrated in Figure 6-5, and for the years before that in Figure 6-6. According to Minerals Yearbook from the U.S. Geological Survey, worldwide, cadmium market prices rose in mid-2004 owing to increased demand (mainly from the Chinese NiCd battery industry), decreased primary production (because some zinc producers cut by-product cadmium output), and decreasing stocks of refined metal (USGS, 2004).

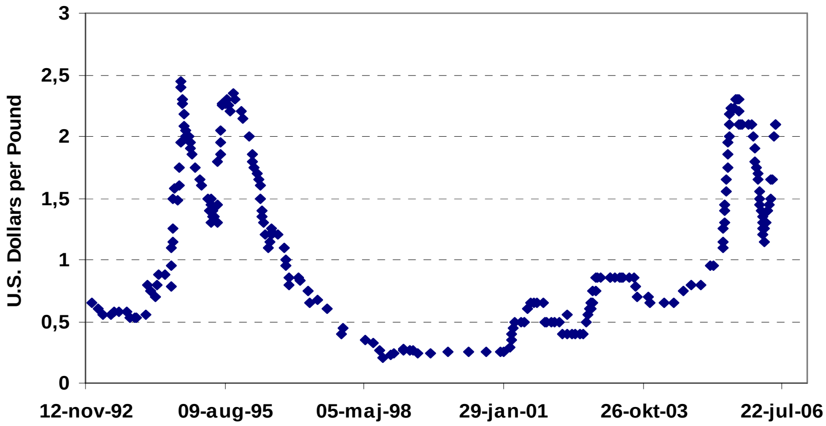


Figure 6-5 Metal Bulletin price history 1993-2006 for upper range for 99.99 percent purity cadmium metal (ICdA, 2006)

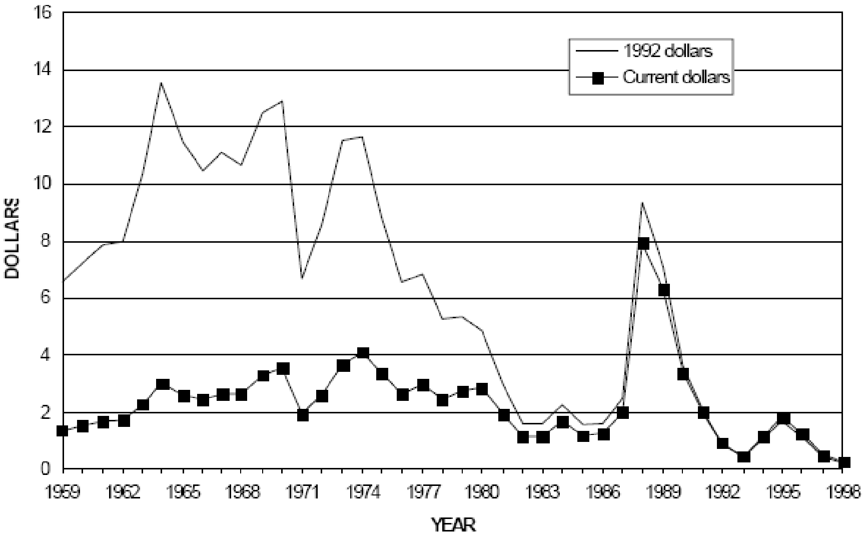


Figure 6-6 Annual average cadmium price in U.S. Dollar per pound during 1959-1998 (U.S.GS, 2006)

6.2 End-uses

355. The general trend in global cadmium consumption over the last two decades has been a steep increase in the use of cadmium for batteries and a decrease in the use for nearly all other applications. In 1980, cadmium pigment and plating were the main application areas followed by batteries which accounted for 23 percent of total global consumption and stabilisers in polymers accounting for 12 percent of the total (Table 6-4). In 2005, the batteries (NiCd batteries) accounted for about 82 percent of the estimated world consumption. Other applications than these four application areas in total accounted for only 0.5 percent.

356. The full dataset showing the development in consumption by main application areas from 1980 to 2005 is further illustrated in Figure 6-7. Please note that the dataset does include recycled cadmium. The apparent decrease from 2003 to 2005 is probably duo to some fluctuations and should according to ICdA not be interpretated as a general downward trend in the consumption.

Table 6-4 Reported global consumption of primary cadmium by end-use, 1980, 1995 and 2005 [1)]

Application	**1980**		**1995**		**2005**	
	Tonnes Cd/year	**Percentage**	**Tonnes Cd/year**	**Percentage**	**Tonnes Cd/year**	**Percentage**
Batteries	3,917	23	12,627	67	13,240	82
Pigments	4,598	27	2,639	14	1,615	10
Plating	5,790	34	1,508	8	969	6
Stabilisers in polymers	2,044	12	1,696	9	242	1.5
Other	681	4	377	2	81	0.5
Total	17,030	100	18,847	100	16,146	100

1) Data compiled by the International Cadmium Association (ICdA, 2006) (see the note to Figure 6-7. The quantities have been estimated from reported percentages and total cadmium consumption.

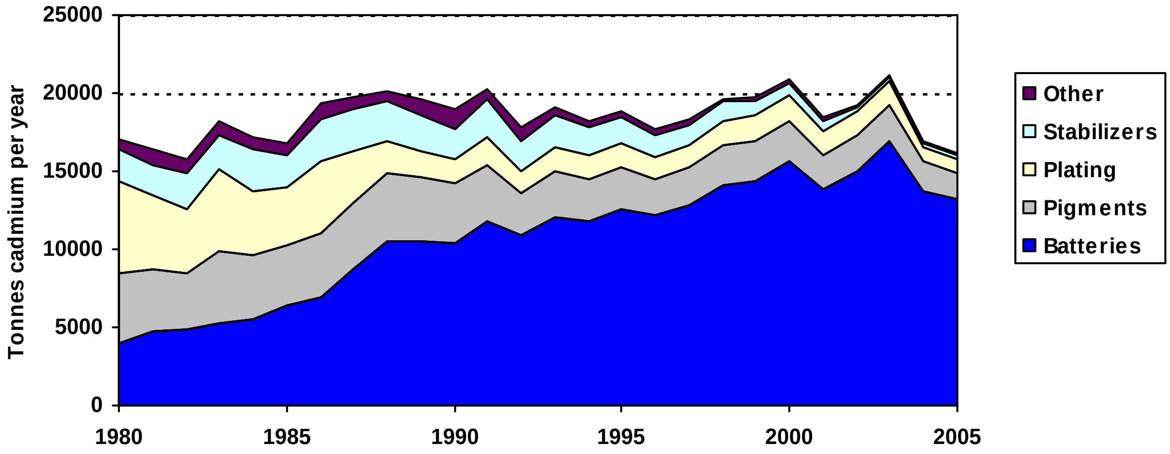


Figure 6-7 *Reported global primary cadmium consumption by end-use, 1980-2005. Data compiled by the International Cadmium Association (ICdA, 2006). The dataset is based on a number of sources including: Mining Annual Review; Metals & Minerals Annual Review; World Bureau of Metal Statistics; The Economics of Cadmium 1990 (Roskill); Metallgesellschaft's Metall Statistik, and the Cadmium Association. To these figures should be added the consumption of secondary cadmium, but comprehensive estimates are not available.*

357. Cadmium is and has been used for many different purposes, see examples in Table 6-5. The major fields of application are as indicated above in Table 6-4: NiCd batteries, pigments, plating and stabilizers, and it should be noted that all other application in 2005 in total accounted for less than 0.5 percent of the total. Cadmium alloys, included in "Other" in Figure 6-7 accounted in 1990 for 3 percent of the total cadmium use (OECD, 1994), but the use for this application has nearly ceased. Solar cells could, become an important field in the future, but the total consumption of cadmium for this application is still insignificant.

Table 6-5 Uses of cadmium

Application	**Current use**
NiCd batteries	Major application of cadmium
Plating on iron and steel	Widespread in many countries for applications requiring a high degree of safety or durability such as applications in aerospace industry, fastener industry, and in electrical parts - restricted in some countries.
Solders	Used in a few types of solders - decreasing trend
Alloying element in copper wires and sheets	Used some types of copper-cadmium and copper-cadmium-titanium alloy wires and sheets used in thermal conductivity and electrical conductivity alloys
Sacrificial zinc anodes for steel structures	Used in some types of anodes, but the total Cd amount may be marginal
Other alloys	Seldom
As control rods (neutron absorbers) and safety shields in nuclear reactors	Cadmium, boron, carbon, cobalt, silver, hafnium, gadolinium, and europium are the most common elements used in control rods E.g. 80% silver +15% indium +5% cadmium
Fuses in electrical and electronic equipment	Used for electrical fuses for certain temperatures
Pigments in plastics, ceramics, paint, etc.	Widespread used for some opaque colours, but phased out in some countries
Coloured glass	Used in some types of yellow or bright red glass
Stabilizers in plastics - in particular in PVC (polyvinyl chloride)	Widespread used for some applications but phased out in some countries - decreasing trend
Opto-electronic devices	Generally used in small amounts for some opto-electronic devices such as photo-resistors, photo-diodes, and photo-transistors used for solar cells, in switches for outdoor lighting etc.
Laboratory analysis reagents	Generally used for some analysis, but the total Cd amount is marginal
Coating for phosphorescence in CRT screen coatings (televisions, computer screens etc.)	Generally used for the application, but the total Cd amount is marginal
Biocides and antiseptics	May be historical
Contact material in form of AgCdO high power relays	Generally used for the application, but the total Cd amount is marginal

358. **Batteries -** The market of rechargeable NiCd batteries covers small, sealed-type batteries for cordless power tools, telecommunications, emergency lighting and security, and portable household applications. The sealed batteries account for about 80 percent of the cadmium consumption in the battery market. The remaining 20 percent is consumed in large industrial NiCd batteries for railroad, aerospace, electric vehicles and standby power, and other applications. The manufacturing countries for portable NiCd batteries today are China and Japan whereas stationary batteries are mainly produced by Sweden and France. The worldwide market of NiCd batteries continues to grow, although for some areas such as Western Europe, other battery types are gaining market share (ICdA, 2005). Batteries are further discussed in section 6.2.2: "Particulars on NiCd batteries"

359. **Pigments -** Cadmium pigments have been used in plastics, enamels, ceramics, paints, and possible other materials, although the use in paints and dyes may be obsolete today. The colours available include yellow, orange, and red shades, and other colours (such as green, brown, beige) that may be based on yellow or red. Important characteristics of cadmium colours are their light-fastness and tem-

perature stability, besides the wide spectrum of brilliant and "warm colours" available (Hansen *et al.,* 2005). Cadmium oxide is also added to glass to produce certain coloured glass.

360. According to OECD (1994), about 85 percent of cadmium pigments were used in engineering plastics which require high-temperature processing.

361. **Plating** - Plating of iron, steel or other materials with coatings of cadmium or cadmium alloys is used for applications requiring a high degree of safety or durability in aerospace, industrial fasteners, electrical parts, automotive systems, military equipment and marine/offshore installations. Important characteristics of cadmium plating are: good corrosion resistance in alkaline or salt solutions, low levels of friction, good conductive properties and solderability (OECD, 1994; Hansen *et al.,* 2005). While coating with cadmium is still being used in the Americas and Asia (only sparingly in Japan, it is however largely restricted in EU (Restriction under 91/338/EC).

362. **Stabilizers** - Organic cadmium compounds, generally cadmium laurates or stearates, used in combination with barium sulphate, have historically been widely used as a stabilizer in PVC and other polymers or copolymers of vinyl chloride. However, cadmium stabilizer systems have mainly been used for outdoor purposes such as pipes and gutters, window and door frames, roofing, etc. From March, 2001, European PVC additive producers stopped placing cadmium stabilisers on the European market (OECD, 2002; OECD, 1994; Hansen *et al.,* 2005). In 2003 the PVC industry in Australia announced a phase out of the use of cadmium stabilisers in vinyl products. In the ‘Product Stewardship programme 2005’ published by the Vinyl Council Australia, it was stated that except for two signatories in the industry, full compliance was achieved by 30 June 2004 (Australia's submission, 2005).

363. **Alloy uses** - The use of cadmium in alloys includes: soldering alloys, alloys with zinc (sacrificial anodes for corrosion protection of iron and steel), alloys with lead and copper (lead cable sheaths, copper wires etc.), alloys with a low melting point for fire alarm systems and safety circuit breakers, alloys for switch contacts where arching occurs, such as high current relays, made of silver-cadmium oxide, and silver-cadmium alloys as a partial replacement for silver (jewellery). The consumption has decreased significantly and is included in "other" applications accounting for about 0.5% of the total global consumption in 2005.

364. **Other uses** - Other uses include cadmium semiconductors that can have opto-electronic effects, which means their electrical properties are responsive to light. Such photosensitive compounds may be used for solar cells or light-sensitive resistors, or other applications. The cadmium compounds in question include cadmium selenide (CdSe), cadmium sulphide (CdS) or cadmium telluride (CdTe). Finally, cadmium mercury telluride semiconductors, used for thermal imaging (i.e. the process of converting invisible infrared radiation into a visible image) may also be mentioned (Hansen *et al.,* 2005).

Country examples

365. Detailed figures on cadmium consumption in Denmark 1990 and 1996 are shown in Table 6-6 The table summarize the total amount of cadmium brought into the economy in one year with final products. The figures are not typical, as the use of cadmium for pigments, stabilisers and plating in Denmark has been restricted since 1983. The figures illustrate the significance of unintentional "consumption" of cadmium as a natural contaminant in other materials such as zinc, fossil fuels, etc.

Table 6-6 "Consumption" of cadmium by end uses in Denmark 1996 (Jensen and Marcussen, 1993; Drivsholm et al., 2000) 3)

Application area	**Consumption/mobilization tonnes Cd/year**		**Percentage of total, 1996**
	1990	**1996**	
Intentional uses			
NiCd batteries	32	36 - 54	80
Pigments 1)	7	0.2 - 3.2	3
Stabilizers 1)		0.007 - 0.7	<1
Alloys		0.6 -2.6	3
Electrical components 2)		0.07 - 0.2	<1
Plating		0.1 - 0.2	<1
Other uses	<0.5	0.3	<1
Subtotal - intentional uses	*39.5*	*37.3 - 61.2*	*87*
Cadmium as natural trace element			
In zinc products	<0.5	0.1 - 2	2
In fertilizer	2.6	1.2	2
In agricultural chalk	1.1	0.8 - 1.2	2
In coal (for combustion)	2	1.4	2
In oil products (for combustion etc.)	1	0.003 - 1.3	1
In cement	2	1.9	3
In other products/materials	2.6	0.1 - 0.2	<1
Subtotal -natural trace element	*11.8*	*5.4 - 9.5*	*13*
Grand total (rounded)	**51**	**43 - 71**	**100**

1) The consumption stated is assumed to be due to import of plastic items from outside Europe.

2) Defined as electronic components apart from batteries and solders - could in principle cover pigments as well as plating or natural contaminants.

3) "Consumption is defined as the total cadmium content in end products sold in the concerned year..

366. The consumption of cadmium has changed significantly over time and a dataset from Sweden illustrates the changes in consumption pattern in Sweden over a period of 55 years from 1940 to 1995 (Figure 6-8. Up to 1970, plating was the major cadmium use in Sweden. In the 1970's, pigments and stabilizers had their golden age, whereas the sintered plate batteries (sealed NiCd batteries) from about 1980 have outdone all other applications. Also, as shown in figure 6-6, the use of cadmium in Jungner batteries (open NiCd batteries) has been fairly constant over past several decades. For the period 1980 to 1995 the data is well in accordance with the global trend shown in Figure 6-7. Information of the historical consumption is valuable for estimating today's sources of cadmium directed to waste.

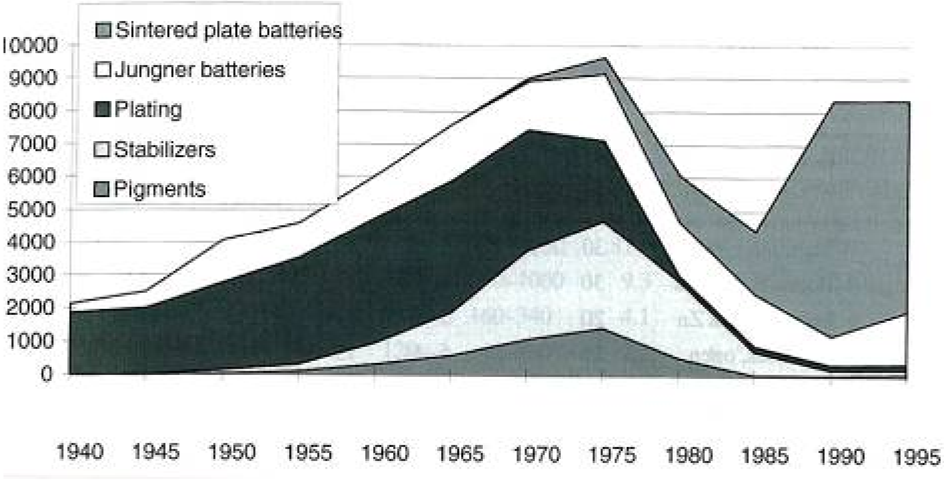


Figure 6-8 Trends in the major uses of cadmium in Stockholm, Sweden 1940 -1995 (Sörme et al., 2001)

367. In Hungary there are a great variety of products containing cadmium as metal or as its' compounds. From the health/sanitary and environmental points of view the hexavalentsome salts of cadmium is considered to be more hazardous (eg. chromates), therefore limitation on manufacturing, marketing or use is more relevant to such products, such as cement. The legal base of limitation is provided by the EüM-KöM Decree No. 41/200. (XII.20.) EüM-KöM, which transposes the Directive 76/769/EEC of the European Community. Additionally, there is system in place to take back used or out of date batteries from consumers. According to Decree 9/2001. (IV.9.) KöM the manufacturers and suppliers of batteries are obliged to report the yearly quantity of batteries they took back. A certain fraction of the batteries are processed, others are managed as wastes, thereby the amount of the take-back batteries (Table 6-7) differ significantly from the amount of waste (Hungary's submission, 2007).

Table 6-7 Yearly amount of take-back NiCd batteries

Calendar year	Total amount of taken-back batteries, [kg]
2004	274.000
2005	308.000
2006	305.000

368. In Japan the presumed main use and consumption are nickel-cadmium batteries, alloys, pigments, electroplating of machine parts and the like (CdO, CdSO4), as a stabilizer of plastics, colour fixing for ceramics (glaze and paint containing 40-80 percent copper oxide and as a silver-alloy brazing constituent used at machine part bonding. As much as 95 percent of the demand in 2005 was for batteries. An overall decrease in demand was noted due to the decrease in demand for pigments. Import of goods containing cadmium (Table 6-8) indicates a significant increase in "other cadmium and its products", whereas it did not indicate substantial decrease in any goods. Table 6-9 provides data on export of goods containing cadmium (Japan's submission, 2007).

Table 6-8 Import of goods containing cadmium in Japan

Goods		unit	1998	1999	2000	2001	2002	2003	2004
ash and residue containing antimony, beryllium, cadmium, chromium, or composite thereof		t	—	—	—	—	170	—	—
cadmium sulfide		kg	—	0	—	—	—	1,200	750
pigment and preparation based on cadmium compound		kg	3,124	2,493	3,015	3,636	4,283	5,830	5,854
cadmium and its product	ingot, powder, and scrap of cadmium	kg	3,561,850	3,332,738	3,916,204	2,463,148	2,818,694	3,819,775	2,626,077
	others	kg	2	18,283	140,013	260,000	126,737	96,015	42,088
nickel-cadmium battery		kg	1,729,660	1,334,154	1,676,227	985,500	956,716	1,176,384	1,750,357

Table 6-9 Export of goods containing cadmium in Japan

Goods		unit	1998	1999	2000	2001	2002	2003	2004
ash and residue containing antimony, beryllium, cadmium, chromium, or composite thereof		t	—	—	—	—	—	77	—
cadmium sulfide		kg	11,300	9,446	1,330	2,065	698	2,270	1,240
pigment and preparation based on cadmium compound		kg	70,073	85,548	73,366	50,649	40,363	93,755	131
cadmium and its product	mass and powder of cadmium	kg	—	—	—	—	35,160	135,700	251,699
	others	kg	244	933	230	35,110	297,869	1,078,153	917,264
nickel-cadmium battery		kg	17,531,368	18,997,251	20,666,983	17,303,251	16,887,247	13,844,137	14,674,200

Note

1: The table refers only to products whose trading data in 1998-2004 was available.

2: Import data by product are not converted into cadmium equivalent.

Source: Trade Statistics of Japan, Ministry of Finance

—: indicates that no data was available in “Trade Statistics of Japan

6.2.2 Particulars on use of cadmium in NiCd batteries

369. Constituting about 81 percent of the global market for refined cadmium and being a globally traded commodity, nickel-cadmium (NiCd) batteries is an important part of the flow of cadmium through society globally. While NiCd batteries could be a potential source of cadmium releases throughout the lifecycle of the batteries in many parts of the world, a comprehensive study done on NiCd batteries in EU showed that for those EU states (11 out of 16 in 2000) having a battery collection system, a collection rate of 75% was achieved for the year 2000 (EU, 2007).

Applications of NiCd batteries

370. Two different main types of NiCd batteries (accumulators) exist: 1) the sealed type that look like ordinary non-rechargeable batteries and are sold for consumer uses in a number of different sizes as individual battery cells or as incorporated in appliances, and 2) the "open" (or "vented"), larger accumulator types which look like car starter batteries and are mainly used in specialised professional equipment (starters for trains and airplanes, emergency lighting in aeroplanes and buildings, standby power

for photovoltaic panels, power supply in some electric cars etc.). The "open" type batteries are not used in consumer products and are generally sold to and used by a small group of professional users. A large part of the sealed type NiCd cells are used in larger battery units where cells a connected inside a shell (e.g. in cordless powertools).

371. The major application areas of sealed type NiCd batteries (also called "rechargeable NiCd batteries") include the following (Maag and Hansen, 2005):

- Cordless power tools;
- Wireless radio communication (LMR).

372. Other, smaller application areas (of which some have ceased in Denmark and likely in most of western Europe today) include the following:

- Emergency light devices;
- Cordless vacuum cleaners ("Dust busters");
- Cordless phones;
- Short range walkie-talkies;
- Other appliances for household and personal care (tooth brushes, shavers, trimmers etc.; many NiMH powered today);
- Individual battery cells (consumer use replacing primary, non-rechargeable batteries; dominated by NiMH in e.g. Denmark);
- Solar lamps;
- Mobile phones (portable cell phones; Li-ion powered today);
- Portable computer equipment (Li-ion powered today);
- Video Cassette Recorder equipment (VCR; NiMH and Li-ion powered today);
- Specialised technical measuring devices (laboratory, medical etc.).

373. Originally, NiCd batteries were the key factor in the success of all types of portable electric and electronic appliances, but today other types of rechargeable batteries have taken over a large part of the more technically advanced applications due to higher battery capacity per weight and some better performance characteristics. Nickel-metal-hydride (NiHM) batteries and lithium-ion (Li-ion) batteries are currently the most important alternatives. The main uses of NiCd batteries today are cordless power tools, among other reasons because these require high discharge rates and rapid discharging modes which the alternative battery types have only been for the last few years. Global supply data (see Figure 6-9) indicate that household and hobby uses (such as cordless vacuum cleaners) and cordless telephones (not to be confused with mobile "cell" phones) are also large uses.

374. The worldwide markets for portable consumer NiCd batteries as well as those of other rechargeable battery types have been described in detail by Hideo Takeshita of the Institute of Information Technology Ltd. in Japan over the past few years (ICdA, 2005). These market analyses are according to ICdA (2005) generally considered by the battery industry to be the best currently available. The trends in the usage of portable consumer NiCd batteries by application from Takeshita's surveys are summarized below. Cordless power tools take up an increasing part of the consumption whereas the use for camcorders and cellular telephones has ceased on the world market.

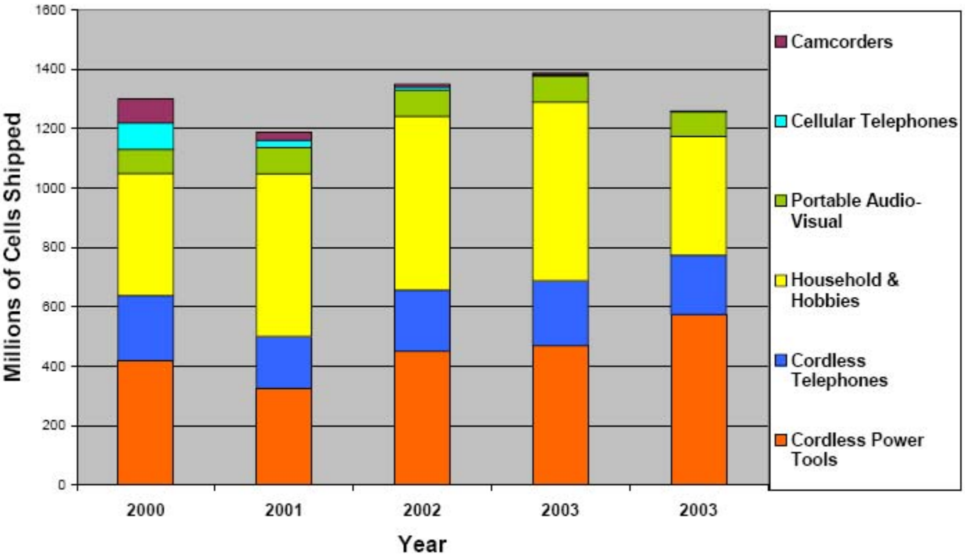


Figure 6-9 Worldwide consumer NiCd battery shipments by applications (ICdA, 2005)

375. Figure 6-10 shows in more detail the development of the consumption of NiCd batteries in Denmark (Maag and Hansen, 2005). As shown, other uses than power tools have been largely eliminated over the last five years in Denmark. This is somewhat different to the pattern shown for the global situation in Figure 6-9 above. One of several possible reasons for this difference is the import fee on NiCd batteries implemented in Denmark. A substantial fee is charged by the tax authorities per imported cell in order to allow the cadmium free alternatives to have a competitive market price and to set NiCd batteries and alternative batteries equal with regard to society's expenses for waste battery management; the collected fees are used for funding a national spent batteries collection system operated by private collection enterprises.

376. In a number of other European countries, a fee is imposed on all types of batteries with the objective to collect all batteries and thereby reduce their impact on the environment. This is in line with the recent development of a revised Battery Directive for the European Union, which earlier required collection of only the most potentially environmentally harmful batteries, those containing mercury, lead and cadmium, whereas the revised Directive require collection of all batteries.

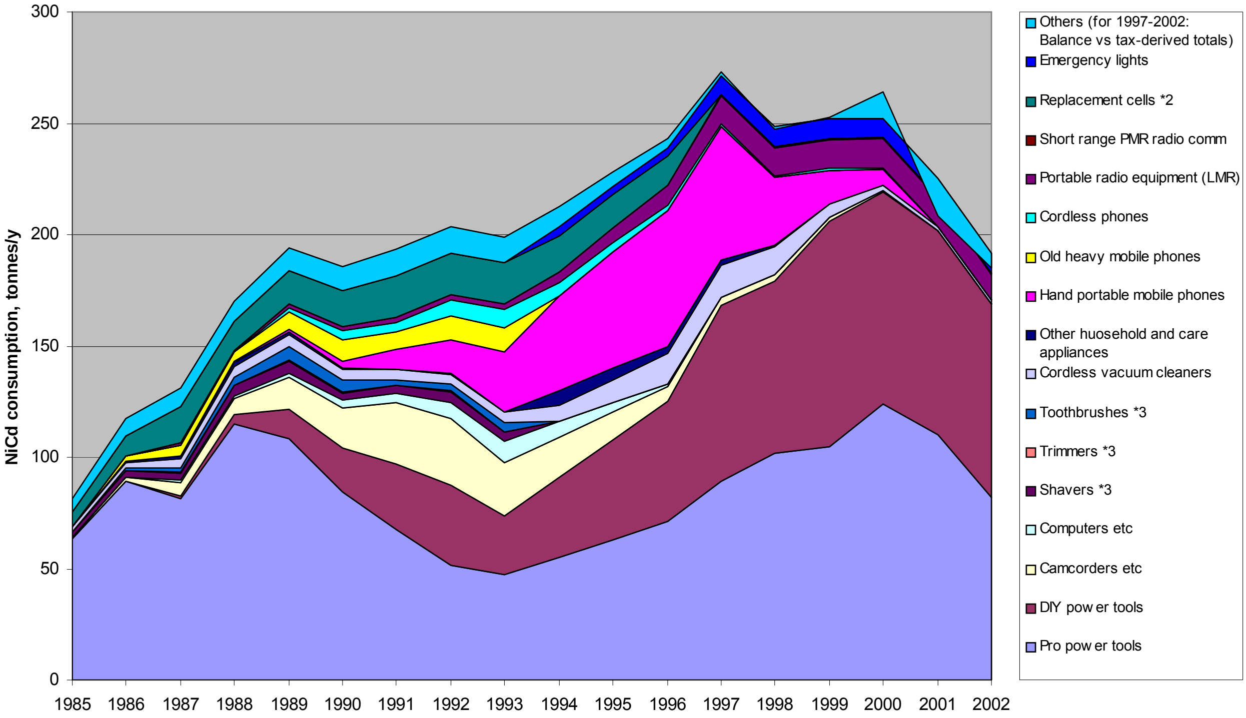


Figure 6-10 The development of NiCd consumption by use category in Denmark in 1985-2002 - note that consumption of power tools is divided in two user segments Do-It-Yourself (DIY) and Professionals (Pro); (reprinted from Maag and Hansen, 2005;
**2: The term "replacement cells" refers exclusively to sales of individual NiCd cells to end consumers.*
**3: From 1994, these products are included in "other household and care appliances")*

377. Alternatives to NiCd batteries and the trend in substitution is further discussed in chapter 8.2.1 NiCd batteries in waste treatment are further discussed in section 8.4.2 on waste management practices.

378. A very comprehensive risk assessment of cadmium and cadmium oxide was performed (currently existing as draft) by Belgium as part of joint European Union work on risk assessments of existing chemicals (ECB, drafts of 2003 and 2005). The risk assessment considers risks to health and the environment from many aspects of cadmiums life cycle - including cadmium used in and disposed of with NiCd batteries - according to a specific, detailed methodology used in the EU context, and under a number of assumptions and exposure scenarios. Future potential exposures from the long term fate of cadmium in landfills (beyond the controlled maintenance period) are not included in the assessment methodology. The assessment concludes in summary the following for the current application and disposal pattern of cadmium and cadmium oxides in the EU context:

- There is no or limited risks to species in the environment associated with the current manufacturing and waste treatment activities in the EU , including those relevant to NiCd batteries;
- There are occupational risks to humans in certain exposure situations;
- Risks to the general public from indirect exposure via the environment cannot be excluded;
- Risks to consumers from a few specific direct product-related exposures cannot be excluded (cadmium-containing brazing sticks and jewellery, not NiCd batteries).

7 Long-range transport in the environment

379. 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 cadmium beyond the local scale. Some long-range transport of cadmium may also take place with migrating fauna.

380. Long-range transport in the environment here refers to transport in air or water of substances (e.g. cadmium) 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 refers to such transport from one continent to another, for example between Asia and North America.

7.1 Atmospheric transport

381. 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.*" (UNECE, 1979). Similarly, 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).

382. Atmospheric transport contributes to cadmium dispersion in the environment. Once emitted to the atmosphere, cadmium 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 cadmium 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 emission source 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. These factors and the main principles of cadmium atmospheric transport are discussed in greater detail below.

7.1.1 Cadmium environmental levels and transport patterns

383. As described in Chapter 5, human activities (such as mining, metal production, and combustion of fossil fuels) can result in elevated cadmium concentrations in the environment. Measurements of cadmium concentrations in ice cores, freshwater sediments and peat bogs demonstrate an essential increase of airborne cadmium depositions compared to the pre-industrial period (Candelone and Hong, 1995; Coggins *et al.*, 2006). Due to anthropogenic emissions of cadmium to the atmosphere cadmium 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 has been 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).

384. As mentioned in section 5.1., cores from 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 year 1800) depositional fluxes of cadmium, the

record demonstrates an eight-fold increase that peaked between the 1960's and 1970's and then displays a steady decline thereafter (AMAP, 2005).

385. Table 7-1 illustrates levels of cadmium concentrations in the ambient air observed in different parts of the globe. It should be noted that the concentrations presented are not directly comparable, because of different measurement periods, sampling and analysis procedures, detection limits, etc., but rather give a general idea of airborne cadmium levels. Cadmium concentrations in the urban environment are commonly considerably higher (an order of magnitude or more) than those in rural areas. The lowest concentrations were observed in remote regions such as the Arctic, the Antarctic and middle parts of the Atlantic and Pacific Oceans.

386. The atmospheric wet deposition fluxes of cadmium were measured at two sites on the shore of the Delaware and Chesapeake Bays (U.S.A.) in 1995/96 (Kim *et al.*, 2000). Measured mean annual wet depositions at these sites were 0.035 and 0.058 mg/m^2/year, respectively. A comparison of annual fluxes during 1991-1996 did not reveal any noticeable trend of cadmium wet deposition in this region. Calculation of the enrichment factors showed that more than 99 percent of cadmium in precipitation is from non-crustal sources (not origination from natural weathering of the Earth's crust - presumably anthropogenic sources).

387. Dry depositions of cadmium were measured near Lake Hartwell, South Carolina (U.S.A.) during six dry sampling events in 2003 (Goforth and Christoforou, 2006). Estimated atmospheric concentrations of cadmium were relatively high - 0.77 ng/m^3, and the largest mass of cadmium was detected as coarse particles (larger than 2.5 μm). Average measured cadmium dry deposition flux was 0.17 mg/m^2/year, which was comparable to or higher than those from other studies found in the literature for rural areas of the U.S.A.

388. Measurements of cadmium concentrations in rain and snow were performed by Takeda *et al.* (2000) in western Japan for 3 years (1995-1997). The measured concentrations were within the range 0.006-1.23 μg/L, with a mean value 0.063 μg/L, which is comparable to concentrations measured in Europe. No systematic seasonal variation was observed. Cadmium concentrations in snow collected across the island demonstrated the 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.

389. Long-term measurements of wet and dry cadmium depositions were also performed by Sakata *et al.* (2006) in 2003-2004 at 10 sites in Japan located in different parts of the country. No systematic difference was detected between observed wet and dry cadmium depositions. Measured annual wet deposition flux varied within the range 0.04-0.3 mg/m^2/year, whereas dry depositions were from 0.04 to 0.2 mg/m^2/year. Elevated wet deposition fluxes were also observed at the coast of the Sea of Japan, indicating a large contribution due to long-range transport from the Asian continent.

390. Total atmospheric depositions of cadmium 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 cadmium depositions (0.07±0.04 mg/m^2/year) were comparable to depositions in North America and Europe.

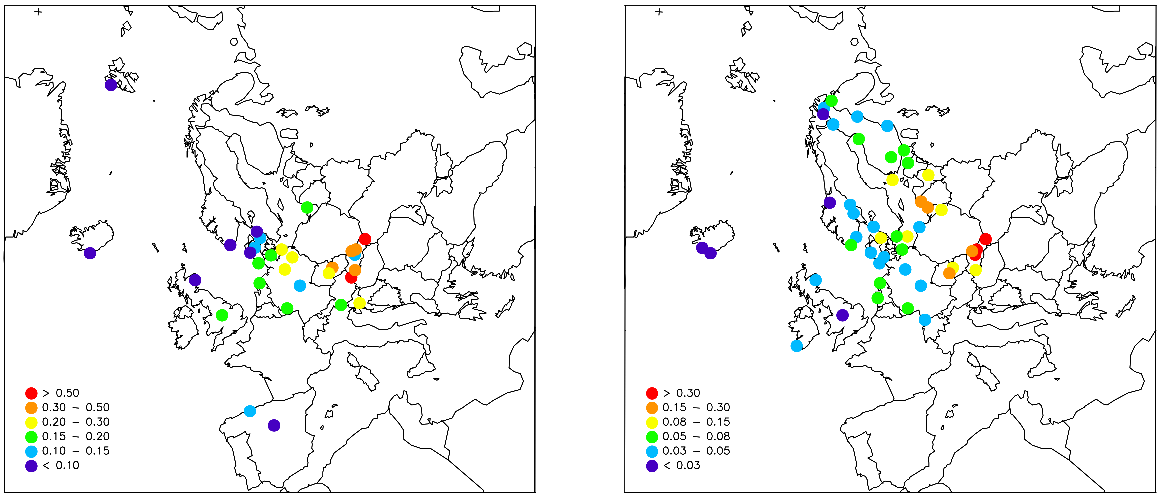
391. Concentrations of cadmium in rainwater and its wet depositions were measured at the remote site of Paradise in Fiordland, New Zealand during 1993-1995 (Halstead *et al.*, 2000). Measured cadmium concentrations in precipitation varied within the range 0.02-1.33 ng/L, with a mean value 0.36 ng/L. These concentrations are among the lowest in remote precipitation of the globe, with the lower values being similar to modern Antarctic ice. Air-mass trajectories showed prevailing Australian and Southern Ocean influence on cadmium pollution levels in this remote area.

Table 7-1 Concentration of cadmium in ambient air measured at various sites in the Northern Hemisphere

Location	**Period**	**Concentration, ng/m^3**	**Reference**
Urban			
United Kingdom	1998	0.84–1.05	EU Position Paper, 2000
Helsinki, Finland	1996/7	0.11–0.13	EU Position Paper, 2000
Zürich, Switzerland	1998	0.29	EU Position Paper, 2000
Lugano, Switzerland	1998	0.45	EU Position Paper, 2000
Hamburg, Germany	1993	1.2	EU Position Paper, 2000
Niedersachsen, Germany	1997	0.2–0.5	EU Position Paper, 2000
Rhine-Ruhr area, Germany	1998	0.5–2.9	EU Position Paper, 2000
Hessen, Germany	1998	0.3–0.5	EU Position Paper, 2000
Stuttgart, Germany	1996	0.9	EU Position Paper, 2000
Köge, Denmark		<1.5	EU Position Paper, 2000
Bilthoven, Netherlands	1998	0.3	EU Position Paper, 2000
Montalto di Casto, Italy	1996	0.42	EU Position Paper, 2000
Cartagena, Spain	1998	2.93–8.98	Moreno-Grau *et al.*, 2000
Zhongshan, China	2002	4.6	Lee *et al.*, 2005
Guangzhou, China	2002	21.6	Lee *et al.*, 2005
Rural			
Kollumerwaard, Netherlands	1998	0.21	EU Position Paper, 2000
Biest, Netherlands	1998	0.39	EU Position Paper, 2000
Sevettijarvi, Finland	1992-1994	0.4±0.19	Virkkula *et al.*, 1999
Delft, Netherlands	1997	0.5	Wang *et al.*, 2000
Burnaby Lake, Canada	1995	0.39	Brewer and Belzer, 2001
Nanling, China	2003	16	Lee *et al.*, 2005
Lake Hartwell, U.S.A	2003	0.77	Goforth and Christoforou, 2006
Austria	2003	0.16–0.56	Aas and Breivik, 2005
Czech Republic	2003	0.27–0.32	Aas and Breivik, 2005
Germany	2003	0.15–0.26	Aas and Breivik, 2005
Denmark	2003	0.07–0.18	Aas and Breivik, 2005
Spain	2003	0.06–0.12	Aas and Breivik, 2005
United Kingdom	2003	0.05–0.18	Aas and Breivik, 2005
Slovakia	2003	0.13–0.55	Aas and Breivik, 2005
Remote			
North Atlantic	1992	0.01-0.08	Véron and Church, 1997
North Pacific	1995-1996	0.3–0.6	Narita *et al.*, 1999
Storhofdi, Iceland	2003	0.02	Aas and Breivik, 2005
Zeppelin, Spitsbergen	2003	0.02	Aas and Breivik, 2005

392. In Europe, long-term measurements of cadmium background air concentration and depositions are performed at stations of the EMEP monitoring network (EMEP/CCC, 2006). In 1990, measurement data on background atmospheric concentrations of cadmium were available from 40 stations in Europe, located in 11 countries. In 2003, measurement data were carried out at 61 stations in Europe situated in 18 countries. However, there are still large areas where measurement data are not available, e.g. southern, southeastern and eastern parts of Europe.

393. Annual averages of cadmium concentrations in air and in precipitation in 2003 in Europe are presented in Figure 7-1. According to these data, typical ranges of cadmium concentrations in air were 0.05–0.2 ng/m^3 (northern Europe), 0.2 – 0.5 ng/m^3 (central Europe) and 0.06 – 0.12 ng/m^3 (southern Europe). The lowest cadmium concentrations were observed in Scandinavia, Iceland, northern United Kingdom, at one Spanish station and in the high Arctic. Concentrations in precipitation typically range from 0.02 to 0.07 µg/L in northern Europe, and in central Europe, from 0.04 to 0.2 µg/L. The highest cadmium concentrations both in air and precipitation were found in Slovakia, the Czech Republic and in some Baltic stations.



(a) (b)

Figure 7-1 Cadmium concentration in aerosol (a) and in precipitation (b) measured at the EMEP monitoring stations in 2003 (Units: ng/m3 for aerosol concentration; mg/L for concentration in precipitation; Ilyin et al., 2005)

394. Taking into account the relatively short residence time of cadmium in the atmosphere (see Section 7.1.2), 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, comparing total values of emission and deposition. The comparison of total officially reported anthropogenic emissions of cadmium in Europe with total wet deposition to European countries based on measurement data only indicates that observed wet depositions of cadmium are about twice as high as the reported emissions in 1990 – 2003 (Figure 7-2) (Ilyin and Travnikov, 2005). However, one should keep in mind that a considerable mass of cadmium is also deposited due to surface uptake (so-called dry deposition, see Section 7.1.2), as well as deposited over marginal seas and transported beyond European boundaries. Dry deposition of this particle-bound heavy metal is, as usual, comparable in magnitude to wet deposition. Hence, one could expect that total (wet and dry) annual cadmium deposition would be approximately 2-3 times higher than officially reported anthropogenic emissions.

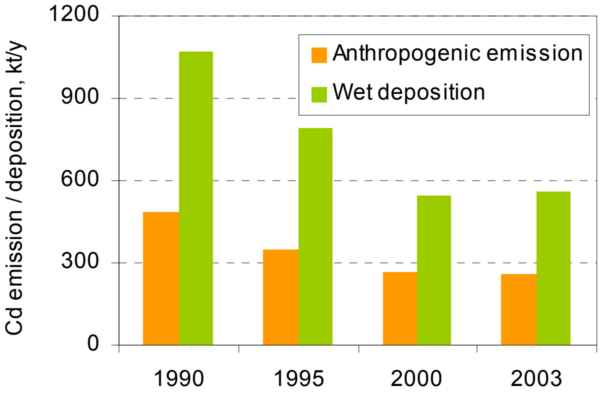


Figure 7-2 Comparison of total officially reported anthropogenic cadmium emissions with total wet deposition to European countries based on measurement data (Ilyin and Travnikov, 2005)

395. These inconsistencies 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.

Spatial patterns

396. The overall patterns of cadmium air concentration and deposition can be illustrated by results of cadmium atmospheric transport modelling (for more details on the atmospheric modelling and its evaluation, see Section 7.1.3). The spatial patterns of modelled cadmium air concentrations and deposition levels in Europe in 2003 are shown in Figure 7-3 (Ilyin *et al.*, 2005). The areas with elevated cadmium concentrations and depositions are located in some countries of Western, Eastern and Southern Europe (Belgium, Germany, Poland, Slovakia, Bulgaria, Ukraine and Russia). Ambient air concentrations of cadmium in these regions are 0.3-1.5 ng/m^{3,} and deposition fluxes exceed 50 g Cd/km^2/year. In the northern part of Europe, cadmium levels are significantly lower – air concentrations and depositions are below 0.1 ng/m^3 and 30 g Cd/km^2/year, respectively.

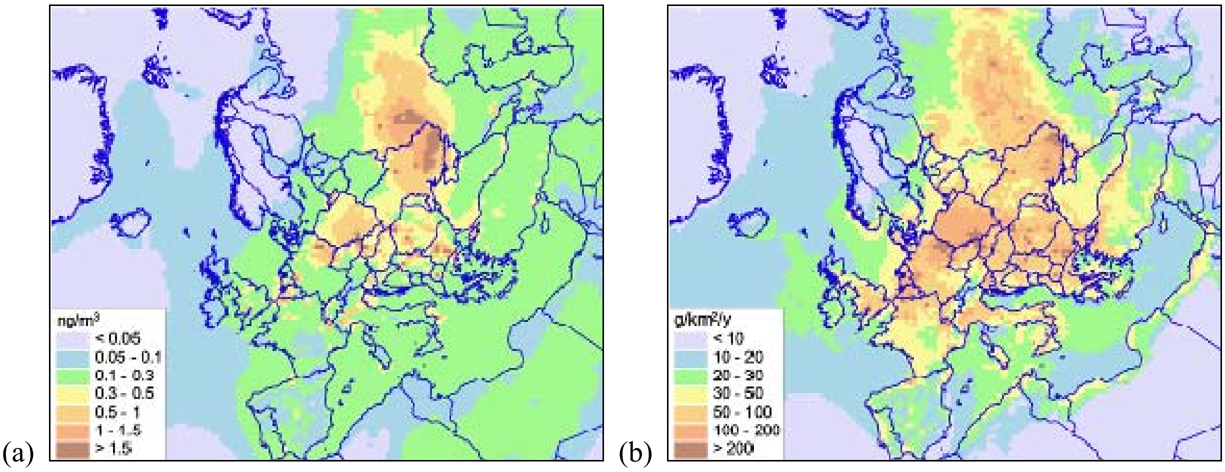


Figure 7-3 Spatial distribution of cadmium air concentration (a) and depositions (b) in Europe in 2003, calculated with the MSC-HM model (Ilyin et al., 2005)

397. Additional information on spatial distribution of cadmium environmental levels can be obtained from measurements of its concentration in mosses. Elevated concentrations of cadmium 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 sources, or from widespread area sources. Figure 7-4 shows mean measured concentration of cadmium in European mosses from the survey by *Working*

Group on Effects (2004). Concentrations tended to decrease from south to north. A north-south increasing gradient is typical for moss concentrations in Scandinavia. Elevated concentrations observed in Central European countries (Poland, the 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 naturally geochemically enriched areas. High concentrations are also characteristic of industrialized areas of northern France and the United Kingdom. Elevated levels in northern Portugal are associated with recent forest fires and, further south, with mining and industrial activity.

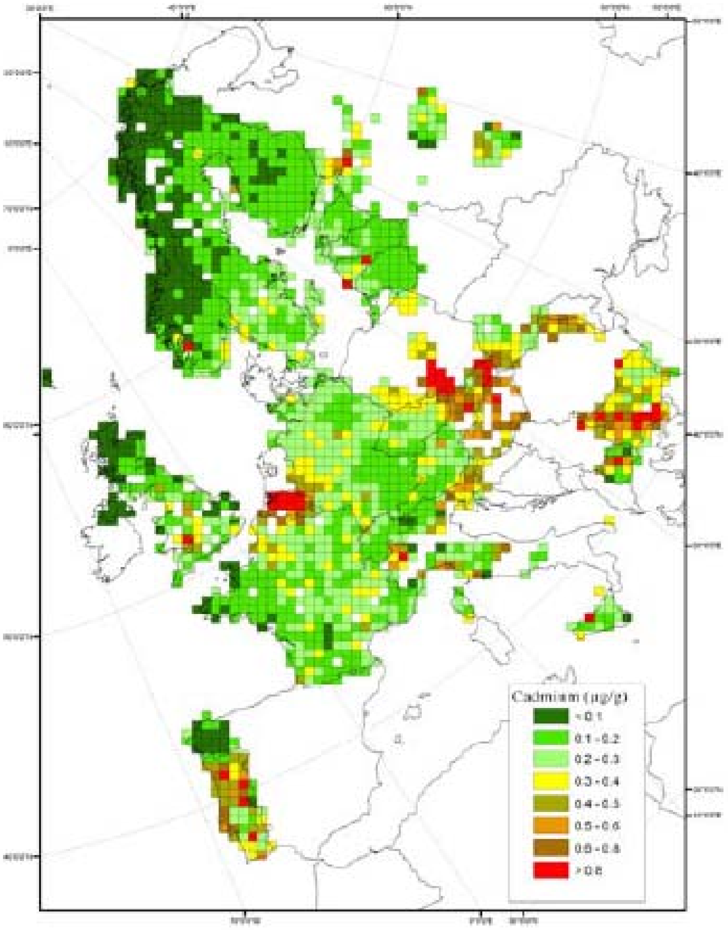
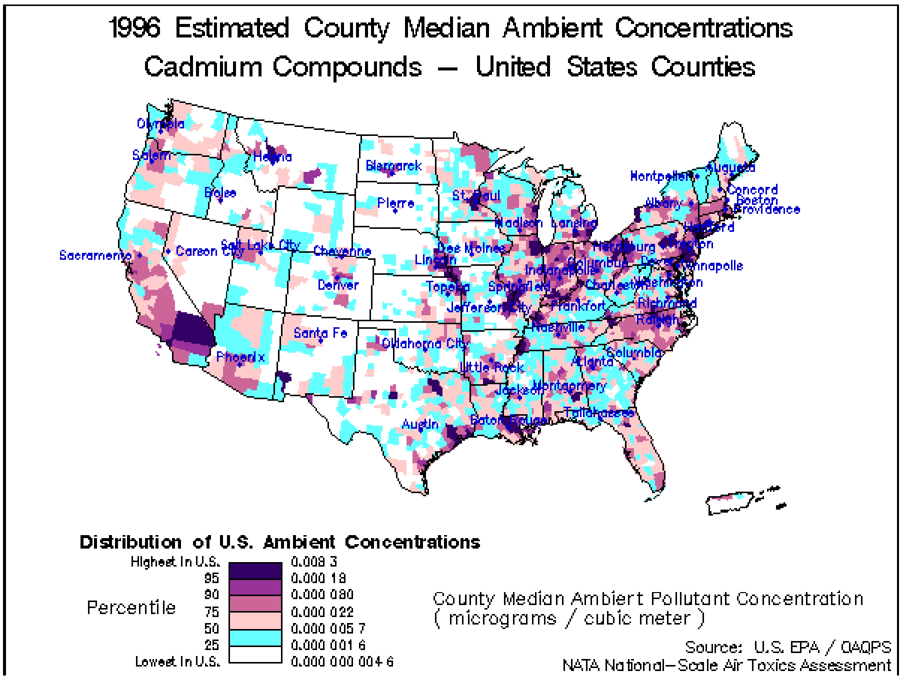
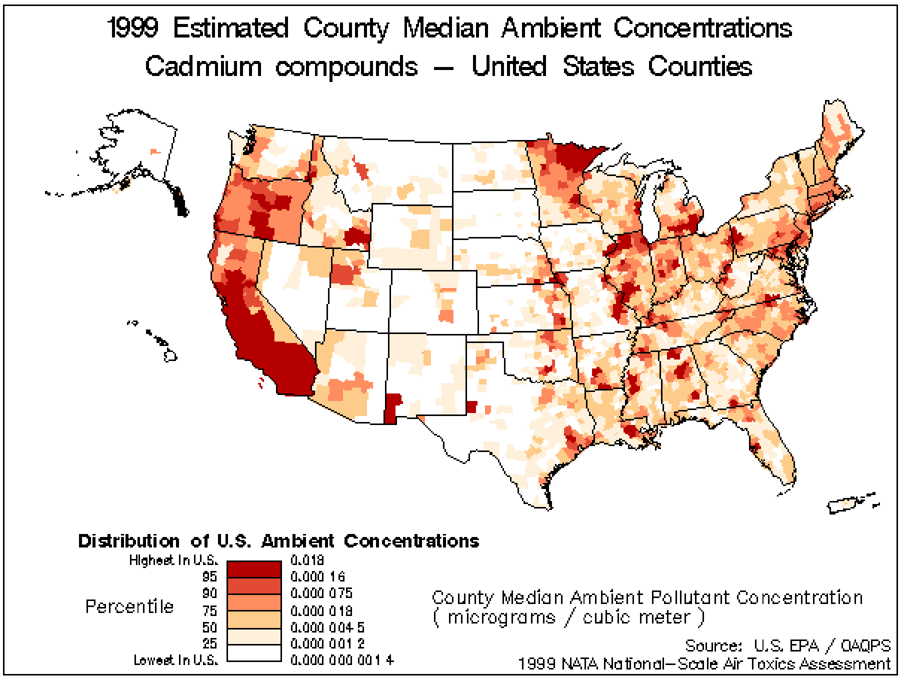


Figure 7-4 The mean cadmium concentration in mosses within the EMEP 50 km x 50 km grid cell. Units: µg/g dw. (Reprinted from Working Group on Effects, 2004)

398. In the U.S.A., the National-Scale Air Toxics Assessment (NATA) is conducted by the U.S. EPA to assess air quality, human exposures and risks for a range of chemicals. NATA includes modelling ambient air concentrations of 33 air toxics (including cadmium). The ASPEN air dispersion model was used to first model air concentrations for individual census tracts (i.e., geographical units smaller than counties). The available NATA results for cadmium based on 1996 and 1999 emissions data are shown in Figure 7-5 (a,b). As shown in Figure 7-5 (a,b) the modelled concentrations for 1996 and 1999 were generally between about 0.0012 ng/m^3 to 0.16 ng/m^3, with the highest results up to 18 ng/m^3 (U.S. EPA, 2002 and U.S. EPA, 2008). There are various uncertainties with this modelling assessment. As described further below, evaluation of these modelling results (compared to measurement data) indicates that the model underpredicted air concentrations of cadmium by about 4-5 times.



(a) 1996



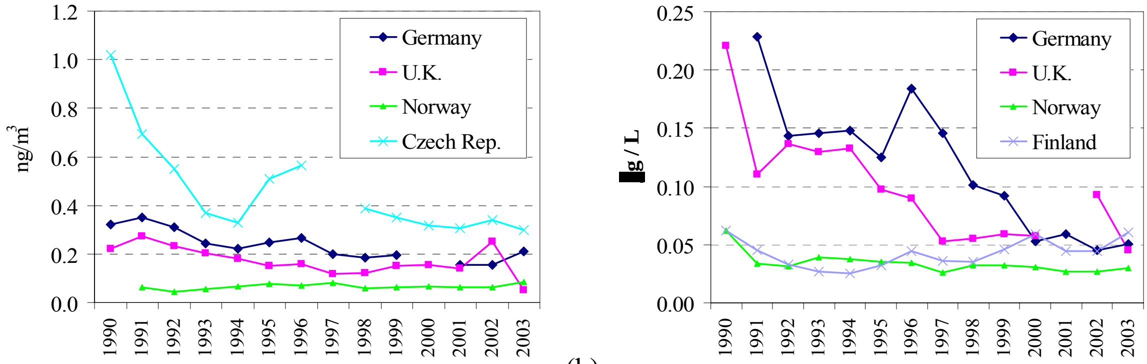
(b) 1999

Figure 7-5 Modelled Median County-Level (annual-averaged) Ambient Air Concentrations for cadmium in the United States of America. for (a) 1996 (U.S. EPA, 2002) and (b) 1999 (U.S. EPA, 2008)

Temporal trends

399. Though changes have not been as significant as for lead, available long-term background measurements show that the reported emission reductions during the last decade resulted in a noticeable decline of airborne pollution loads of cadmium in some European countries, whereas in other parts of Europe there has not been observed significant changes (EMEP/CCC, 2006). Figure 7-6 shows long-term trends of measured cadmium concentrations in air and precipitation averaged over different European countries. As seen from the figure, the long-term changes of cadmium levels in air and precipitation vary considerably across Europe. From the early 1990’s to 2003, the country-averaged concentra-

tions of cadmium in air approximately halved in central and north-western Europe. Moreover, measured concentrations in precipitation in central and north-western Europe decreased to between a fourth and a third of 1990 levels. On the other hand, in the northern part of Europe, changes in concentrations in air and precipitation are not evident during this time period (from 1990 to 2003).



(a) (b)

Figure 7-6 Long-term changes of cadmium concentrations in air (a) and in precipitation (b) in different parts of Europe based on EMEP monitoring data (EMEP/CCC, 2006)

400. A study on trends in metals and persistent organic pollutants in the European marine environment shows that at seven locations, different from the observed hot spots, increasing trends in cadmium concentrations of mussels and fish were observed. A total of 283 temporal trends have been analysed statistically on a station-by-station basis, of which only 27 were statistically significant: 20 downwards and seven upwards (Green *et al*., 2003 in Finland's submission, 2007).The decrease of cadmium levels in the environment can also be illustrated by changes in its concentration in mosses. Figure 7-7 shows changes in the cadmium concentrations in mosses in Finland during 1985–2000 (Poikolainen *et al.*, 2004). The cadmium concentrations in mosses 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 was detected over the whole territory of Finland since 1985. The reduction in cadmium concentrations in mosses between 1985 and 2000 was, on average, 67 percent. Besides this, the reduction of cadmium concentrations increased from north to south. The concentration of cadmium in mosses did not highlight any major single industrial emission source of cadmium in Finland.

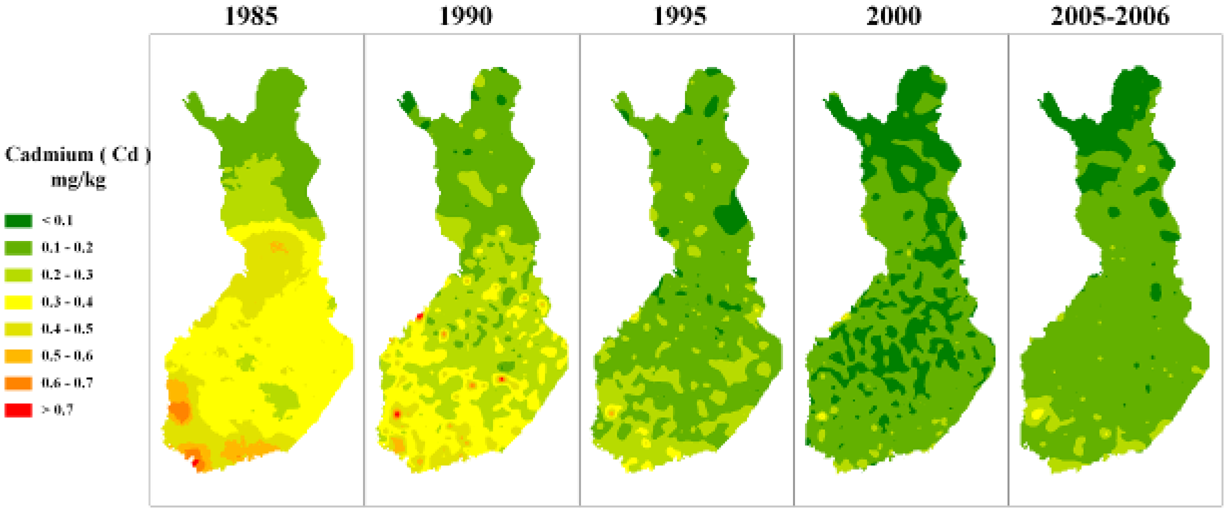


Figure 7-7 Changes in the cadmium concentration in mosses in Finland during 1985–2000 (reprinted from Poikolainen et al., 2004 and Piispanen, J (2007))

401. Long-term changes of cadmium levels in the Arctic can be characterized by measurements available from station Zeppelin, Spitsbergen, Norway (EMEP/CCC, 2006). Observations of cadmium concentrations in air did not exhibit any noticeable trend during the period from 1994 to 2003 (Figure 7-8a). However, seasonal variability of cadmium concentrations at the Zeppelin station is significant (Figure 7-8b). Minimum concentrations are observed in summer, and maximum, in winter. This seasonal character of higher Arctic levels of cadmium is associated with intensive atmospheric transport of contaminants from Eurasian sources in winter known as the phenomenon of arctic haze (Macdonald *et al.*, 2005).

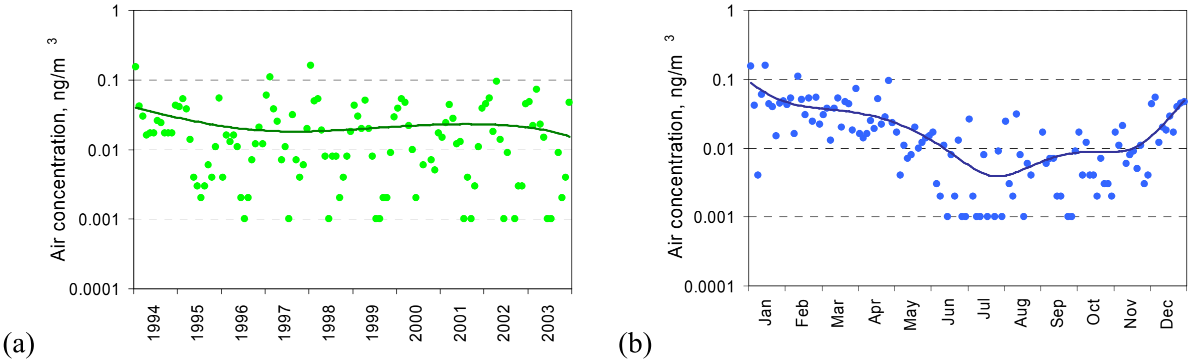
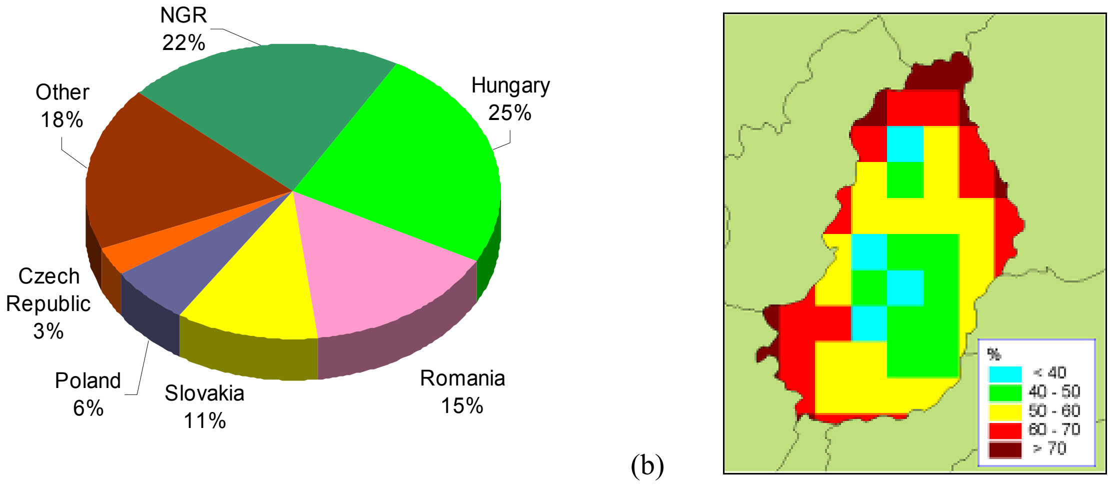


Figure 7-8 Long-term trend of cadmium concentration in aerosols (a) and its seasonal variation (b) at Zeppelin, Spitsbergen, Norway. Circles show monthly mean values, solid lines show polynomial approximation (EMEP/CCC, 2006)

Regional scale transboundary pollution

402. Operational calculations of cadmium 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). Figure 7-9 illustrates an example of the assessment of cadmium transboundary pollution based on modelling in one of the European countries – Hungary. As shown below, an estimated 25 percent of the cadmium deposition in Hungary comes from anthropogenic emissions sources within Hungary, about 53 percent of total cadmium depositions to this

country are defined by the atmospheric transport from anthropogenic sources located in other nearby countries (such as Romania, Slovakia, Poland and Czech Republic) and 22 percent from a combination of natural sources, re-emission of former anthropogenic releases and global sources. In regions close to national borders, the contribution from sources outside the country can exceed 70 percent, whereas in the central part of the country it can be less than 40 percent.



(a) (b)

Figure 7-9 Main contributors to deposition of cadmium in Hungary (a) (NGR - natural, global sources and re-emission). Spatial distribution of contribution of external anthropogenic sources to cadmium depositions in Hungary (b) (calculated with the MSCE-HM model, Ilyin et al., 2005).

403. Contribution of transboundary transport from anthropogenic sources in Europe to depositions of cadmium in European countries varies as shown in Figure 7-10 from more than 70 percent in the Republic of Moldova, Belarus and Lithuania to less then 15 percent in the United Kingdom, Spain, and Iceland (Ilyin *et al.*, 2005). In one-third of European countries, this estimated contribution exceeds 50 percent, and in two-thirds it exceeds 25 percent.

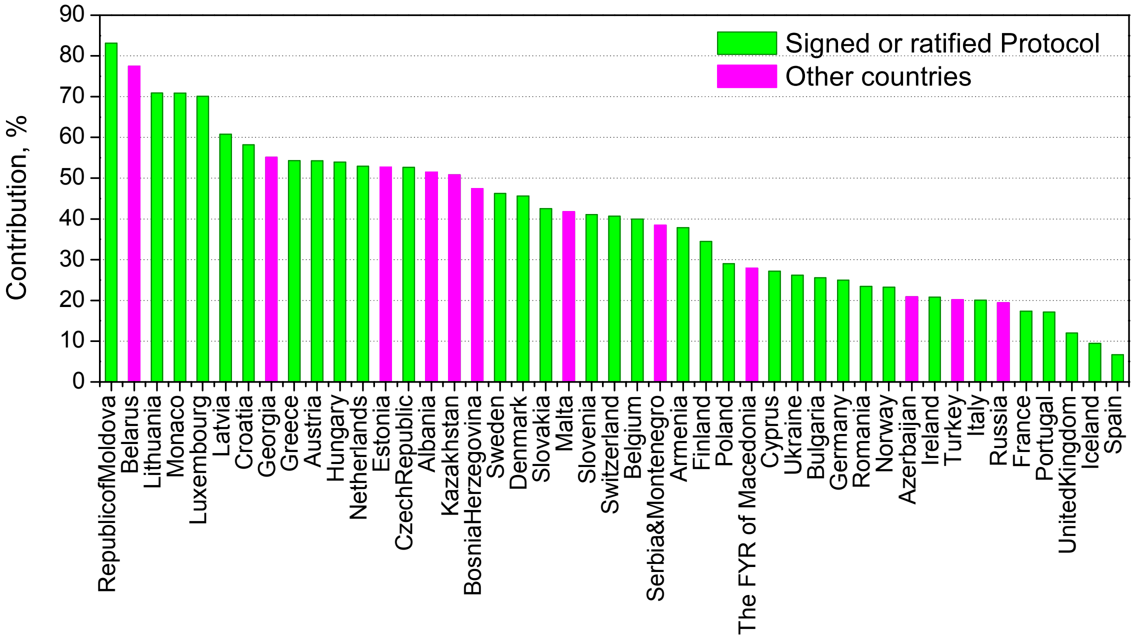


Figure 7-10 Contribution of external European anthropogenic sources to depositions of cadmium in European countries in 2003 (with reference to the LRTAP Convention Heavy Metals Protocol, see section 9.2.1).

Intercontinental transport

404. Specific evidence of cadmium intercontinental transport is very scarce. Due to the relatively short residence time of cadmium 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 indicate that cadmium can be transported over distances of up to thousands of kilometres (Candelone and Hong, 1995). Analysis of cadmium in aerosols in a few regions also illustrates long-range transport. Some small portion of anthropogenic cadmium from North America has been noted in the Russian Arctic (Shevchenko *et al.*, 2003). Further, aerosol measurements in Taiwan show that a portion of airborne cadmium can be transported over a thousand kilometres from developing areas of China (Hsu *et al.*, 2005).

405. Besides, some indication of cadmium potential to intercontinental transport can be 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 provide evidence that aerosols are transported intercontinentally, as well as from industrialised regions to remote regions with few local emission sources such as the Arctic. As cadmium is transported in the atmosphere adhered to aerosol particles, these studies indicate that cadmium has a potential to be transported intercontinentally.

406. Due to lack of hemispherical or global emission datasets, intercontinental cadmium transport has not been assessed in transport models so far. However, cadmium transport in the atmosphere is governed by the same transport principles as other particle-bound heavy metals, such as lead. Indeed, atmospheric transport characteristics of cadmium and lead are completely defined by properties of their carrier particles. According to available measurements, aerosol particles containing cadmium and lead are characterized in the ambient air by similar particle size distributions (e.g. Milford and Davidson, 1985; Allen *et al.*, 2001). This fact indicates that these two substances have similar removal properties (such as scavenging and dry deposition efficiency) defining their residence time in the atmosphere and

dispersion distance. Therefore, some features of lead long-range transport described in the companion review report on lead can serve as a qualitative indication of the potential for very long distance atmospheric transport of cadmium.

407. Particularly, following the analogy with lead, cadmium is expected to be mainly transported over local or regional distances due to the relatively short residence time in the atmosphere. Intercontinental transport can make only minor contributions to regional environmental levels of cadmium in industrially developed regions on a long-term basis. Episodically, the contribution of intercontinental transport can be significantly higher at certain locations. However, theoretical assumptions on cadmium intercontinental transport mentioned above could be confirmed with direct modelling and additional measurements. Therefore further investigation may be warranted, particularly, for aggregation of a global set of emission data and development or application of existing models for assessment of intercontinental transport of cadmium.

Arctic pollution

408. The Arctic is a remote region with vulnerable ecosystems which has virtually no significant emission sources on its territory. That is why the transport of pollutants like cadmium from adjacent industrial areas (e.g. Kola Peninsula, Norilsk region, etc.) or from other continents of the Northern Hemisphere may be of importance for contamination of the Arctic region.

409. Taking into account the general similarities between the long-range atmospheric transport of cadmium and lead (both are transported on aerosol particles with similar properties), and building on observations for lead, one can expect that major contributors to Arctic pollution are sources located in Europe and in Siberia. Cadmium concentrations in the Arctic air also have well pronounced seasonal variation, with a maximum in winter and a minimum during summer (see Figure 7-8), indicating a connection with Arctic haze. Nevertheless, cadmium transport is characterized by some peculiarities. In particular, it appears to deposit more readily in the Arctic than other particulate elements (AMAP, 2005). This is related to the anthropogenic releases and characteristics of air mass movement to the Arctic. It was reported that, of 15 major elements in Arctic haze particles, cadmium was the only one found exclusively below 2000 meters (Pacyna *et al.*, 1985, as cited in AMAP, 2005). Since low altitude is a prerequisite for deposition from the atmospheric boundary layer, this may explain increased deposition of cadmium from Arctic haze.

410. A spatially extensive snow-sampling program covering the Canadian and Russian Arctic islands and the Arctic Ocean was undertaken between 1993 and 1996 (AMAP, 2005). Most snow samples were from the interior regions of the polar ice caps, collected between late March and early May. Surface snow was considered a better indicator of spatial patterns in contaminants from long-range atmospheric transport than sub-surface snow, which can retain a fingerprint from soil or losses deposited in summer from local, seasonally snow-free areas. Cadmium concentrations were generally <5 picograms per gram (pg/g) on the Canadian ice caps and sea-ice transect, reaching a maximum of 38.6 pg/g at Aleksandry Island (Figure 7-11). Total cadmium deposition showed a similar pattern (AMAP, 2005).

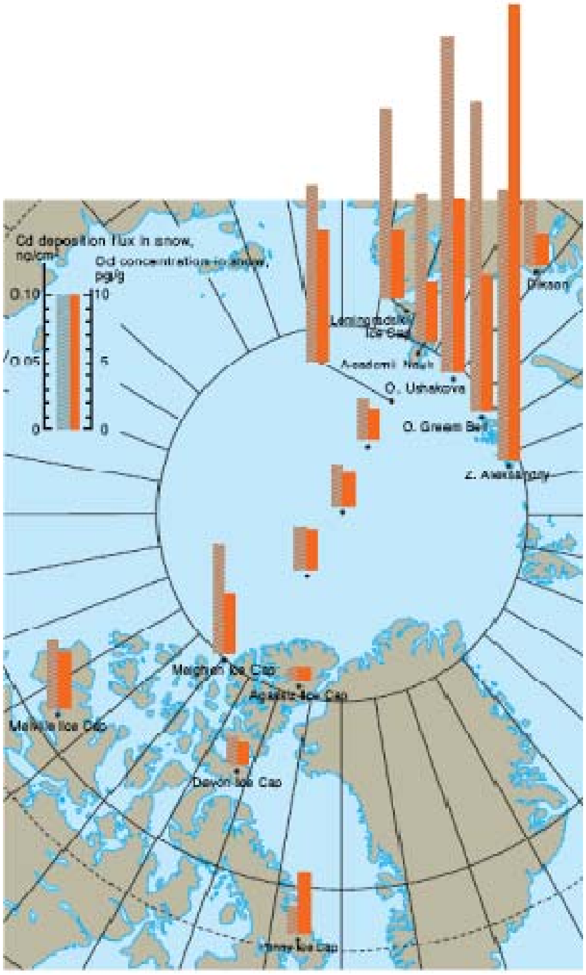


Figure 7-11 Cadmium concentrations in snow and deposition across the Russian and Canadian Arctic Islands and the Arctic Ocean (Reprinted from AMAP, 2005)

7.1.2 Factors affecting the long-range atmospheric transport of cadmium

411. Factors affecting the behaviour, fate and deposition of cadmium during its long-range atmospheric transport include:

- Characteristics of emission sources;
- Physical and chemical forms of cadmium in the atmosphere, especially particle size;
- Atmospheric stability and wind speed influencing vertical mixing and dispersion;
- Removal properties determining washout of cadmium 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 cadmium 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 these processes could enhance long-range transport potential of cadmium (Switzerland submission, 2010).

412. Cadmium 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 dis-

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

413. Besides the height of the emission plume, the stability of the atmospheric boundary layer significantly affects the rise of the pollution plume and the 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 ground, and elevated pollutant concentrations. On the other hand, unstable conditions common on sunny days lead to the 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.

414. Because of low volatility (see Chapter 2), cadmium is primarily emitted to the atmosphere as a component of aerosol particles with a wide range of particle size. From atmospheric combustion sources, cadmium may, however, be emitted partly as elemental gaseous cadmium, but as the emission plume is cooled, this cadmium is also quickly bound to soot particles.

415. Cadmium on larger particles (from a few to tens of micrometers) is deposited closer to the emission source and has more local impact. On the contrary, finer particles (less than a few micrometers) can be transported for large distances up to a thousand kilometres. Therefore, size distribution of the emitted cadmium-containing particles can significantly affect the range and properties of long-range transport.

416. During its pathway in the atmosphere, the size distribution of particulate cadmium changes dynamically due to interaction between particles of different sizes, and to 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.

417. According to measurement data, cadmium mostly occurs in the atmosphere as aerosol particles of sub-micron size. The mass median diameter of airborne cadmium particles was estimated by Milford and Davidson (1985) at 0.84 µm based on the literature survey. A distribution for cadmium particles with the larger peak in the fine fraction and additional minor coarse mode was measured by Allen *et al.* (2001). The mass median diameter for cadmium samples in the fine fraction was 0.5 µm, and additional smaller modes at either 1.2-3.5 µm or 6.0-20.0 µm were observed in the coarse fraction.

418. Cadmium 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 cadmium-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 particle at a size between 0.1 and 1 µm (Slinn *et al.*, 1978; Sehmel, 1980). It also strongly depends on the type or roughness of the ground surface. The highest dry depositions take place over rough terrain, such as areas covered with vegetation (forest, shrubs etc.) and urban areas; the lowest dry depositions occur over smooth terrain (desert, snow cover) and water bodies.

419. Wet deposition of cadmium takes place during precipitation events (rain, snow). The scavenging of cadmium-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” with particle sizes 0.1–2 µm (Volken and Schumann, 1993; Laakso *et al.*, 2003). Relative contribution of dry and wet depositions to the overall cadmium removal varies from one location to another, and depends on local climatic conditions and the type of ground surface.

7.1.3 Atmospheric transport models for cadmium

420. Measurements of cadmium concentration in ambient air and in precipitation performed episodically or on a regular basis at certain locations can not supply thorough information on the environmental levels of this metal. The first reason for this is relatively scarce spatial coverage of the territory with measurement sites. Second, they have very limited ability to characterize transboundary and intercontinental transport. And finally, the current observations can hardly be used for long-term predictions of future cadmium levels. In order to respond to these challenges, various numerical models of cadmium atmospheric transport are employed.

421. Most models employed for simulation of cadmium atmospheric dispersion relate to the regional scale or continental scale, considering the atmospheric dispersion and transboundary transport within the boundaries of a continent or a specific region (e.g. Baltic Sea, the Arctic). In contrast to lead, practically no calculations of cadmium transport have been performed at the hemispheric (or global) scale partly because of the absence of global emission inventories for cadmium.

422. According to their formulation, the models may be distinguished between Lagrangian and Eulerian types. Lagrangian models follow parcels of air moving though space with the wind direction. The pollutant emissions enter the parcel at different locations and times. On the contrary, 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 cadmium are summarized in Table 7-2

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

Model	**Type**	**Coverage**	**Reference**
TRACE	Climatological	Europe	Alcamo *et al.*, 1992
HMET	Eulerian	Europe	Bartnicki J., 1996
GKSS	Lagrangian	Europe	Krüger, 1996
ASIMD	Eulerian	Europe	Pekar, 1996
EMAP	Eulerian	Europe	Gusev *et al.*, 2000
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	Eulerian	Europe	Travnikov and Ilyin, 2005

423. The climatological TRACE model was used for evaluation of air concentration and deposition of some heavy metals (including cadmium) in Europe (Alcamo *et al.*, 1992). Atmospheric residence time of cadmium was estimated at 27 hours. The dominant role of wet deposition over dry was demonstrated for most of the European territory.

424. 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 cadmium and other heavy metals emitted from European countries undergo transboundary transport and deposits outside the territory of the source country.

425. 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 cadmium to the North Sea is higher than for the Baltic Sea, and the highest deposition fluxes took place mainly over coastal regions.

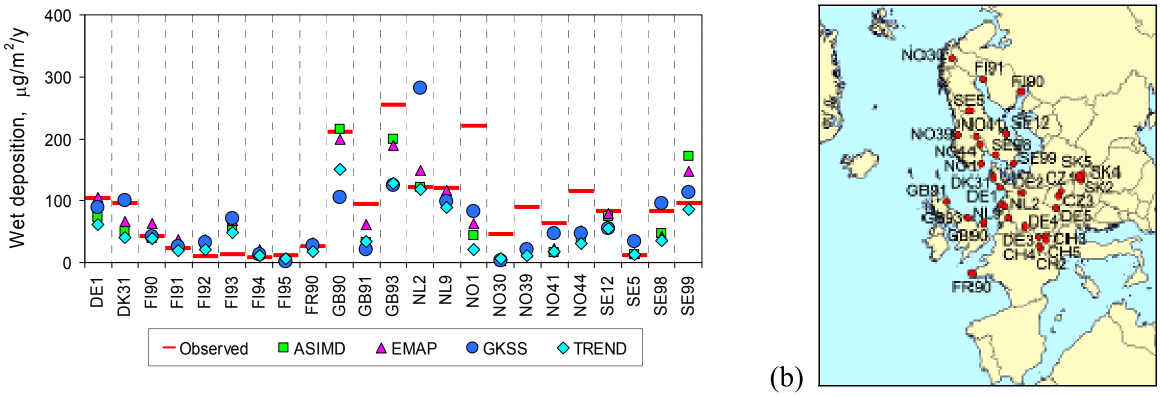
426. The Lagrangian model (EU) TREND was applied to calculate the transport and deposition of cadmium and other heavy metals to the OSPAR Convention waters (Nijenhuis *et al.*, 2001). Results were obtained for the following regions: Greater North Sea, Celtic Sea, Bay of Biscay and Iberian coast and parts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

427. Two nested Eulerian atmospheric transport models, ADOM and HILATAR, were used for 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 cadmium to the Baltic sea in 1997/98 was estimated at about 9-10 tonnes, which is approximately half of the measurements-based value (Schneider *et al.*, 2000)

428. The European-scale atmospheric transport model MSCE-HM (Travnikov and Ilyin, 2005) is actively used for operational calculations of cadmium 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 cadmium in the ambient air, and deposition fields for each Party to the Convention within the EMEP area are evaluated annually along with transboundary transport between countries (e.g. Ilyin *et al.*, 2004; Ilyin *et al.*, 2005).

Model intercomparisons

429. Some of the models mentioned above were included in an intercomparison study for cadmium conducted under the coordination of EMEP/MSC-E (Gusev *et al.*, 2000). The aim of the study was evaluation of the modelling results obtained by different transport models via comparison between the models and with available measured values. Four regional-scale transport models (ASIMD, EMAP, GKSS, TREND) with various numerical approaches were included in the study. The comparison has shown that the discrepancy of the modelling results did not exceed a factor of two for all the models. Figure 7-12a illustrates the comparison of modelled wet depositions of cadmium with observations at different monitoring sites located in Northern, Western and Central Europe. The locations of the observation sites are shown in Figure 7-12b. As seen from the figure, discrepancies between modelling results are not considerable at most monitoring sites. However, at some stations (particularly British and Norwegian) all the models demonstrated significant underestimation in comparison to the observed values.



(a) (b)

Figure 7-12 Comparison of modelled wet depositions of cadmium with observations at different monitoring sites (a) and location of monitoring sites involved in the intercomparison study (b) (Adapted from Gusev et al., 2000)

430. In the other part of the study, the models' ability to simulate transboundary cadmium transport was examined. In particular, budgets of cadmium atmospheric deposition in three selected European countries (Italy, Poland and the United Kingdom) were compared. These countries are located in differ-

ent parts of Europe and have diverse positions with regard to major European sources. Figure 7-13 shows an example of the comparison of modelled total cadmium deposition to Italy from its national anthropogenic sources. Variation of total deposition values obtained by different models does not exceed 14 percent.

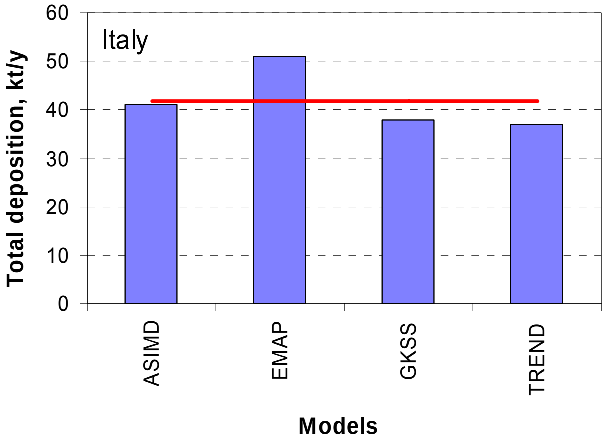


Figure 7-13 Comparison of modelled total cadmium deposition to Italy from its national anthropogenic sources. Read line shows mean value for all models (Adapted from Gusev et al., 2000)

Model comparison with measurements

431. An essential part of the model evaluation is a 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. Available estimates of cadmium emissions are still very uncertain; in particular, as mentioned in section 5.2.1, the estimates of total cadmium emissions in Europe are significantly lower than total depositions of cadmium derived from measurements in Europe.

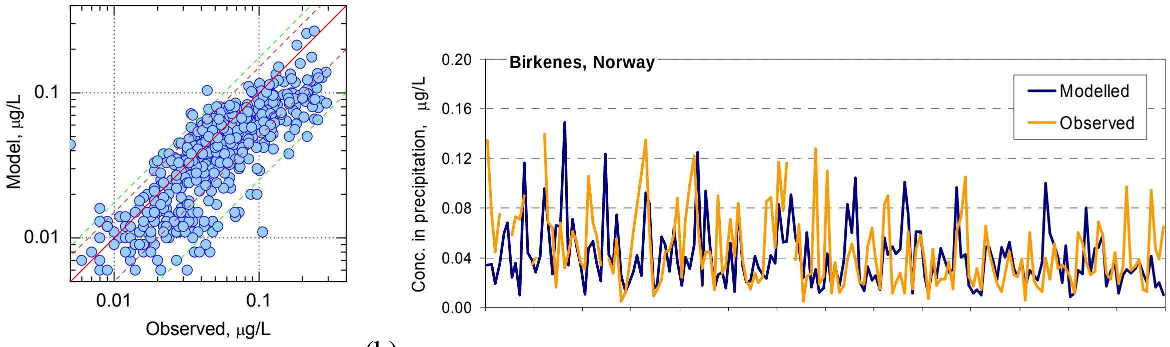
432. Application of different transport models to simulate airborne cadmium pollution commonly demonstrated underestimation of observed pollution levels by modelling results. For example, modelled cadmium concentrations obtained with the TRACE model (Alcamo *et al.*, 1992) revealed significant (2-3 times) under-prediction of the observations, but a good relative description of the temporal and geographical variation patterns. In addition, the sensitivity analysis showed that even radically changing the model parameters could not explain the model bias. The underprediction was even higher when cadmium concentrations in air simulated by the GKSS model were compared with available measurements (Krüger, 1996). The model systematically underestimated observations at all measurement sites by a factor of about 6.

433. Modelling results obtained by the TREND model (Nijenhuis *et al.*, 2001) were based on UBA/TNO estimates of cadmium anthropogenic emissions for 1990 (Berdowski *et al.*, 1997). The emission figures referred, as far as possible, to data officially submitted by the countries. The comparison of modelled results with measurements has shown underprediction of the measured cadmium concentrations in air by a factor of 3.

434. The same set of expert emission estimates for 1990 (Berdowski *et al.*, 1997) was used for airborne cadmium pollution modelling in 1997/98 with the nested models ADOM and HILATAR. Calculations of cadmium concentrations in aerosols at some Baltic stations demonstrated underestimation of measured values by the HILATAR model and somewhat better agreement for the ADOM model. Comparison with highly resolved data showed that the models reproduced the major episodes with high cadmium concentrations; however, some of the high wet deposition events were not captured, most probably because of missed significant local/regional emission sources.

435. The U.S. EPA compared modelled ambient concentrations from NATA for 1996 with available ambient monitoring data (from 20 sites) to evaluate the modelling results. This evaluation indicates that NATA underpredicted ambient concentrations of cadmium for 1996 by an average of about 4-5 times. A combination of several factors may be responsible for these discrepancies, including: missing emissions from the inventory (e.g., re-emissions of historic cadmium emissions, possibly some point sources); spatial uncertainty in emission locations for sources; spatial uncertainty of nearby impacts from elevated point sources and local terrain; and high coarse particle deposition velocities (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, 2008).

436. Comparison of MSCE-HM modelling results based on reported emission data against measurements resulted in substantial (about 3 times) underprediction of observed values by the model. Discrepancies between modelling results and observed levels of cadmium could be mainly caused by uncertainties of anthropogenic emission data, natural emissions and re-emission of historic deposition of cadmium. Cadmium concentrations in air predicted by the model for 1990–2003 on the basis of independent expert emission estimates were in satisfactory agreement with available monitoring data in the aggregate (Ilyin and Travnikov, 2005). The correlation was high (the coefficient is about 0.8) and for more than 70 percent of compared values the difference between modelled and measured concentrations did not exceed ±50 percent. The observed cadmium concentrations in precipitation were commonly underestimated by the model Figure 7-14. However, correlation between the modelled and measured values was also significant (almost 0.8), and almost 80 percent of the model/measurement pairs of concentration in precipitation agree with each other within a range of ±50 percent.



(a) (b)

Figure 7-14 Comparison of annual mean modelled (with MSCE-HM) and measured cadmium concentrations in precipitation in Europe for 1990–2003 (a) and monthly-mean concentrations at station Birkenes, Norway (b) (Reprinted from Ilyin and Travnikov, 2005)

437. In summary, the assessed models tended to under-predict estimated air concentrations and deposition of cadmium compared to actual measurements. For one model, a satisfactory prediction was obtained using supplementary expert estimates for emissions input data. The uncertainties of emission estimates, and lack of inclusion of natural emissions and re-emission of former cadmium depositions in the model inputs, are considered the major possible causes for the under-predictions.

7.2 Ocean transport

438. Quite extensive data regarding cadmium 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 cadmium - 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.

439. **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 $\mu g\ L^{-1}$ to 0.29 $\mu g\ L^{-1}$ in a single month at one sampling site) whilst Cd was rarely above detection limits, with highest recorded concentration in SPM of only $3.92 \times 10^{-3}\ \mu g\ L^{-1}$. 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.

440. **Bioaccumulation and Transport via Biota**- Concentrations of Cd and Pb in various species of fish have been reported (Table 7.3) though often with the aim of assessing potential contamination in food rather than potential for bioaccumulation and contribution to the long-range transport of 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.

441. 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 7.4) – 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. Results from the Mussel Watch Programme in the USA, which monitors Cd levels in sediment and mussels around the US coastline, found that sediment and mussel concentrations were not well correlated, and that high concentrations ($>5.6\ \mu g\ g^{-1}$ dry weight) were related to salinity along the east and gulf coasts, but to upwelling of Cd-rich waters in the Pacific (*Apeti et al.*, 2009)

442. There is also recent research on levels of Cd and Pb in large migrating mammals such as dolphins (Lahaye, 2006) and whales (see Table 7.5). 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 7.3 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 7.4 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 7.5 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.

7.2.1 Examples of ocean transport of cadmium in the Arctic

443. 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).

444. Macdonald *et al.* (2000, as cited by AMAP, 2005) provided an example of how significantly ocean currents may influence cadmium concentrations, with their construction of a cadmium budget for the Arctic Ocean (see Figure 7-15). According to this budget, inputs from the atmosphere and runoff from land (rivers inputs etc.) are minor to the Arctic Ocean compared to inputs with ocean currents. The natural oceanic geochemistry of cadmium results in higher cadmium concentrations in the North Pacific, by a factor of about five, compared to the North Atlantic (Bruland and Franks, 1983, as cited by AMAP, 2005). According to this budget, this nutrient-rich water of the Pacific entering the upper Arctic Ocean provides the most important source of cadmium to this ocean. The budget thereby indicates that most cadmium in biota in the Arctic Ocean may probably be derived from natural oceanic geochemical processes in the Pacific Ocean. Other cadmium inputs to the budget originate from the North Atlantic

(Macdonald *et al.*, 2000), which may have been enriched with cadmium from anthropogenic sources in North America and Europe transported to the North Atlantic by the Gulf Stream.

445. Another example of heavy metals transports with ocean current - in this case lead - in the Arctic region was provided by Gobeil *et al.* (2001); please refer to the UNEP (2006) sister review on lead for the description.

7.2.2 Potential of ocean currents for transport of heavy metals

The "global conveyer belt"

446. 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).

447. Figure 7-16 shows a simplified presentation of the thermohaline circulation, or "global conveyor belt" (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).

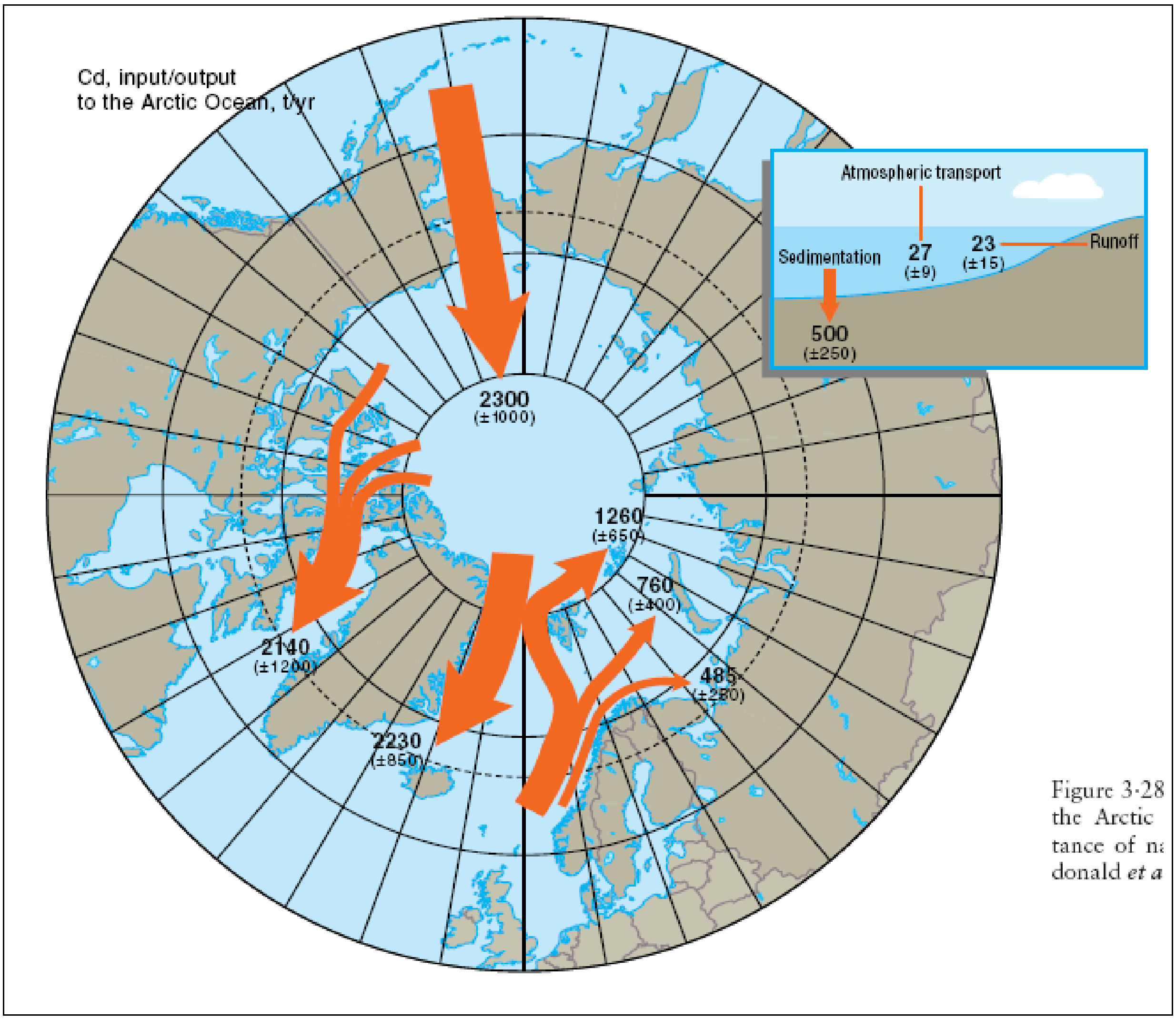


Figure 7-15 Cadmium budget for the Arctic Ocean indicating the significance of ocean currents for heavy metal transport (Macdonald et al., 2000, as cited by AMAP, 2005)

448. 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.

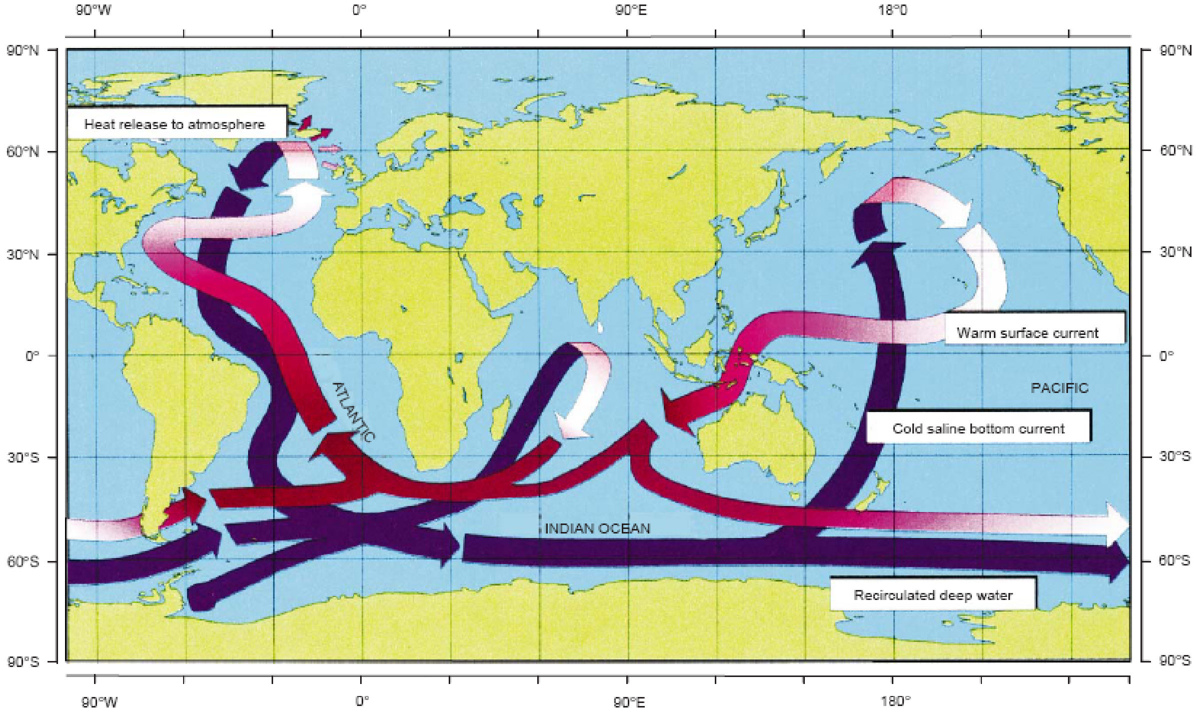


Figure 7-16 The Atlantic thermocline circulation as a key element of the global oceanic circulation (Reprinted from Zenk, 2001.)

Residence time of cadmium in the water column

449. Research over the last decades has shown that trace metals (such as for example cadmium and lead) can 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 are assimilated in phytoplankton near the surface and are recycled many times in the upper water layers before they eventually sink to the depths. Due to the similarity of distribution pattern with nutrients, these elements are called "nutrient-type" elements in the oceanographic terminology. Another 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 (for example lead - Pb - belongs to this group; Bruland and Lohan, 2004).

450. Cadmium’s behaviour follows the distribution pattern called the "nutrient-type distribution". This is due to the fact that cadmium, which is not implicated in any other known essential life-processes, actually plays a biological role in certain phytoplankton species in the offshore waters poor in nutrient and essential elements. This is because cadmium’s chemical characteristics are close enough to those of the essential element zinc to allow cadmium to substitute for zinc in some vital enzyme reactions (photosynthesis with carbon anhydrase in diatoms) in situations where zinc is scarce in the biotope; Lane and Morel, 2000 and Lee *et al*, 1995, as cited by Morel *et al*, 2004). By degradation of organic material and grazing by zoo-plankton, cadmium is partly recycled internally in the bio-zone of the upper water layers, and partly sedimented with zoo-plankton faeces to sub-surface water layers, where some of the cadmium is re-dissolved through bacterial processes and re-distributed to the biologically active water layers. In this way, a nutrient-type element like cadmium can undergo many internal cycles within the ocean prior to ultimate burial in sediments (Bruland and Lohan, 2004).

451. Nutrient-type metals like cadmium exhibit a relatively low level of scavenging in the deep sea, and thus their concentrations increase along the flow path of water in the world's oceans as the water ages. Due to the above-mentioned processes, the oceanic residence time of nutrient-type metals like

cadmium is characterised as intermediate - a few thousand to one hundred thousand years (Bruland and Lohan, 2004). AMAP (2004) cite Boyle *et al.* (1976) and Yeats and Bewers (1987) for a residence time of cadmium in the ocean of about 15,000 years - a residence time considerably longer than the time required for the global thermohaline circulation to transport water from the North Atlantic to the North Pacific Ocean. This could indicate that cadmium may perhaps be accumulated and transported over much longer distances in the ocean than scavenge-type metals (such as lead).

452. For comparison, scavenger-type metals (such as lead) follow a rather different pattern. Lead entering the ocean will normally be in the particulate state, and will 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. The concentration distribution of dissolved lead in the water column is accordingly called the "scavenge-type distribution" (Bruland and Lohan, 2004).

453. Upwelling may be an important mechanism for bringing cadmium-rich water up to the surface waters from the depths. Cadmium enrichment in the surface waters of areas of upwelling has been observed, which lead to elevated levels in plankton unconnected with local human activity (Martin and Broenkow, 1975; Boyle *et al*., 1976; both as cited by IPCS, 1992a). Oceanic sediments under-lying these areas of high productivity can contain markedly elevated cadmium levels as a result of inputs associated with biological debris (Simpson, 1981; as cited by IPCS, 1992a).

Modelling of ocean transport of anthropogenic pollutants

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

455. 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

456. 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.

457. 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

458. 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). 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 (see Figure 7-15 above; Macdonald *et al.*, 2000, as cited by AMAP, 2005).

459. The significance of rivers as transport pathway for cadmium can be illustrated by data for the Greater North Sea. The total annual riverine and direct input of waterborne cadmium the in the UK, Sweden, Norway, the Netherlands, Germany, France, Denmark and Belgium is shown in Figure 7-17. In 1996 these inputs totalled about 25.5 tonnes of these the riverine inputs accounted for 23 tonnes or more that 90 percent (both estimates based on the lower estimates for riverine inputs). The main source to the river input are agricultural activity. According to OSPAR (2000) the waterborne inputs to the marine environment in these countries was at that time larger than the airborne inputs. The atmospheric deposition was 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.

460. 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).

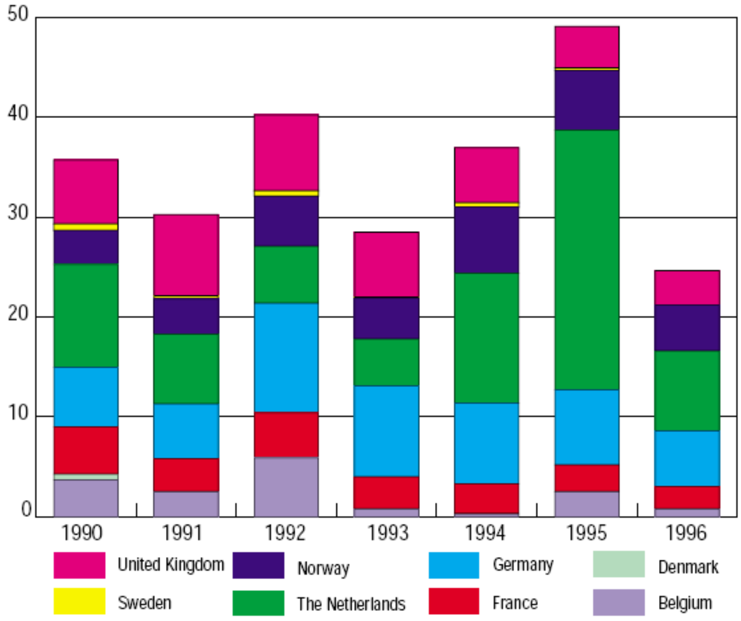


Figure 7-17 Total waterborne cadmium input to the Greater North Sea from eight European countries in tonnes per year using lower estimate for riverine inputs (OSPAR, 2000)

461. 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 cadmium was monitored at 20 different locations over a stretch of 800 km. As per the study, cadmium levels ranged from "not detectable" to 0.21 mg/L. The average annual water runoff in the Ganga river is 150,000 million m^3 .

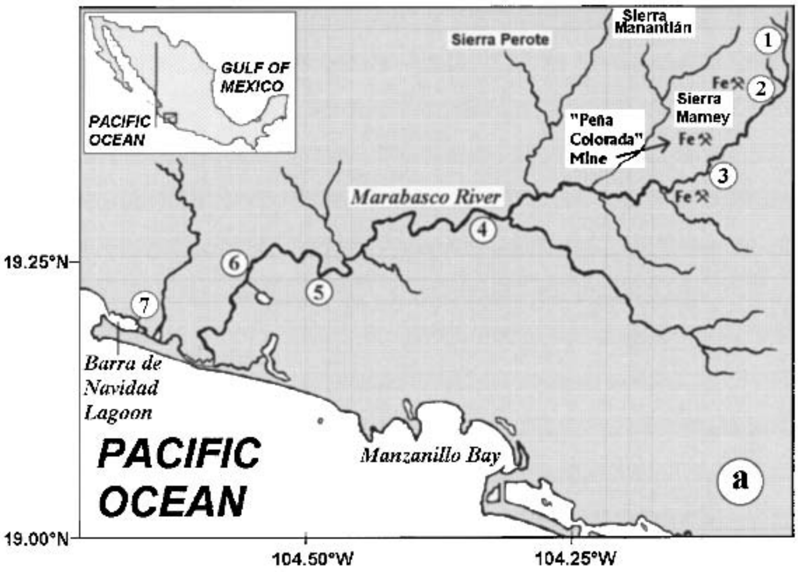
462. Big lakes can be transport pathways for heavy metals on a national and sometimes regional scale. The Great Lakes on the border between Canada and the U.S.A. in North America are examples of lakes where heavy metal pollution has become a common problem.

463. Groundwater movement is not expected to be a major pathway for cadmium as concerns long-range transport. Cadmium does however have a certain solubility in ground water, depending on the chemical conditions (see section 2.4 on chemistry in soil). This topic has not been investigated in detail for this review.

7.4 Transport by world rivers to the marine environment

464. 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, with biological processes possibly playing a secondary role (Scoullos and Pavlidou, 2003). Work on the Marabasco river in Mexico (Figure 7.18) 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.

Figure 7.18 Marabasco River study area (Shumilin et al., 2005).



465. 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

466. 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 cadmium, including the use of suitable substitutes, where applicable.

467. The specific methods for controlling cadmium releases from these sources generally fall under the following four groups:

- Reducing consumption of raw materials and products that include cadmium as impurity or use of low-cadmium raw materials;

- Substitution (or elimination) of products, processes and practices containing or using cadmium with non-cadmium alternatives;

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

- Management of cadmium-containing waste.

468. **Guidelines and methods for the reduction and prevention of release to the marine environment** - 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)

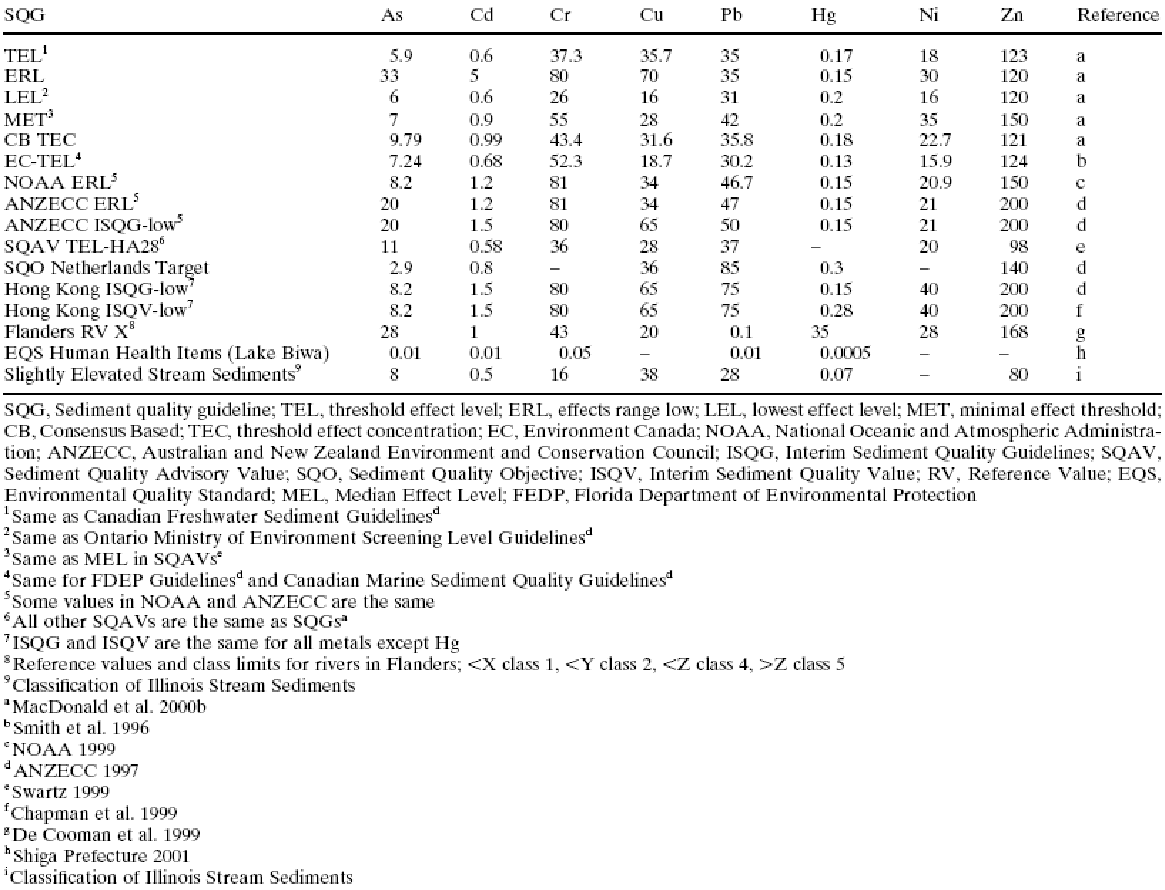
469. New, non-biological methods for the remediation Cd- and Pb-contaminated water, and sediment, are also being developed. The microbially-produced surfactant, rhamnolipid has been shown to remove 80% of Cd and 36% of Pb from contaminated sediment under optimised condition (4 successive batch washings 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).

470. **Guidelines for monitoring the marine environment** - 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 interrelationships, 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, 2002; 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, 2006).

471. 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

472. 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

473. 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

8.1 Use of low-cadmium raw materials

474. Cadmium in phosphate fertilizers contribute to cadmium releases to agricultural soils as discussed in section 5.4.

475. Options for reducing the cadmium content of fertilizers are to use phosphate rock with low cadmium content as a raw material or to remove the cadmium in the manufacturing of the phosphate fertilizers.

476. A shift to low phosphate rock would first of all be difficult as alternative sources are not readily available in sufficient amounts but it may as well have severe socio-economic consequences for some developing countries, which at present supply phosphate rock to the world market.

477. A number of processes are have been applied in pilot scale for removing cadmium from either the phosphate rock or from the intermediary phosphoric acid by the manufacturing of phosphate fertilizers. The achievable reduction in cadmium content is in the range of 50 to 90 percent (Hutton and de Meeûs, 2001). No information has been available indicating that decadmiation processes have not been implemented at industrial scale in any country.

8.2 Substitution

478. The present status regarding development and marketing of substitutes for cadmium is indicated in Table 8-1. The table indicates to what extent substitutes are available today. It should be noted that the table only lists a few of the most promising substitutes and that many more substitutes may be available or are being developed. Furthermore, the table indicates the cost level of the substitute solution as compared to the cadmium solution. For applications where no alternatives exist or research is ongoing, it is not possible to state precisely when alternatives would be available and ready for being marketed, as this depends heavily on the demand for these alternatives. It should be noted, that some alternatives to cadmium may themselves have undesired environmental and health properties.

479. A similar table in Hansen *et al.* (2002) has been used as a starting point, but the table has been extended and updated as necessary. One of the main drivers for development of alternatives to cadmium in Europe has been the introduction of the ban of certain applications of cadmium 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 the collection of updated information.

Table 8-1 Options for substitution of cadmium with initial indication of level of expenses relative to cadmium-technology

Application	**Alternatives**	**Prices relative to cadmium technology** [1)]	**Extension of alternatives**
Plating	Zinc, aluminium, tin, nickel, silver, gold plating, etc. depending on application.	"?" – No data are available	Since 1995, cadmium plating has been banned in EU for all purposes except aerospace, mining, offshore and nuclear activities according to Directive 91/338/EEC.
Silver-cadmium alloys for solders	Several alternative solders exist including e.g. Sn-Ag solders.	"+" - The present use of cadmium in Ag-Cd alloys partly reflects the current low world market price on cadmium.	Cadmium-bearing solders have largely been phased out (Goodman and Strudwick, 2002).
Copper-cadmium alloys, and other alloys	Alternatives depend on application: Cu-Cd alloys may be replaced by pure copper Pb-Cd alloys for cable sheaths may be replaced by other types of cable sheaths like PE/XLPE-sheaths, aluminium sheaths or normal lead sheaths.	"=" - The content of cadmium in the alloys is typically around 1%, and other materials exist and are utilised on the market parallel to the cadmium alloys.	Alternatives are present and utilised on the market parallel to cadmium products. In cable sheaths manufactured in Denmark, cadmium is only present in special flat cables for electricity supply. The content of cadmium is below 1‰ (Drivsholm *et al.,* 2000).
Thermal elements/low melting alloys	E.g. InSb and BiSn alloys. However, substitutes may not be available for all purposes (Goodman and Strudwick, 2002). In some cases, the use of components may be avoided by improved cooling.	"+/++" - Indium is very expensive	Alloys based on cadmium or lead dominate the market. (Goodman and Strudwick, 2002)
NiCd batteries	Nickel-metal hydride, lithium-ion-polymer etc.	"-/+"? Although alternatives are typically more expensive to produce, they have environmental and technical benefits, e.g. the life of battery is longer, as alternatives are not suffering from the so-called memory effect [2)].	NiCd still dominates power-hungry applications like portable electric tools. For other applications, alternatives are gradually taking over the market (Drivsholm *et al.*, 2000).

Table 8-1 Continued

Application	**Alternatives**	**Prices relative to cadmium technology** [1)]	**Extension of alternatives**
PVC stabilisers	Depends on application. For indoor purposes, substitutes have generally been calcium/zinc compounds. For outdoor purposes and other demanding applications like electrical cables/wires, the alternatives have so far been stabilisers based on lead or organic tin compounds, but research/development based on calcium/zinc compounds is ongoing.	"?" - Likely more expensive	By March 2001, cadmium stabilisers were no longer marketed in Europe by European PVC additive producers (OECD, 2002).
Pigments	Many alternatives are available on the market. Ultimately, the choice is a matter of costs versus colour and other characteristics preferred like weather resistance, torsion stability and brilliance. Bismuth vanadate and tin-zinc-titanate for applications with high requirements.	"-/++" Other pigments providing other colours can easily be found at lower costs. Trying to develop the perfect substitute may be rather costly.	Other pigments are already widely used, e.g. the use of cadmium pigments for plastic manufacturing in the Netherlands had almost ceased by 1990 (Koot, 1996).
Coloured glass and pigments in glass ceramics and enamels	Pigments and glass constituents based on gold, copper, and perhaps molybdenum selenide or $CaTaO_2N$ and $LaTaON_2$ (Jansen and Letschert, 2000; Bring and Jonson, 2003; Issitt, 2003)	? - Likely more expensive	Cadmium pigment is the most commonly used, but gold and copper pigments are available on the market (Bring and Jonson, 2003; Issitt, 2003).
AgCdO in high power relays	$AgSnO_2$, AgNi (Chan, 2005; Goodsky, 2004; Goodman and Strudwick, 2002)	"+" (Chan, 2005)	Marketed today (Goodsky 2004; Goodman and Strudwick, 2002).
Light sensitive semiconductors, infrared detectors photodiodes and the like	GaAs, InGaAs, InSb, InAs, etc.	" =" - depends heavily on the outcome of ongoing research	Mercury cadmium telluride is frequently used today (Malik, 2003; EOS, 2004).
Solar cells	Cadmium telluride is used in modern thin-film cells based on CdTe, but not in traditional crystalline cells. Other alternatives are copper indium gallium diselenide, titanium dioxide etc.	"=" - depends heavily on the outcome of ongoing research	Traditional crystalline cells dominate the market today (Drivsholm *et al.,* 2000)

1) Indication of the overall current user/consumer price levels for cadmium-free alternatives as compared to cadmium 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.
"–": lower price level (the alternative is cheaper)
"=": about the same price level
"+": higher price level
"++": much higher price levels

2) Memory effect is a characteristic for NiCd-batteries. A NiCd-battery shall be completely emptied and completely recharged in each cycle. If not, its capacity will slowly be reduced, as it only remembers the capacity actually utilised. It is the experience of many consumers that the effective life of NiCd batteries is, for this reason, shortened significantly (Drivsholm *et al.*, 2000).

8.2.1 Substitution trends for NiCd batteries

480. The 2003 situation in the European Union for substituting NiCd batteries was summarised as presented in Figure 8-1 developed by Bio Intellegence (2003). As shown, substitutes were considered readily available for most consumer products run by NiCd batteries, whereas some of the industrial uses of large (open type) NiCd accumulators could only be substituted through the acceptance of certain

modifications to the processes in question (different modifications depending on the use). Lead acid batteries were not considered as an alternative due to lead's toxic properties. Since then cadmium-free alternatives for the largest use, power tools, have developed further and have gained market shares as discussed below for the Nordic situation.

481. Note also that the figure shows the consumption of NiCd batteries split on individual uses, as well as on portable (sealed type) batteries and industrial (open type) accumulators in the EU15 (15 member countries; before enlargement to EU 25 in 2005).

Figure 8-1 2003 status for substitution possibilities for NiCd batteries in the EU, and consumption of NiCd batteries distributed on uses in EU15 (as assessed by Bio Intellegence, 2003).

battery segment	Application		EU NiCd battery sales (tonnes/year)	Market segment where a ban on the use of Cd in batteries is technically feasible in 2003		
				Viable substitutes with modified performances and costs are available	**Viable substitutes other than lead-acid batteries are available, with modified performances and costs are available**	**Viable substitutes other than lead-acid batteries are available, with neither economic nor technical impact**
portable batteries (<1 kg)	household	- cellular telephones -portable computers -camcorders - digital cameras - remote contrl toys -other small household appliances (small vacuum cleaners, shavers).	3,600	YES	YES	YES
		codless power tools	3,950	YES	YES	NO
	professional	cordless power tools	1,800	YES	YES	NO
		emergency lighting systems (building, aircraft, …)	3,050	YES	NO	NO
		medical equipment	200	?	?	?
industrial use (>1 kg)	stationary	- power supply (hospital operating theatres, offshore oil rigs, standby power in industry, emergency power system in airports, large telecommunication station, …) - power back-up (large computer systems in bnnks and insurance companies, …)	2,600	YES	NO	NO
	mobile	railways, aircraft (braking and security functions)		YES	NO	NO
	specialized	space and military applications (engine starting, emergency back-up functions)	200	?	?	?
electric vehicles	off-road vehicles		600	YES	NO	NO
	on-road vehicles			YES	NO	NO
		Total	**16,000**			

482. For the largest single use of NiCd batteries, cordless power tools, a more recent survey of the market shares of power tools with cadmium-free batteries in the Nordic Countries was performed by the

Nordic Council of Ministers in order to assess the future needs for NiCd batteries for this purpose (Maag and Skaarup, 2005). Data from the study show that NiMH (Nickel-Metal-Hydride) batteries has now gained substantial market shares both among professionals and private consumers in the Nordic countries. An overview of estimated market shares of NiMH-driven cordless power tools is given in Table 8-2. It is important to note a difference between the Nordic countries: Sweden and Denmark have specific taxes on NiCd batteries, including power tool batteries. This is not the case for Iceland, Finland and Norway. The Swedish and Danish markets have therefore been put under extra pressure to shift to NiMH batteries. It is however interesting in this perspective, to observe that NiMH batteries also have substantial market shares in Norway and Finland.

Table 8-2 Market shares of NiMH-driven cordless power tools in 2003/2004 in the Nordic countries (Maag and Skaarup, 2005)

Country and product sub-category	**NiMH share of market (% of number of tools sold) [1)]**	**Remarks**
Denmark		
Professional power tools	60%	2003, based on a 2004 study performed in Denmark; probably larger in 2004
Do-It-Yourself	30-50%	Rough estimate from this study
Iceland		
Total market		Likely only a minor share of NiMH in 2004, based on data from this study
Finland		
Total market	30%	Estimated by TKL, Finland, 2004
Norway		
Professional power tools	50-60%	Estimated from detailed data in this study, 2004
Do-It-Yourself		Unknown, but may be substantial (perhaps near levels in Denmark or Sweden)
Sweden		
Professional power tools	90%	Estimated by LEH, Sweden, 2004
Do-It-yourself	35%	Estimated by LEH, Sweden, 2004

1) NiCd batteries and NiMH batteries currently dominate the market, while a third battery type, Li-ion batteries, is expected to have a small but rising market share in the Nordic countries.

483. For this study Recharge, a European trade organisation organizing much of the industry and trade engaged in manufacturing and trade of NiCd batteries and equipment containing such batteries, has supplied additional data on the share of NiCd versus NiMH batteries in powertools on the Scandinavian market. According to Recharge two major powertools suppliers which together have an estimated 50 percent share of the Scandinavian market had the following shares of NiCd batteries for professional power tools (not Do-It-Yourself) on the Scandinavian market: 2002: NiCd 78 percent; 2003: 71 percent; 2004: 66 percent; 2005: 63 percent (Recharge, 2006).

8.3 Emission control

484. 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 cadmium and a number of other volatile trace elements into the atmosphere.

485. There are several possibilities for controlling or preventing cadmium emissions. Emission reduction measures focus on add-on technologies and process modifications (including maintenance and operating control).

486. Cadmium can be emitted from processes by fugitive emissions or though 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.

487. 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).

488. During high-temperature processes, a number of chemical transformations of the cadmium present in the feed materials takes place and the distribution of cadmium 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.

489. At the temperatures at which flue gases usually pass dust-emission controls, the major part of the cadmium in the flue gas will be bound to particles, and the emission of cadmium 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, cadmium-specific controls are in general not applied.

490. Typical dust concentrations after gas cleaning with selected techniques are given in Table 8-3, derived from the UNECE Heavy Metals Protocol (UNECE, 1979). 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 per m^3.

Table 8-3 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

491. The cadmium 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

492. The non-ferrous industry, especially primary zinc/cadmium smelters, has the potential for particularly high emissions of cadmium, both as fugitive and stack emission. Fugitive emissions can be a very significant source of occupational exposure and releases of cadmium to the local environment. Fugitive emissions to air arise from the storage, handling, pre-treatment, pyro-metallurgical and hydro-metallurgical stages. During cadmium and cadmium oxide production, cadmium is emitted from melting furnaces, retorting, casting and tapping, and packaging (U.S. EPA, 1993). Cadmium melting furnaces and cadmium retort furnaces were identified as the two types of process emission sources at cadmium refining plants (U.S. EPA, 1993).

493. According to the European Union 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; a very energy consuming measure that should be a last resort.

494. 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 clog up under 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 in the European non-ferrous industry are shown in Table 8-4. Some of the techniques may be used in combination.

Costs of controls

495. As mentioned above, cadmium is efficiently captured by multi-pollutant emission control technologies and cadmium-specific controls are in general not applied.. The annexes regarding best available techniques (BAT) for emission abatement in the Protocol on Heavy Metals to the Convention on Long-range Transboundary Air Pollution are currently under review by the Heavy Metals Task Force. In the following the relevant multi-pollutant abatement technologies and their costs are briefly described on the basis on a review provided voluntary 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.

496. 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 U.S. 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.

497. 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.

498. Emission sources, control measures, dust reduction efficiencies and costs for the metallurgical industry are shown in Table 8-4 and for other emission source categories in Table 8-5.

Table 8-4 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	-	
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 induration zone	95 ->99	<20		
	Gas Suspension Absorber	99.9	2		

Table 8-4 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	
Hot blast cupola	FF + pre-dedusting	> 99		23/Mg iron	
	Venturi (UC)		36 – 41	-	-
	Disintegrator (UC)		5	-	-
	FF (AC/UC)		1.1 – 20	-	-

Table 8.4 Continued

Emission source	**Control measure(s)**	**Dust reduction efficiency, Percentage of input to controls**	**Reported dust emissions mg/Nm^3**	**Abatement costs (total costs)**	
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

499. 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 cadmium is in general above 90 percent, and through the use of efficient fabric filters efficiencies of 99 percent can be reached.

500. The distribution of cadmium between the bottom ash and the fly ash is, among other parameters, dependent on the temperature of the process. In waste incinerators in general, the main part of the cadmium ends up in the collected ash as illustrated by the behaviour of cadmium in a Japanese MSW incinerator in Figure 8-2. About 92 percent of the cadmium ended in the ash, and about 2 percent passed the electrostatic precipitator.

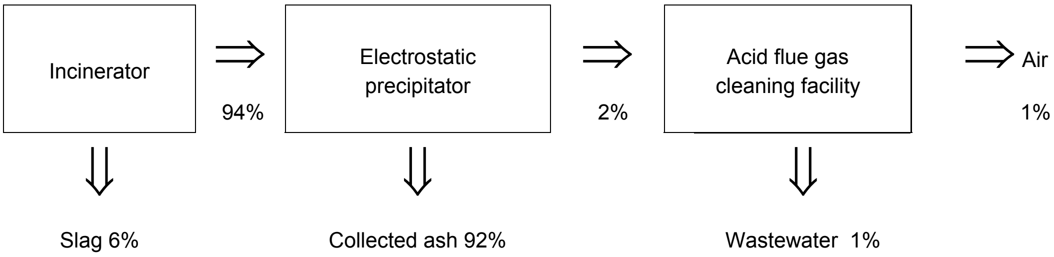


Figure 8-2 Behaviour of cadmium in the Japanese MSWI plant equipped with ESP and wet scrubber incinerating bulky waste and household waste (Nakamura et al., 1996)

8.4 Waste management practices

501. 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, dumping/landfilling and waste water treatment. The overall flow of heavy metals to waste is indicated in Figure 8-3 below. It should be noted that in practice, each step in the figure may consist of several minor steps. Note that releases of cadmium from the treatment processes to the environment are not illustrated on the figure.

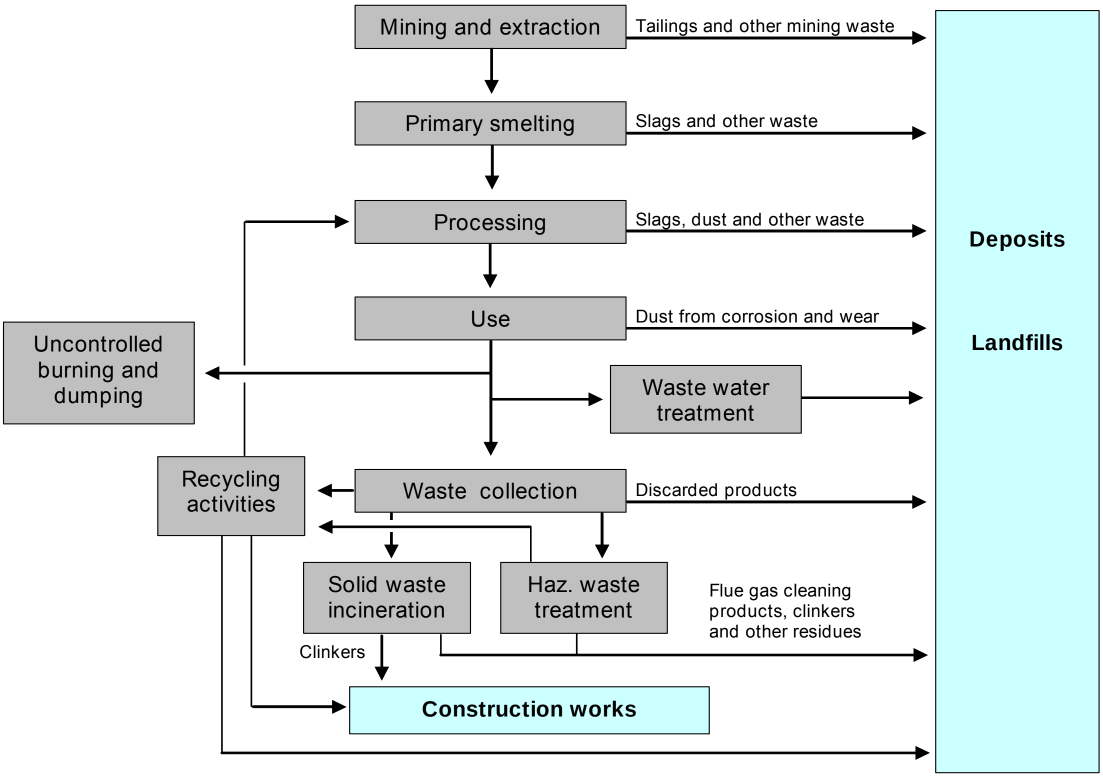


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Figure 8-3 Schematic illustration of the overall flow of heavy metals to waste

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	Pb, 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.

502. Cadmium in waste may be a significant source of cadmium 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 cadmium in the waste. Waste streams that may cause releases of cadmium to the environment are listed in Table 8-6.

Table 8-6 Waste streams causing release cadmium to the environment

Emissions of cadmium 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. ▪ cadmium contained in scrap and NiCd batteries treated for recovery of the cadmium.
Discharges of cadmium 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 cadmium from recycling operations.
Releases of cadmium 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

503. The options for preventing and controlling cadmium emissions related to waste management are briefly presented in the following section. In this section, it is assumed that cadmium is already present in the waste. The issue of substitution as a way of eliminating cadmium from waste in the longer-term perspective is only briefly addressed in this section; for more detail see the section below on landfilling.

A. Non-technical measures

504. 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 cadmium in product waste, etc. from being released directly to the environment, by means of an effective waste collection service;
- Prohibit cadmium 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 cadmium 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 cadmium to normal drains or the water treatment system, or any disposal of cadmium in water;

- Prohibit or restrict cross-border transport of cadmium (and other hazardous) wastes;
- Require that any cadmium-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 cadmium content;
- Put in place an environmental management strategy that includes responsible monitoring and enforcement of cadmium regulations, tracking of all cadmium flows (from raw material to process to product to waste), and periodic independent control.

(2) Economic measures

- Set taxes and fees on cadmium-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 cadmium-containing products, in particularly NiCd batteries;
- 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 cadmium.

B. Technical measures

505. Some examples of technical measures include:

- Require landfills to be properly licensed and equipped for the type of waste they accept, including membranes to prevent cadmium from leaching, collection and treatment of landfill effluent, routine and long-term testing of groundwater quality, air emissions, etc.;

- Ensure that cadmium wastes are incinerated only at facilities equipped with best-available-techniques emission controls.

C. Long-term solutions

506. A long-term measure is keeping cadmium out of the general waste stream. Once present in the general waste stream (if pollution control is considered a priority), cadmium contributes to the need for emission controls on incinerators, special disposal of incinerator residues, landfill leachate treatment, etc. – all associated with extra costs. Cadmium may be kept out of the general waste stream by separate collection of cadmium containing waste products (e.g. NiCd batteries) or by minimising the intentional use of cadmium. The latter has been the main driving force behind the cadmium substitution policy of the countries where such a policy has been implemented.

Recycling

507. As stated in section 6.1, approximately 17.5 percent of present cadmium consumption worldwide is estimated to be recovered by recycling, with spent nickel-cadmium batteries as the dominating input source. The end products collected for recycling will, furthermore, be alloys and cadmium plated items. In addition, some plastics containing cadmium as pigments or stabilizers are recycled as well. To the extent that products containing cadmium are not collected for recycling the cadmium, cadmium will end up in the municipal solid waste stream, typically directed to landfilling or incineration.

508. Although primary cadmium supply has been decreasing, secondary cadmium supply has been increasing steadily over the past ten years so that supply and demand are in reasonable balance. There are three major industry battery collection and recycling programmes in the world – the Rechargeable Battery Recycling Corp programme in the United States of America and Canada, the Battery Association of Japan programme in Japan, and the RECHARGE programme in Europe. All three programmes

have recorded consistent increases in the tonnages of NiCd batteries collected and recycled in their areas, and all of the recyclers associated with these programmes have shown increased secondary cadmium output from year to year (ICdA's submission, 2007).

509. The efficiency of NiCd battery collection is dependent on battery types. In the U.S.A., the U.S. Geological Service reports that "large industrial batteries are easy to collect and are recycled at a rate of about 80 percent", whereas "the small consumer NiCd batteries are frequently discarded by the public (U.S. GS, 2004)". Danish experience from 2004 with separate collection of small NiCd-batteries supported by a fee arrangement indicates a collection efficiency at about 50 percent. The percentage is estimated considering the effect of household practices of setting aside batteries (hoarding effect), which may delay delivery of worn-out batteries by several years (Maag and Hansen., 2005). The experience in both countries is that a significant part of the batteries will be disposed of with municipal solid waste.

510. Recycling of cadmium from coatings and alloys has generally not been justified economically in recent years in view of the low price of cadmium and/or the low cadmium content in the waste material being recycled. With the current price of cadmium moving up, the economics for recycling these products may become more justifiable. Technologically it is possible to recycle both cadmium coatings and alloys, and both have been recycled in the past when economics were more favourable or when the recycling of very valuable metals was simultaneously involved such as in the recycling of silver-cadmium oxide electrical contact alloys (whole paragraph: ICdA, 2005). For plated items, where the cadmium follows the steel for recycling, cadmium recycling may be related to recovery of cadmium from electric arc furnace dust. Recovery of cadmium from electric arc furnace dust takes place in some countries, whereas the dust in other countries will end up in landfills.

511. Sacrificial anodes, on the other hand, are meant to be dissolved in the environment where they are used (especially in the marine environment), while small pieces of alloys integrated in other products, e.g. fire alarm systems, are not likely to be collected separately and recycled.

512. Corrosion of surfaces will often take place leading to soil contamination, in addition to small metal parts being buried in mud during rainy seasons, if metal scrap if stored outside on bare ground (this varies between countries due to national regulations and their enforcement).

513. Cadmium used as pigments or stabilisers in plastics, as well as cadmium used for many other minor purposes, is not likely to be recycled to any significant extent. However, CdTe solar cells (cadmium-tellurium) are recyclable (ICdA, 2005), and cadmium in plastics may follow recycled plastic materials, whereby the final disposal of the cadmium may be delayed for several years. Drivsholm *et al.* (2000) describe the principle of the closed-loop recycling system in Denmark for beer and software boxes made of polyethylene and coloured with cadmium pigments. The boxes have an effective life of 25-50 years and are recycled by being moulded into new boxes, until they occasionally break apart.

Biological waste treatment

514. Waste mainly consisting of organic materials, such as food waste or garden waste, may be treated biologically, e.g. by composting or fermentation aimed at developing a waste product that may be used as soil improvement media or fertilizer due to the content of nutrients. Danish experience indicates a content of cadmium in compost and products from biological waste treatment of 0,25 - 0,7 mg Cd/kg dry matter (Drivsholm *et al.,* 2000). The sources of cadmium to the waste are not well investigated, but could be fractions of plastics, pieces of zinc, atmospheric deposition as well as natural content in organic materials concentrated by the treatment process. The residues removed by sifting in the process consist of plastics, metals and other materials not degradable in the process.

Incineration

515. 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, cadmium 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

516. 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.

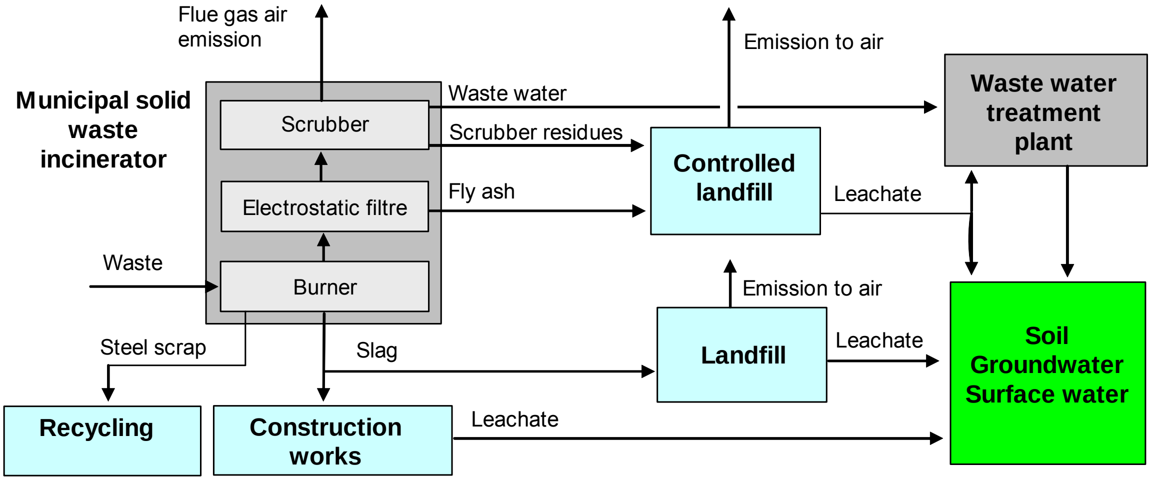


Figure 8-4 Schematic view of the flow of heavy metals by incineration using wet acid gas cleaning process (Hansen et al., 2002)

517. The incineration process typically takes place at temperatures around 1000°C, at which temperature organic materials will burn and be mineralised. At this temperature cadmium will melt and the main part of the cadmium will vaporise and adhere to dust particles.

518. Cadmium is first of all collected with filter dust with a small part ending up in the bottom ash. Table 8-7 presents examples of the distribution of cadmium among outlets from modern European and Japanese incinerators. Due to advanced emission abatement technology, the emission of cadmium to air from modern incineration plants is relatively small.

Table 8-7 Cadmium in outlets from MSWI plant incinerating clean household waste

Metal	**Percentage of total outlet to:**				
	Emission to air	**Electrostatic filter dust**	**Flue gas cleaning filter cake**	**Wastewater**	**Bottom ash, clinker**
MSWI plant Spittelau, Austria 1)	<1	90	<1	<1	9
MSWI plant Amagerforbrænding, Denmark 2)	0.2	94		0.01	6
MSWI plant, Japan (1) 3)	7.4	82.3		-	10.3
MSWI plant, Japan (2) 3)	1.2	91.8		0.9	6.1

1) (Schachermayer *et al*., 1995) quoted by (Hansen *et al.,* 2002). Flue gas cleaning by electrostatic filter followed by a denox flue gas cleaning system.

2) (Amagerforbrænding, 2000) quoted by (Hansen *et al.,* 2002). Flue gas cleaning by filter bags, acid gases are neutralised by spraying a slurry of lime into the flue gas.

3) Two Japanese incinerators (Nakamura *et al*., 1996). Flue gas cleaning by: (1): ESP and slaked lime injection. (2): ESP and wet scrubber.

519. At the Session on Cadmium in Waste at the OECD Cadmium Workshop in Sweden in October, 1995, it was concluded that NiCd-batteries was identified as the most important source of cadmium to municipal solid waste, accounting for 60-70 percent of the input. The second most important source was plastics, followed by organics and other sources (OECD, 1996c).

520. While air cleaning residues must be directed to landfills, clinker may in some countries be utilised for construction works such as road construction in order to save landfill capacity and minimize consumption of sand, gravel and similar construction materials. The content of cadmium in clinker from incineration plants is generally in the range of 0.3-70.5 mg Cd/kg (EEA, 1998). Utilisation of incineration residues for civil works allows a minor part to be spread 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 cadmium stored in civil works represents a potential for future releases to the environment.

Landfilling

521. 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, 1998).

522. 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.

523. 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 cadmium 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 cadmium landfilled (Hansen *et al*., 2002; Hansen *et al.,* 2004).

524. 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.

525. The question remains to what extent landfills in the longer-term perspective can be regarded as a permanent containment of cadmium. 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 cadmium) 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 cadmium stored in roads and other construction works represents a potential for future release to the environment (Hansen *et al*., 2004). 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.

Uncontrolled burning and dumping

526. 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.

527. Uncontrolled burning will inevitably cause emissions of cadmium 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 cadmium 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 will be significantly higher than for incineration plants. However, no measurements of cadmium emission 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 gases from incinerators before the dust controls. As shown in Table 8-7 only about 10 percent are retained in the bottom ash. Even though the temperatures by uncontrolled burning are generally lower than in incinerators, and that NiCd batteries, most probably not are burned in the backyard to the same extent as in incinerators, the data indicates that a substantial amounts of cadmium may be released to the air by uncontrolled burning.

528. The main measures to reduce releases of cadmium from uncontrolled burning are implementation of efficient waste collection systems and practices for prevention of releases from landfills by covering the landfill by soil.

529. 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. For example, experience from Greenland indicate, e.g., that uncontrolled burning of waste on dumpsites, in order to reduce waste quantities, may lead to emission of cadmium of the same amount as organised waste incineration in waste incineration plants (Hansen *et al*., 2006). 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 1990’s 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, 1998). 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

530. Wastewater may be treated by mechanical, biological and chemical treatment techniques. Removal of cadmium by wastewater treatment will depend on the actual technique employed. Danish experience indicates that 11-59 percent (depending on plant type) of the cadmium in municipal wastewater is ending up in the sludge (Drivsholm *et al.,* 2000). The amount removed from wastewater will be retained in sludge that is directed to agricultural areas, incineration or landfills.

8.4.2 NiCd batteries in waste treatment

531. Besides in manufacturing, sealed NiCd batteries generally give rise to the largest cadmium releases to the environment in their life-cycle in the waste disposal/treatment phase (Bio Intellegence, 2003; Drivsholm *et al*., 2000). Many countries have implemented systems for separate collection of NiCd batteries in order to minimize the contamination of the general waste stream with cadmium. Yet, even countries which do make an effort to separate NiCd batteries from the general waste stream have found it difficult to achieve satisfactory collection rates, and they have discovered that separate collection and treatment implies significant extra costs to society. Some countries (e.g. Denmark and Sweden) have therefore worked goal-oriented towards minimizing NiCd battery consumption, among other means by introducing import fee systems which also have the role of covering society's costs for separate collection and treatment of waste batteries (Maag and Skaarup, 2005; European Commission, 2003).

532. The efficiency of NiCd battery collection is dependent on battery types. In the U.S.A., the U.S. Geological Service reports that "large industrial batteries are easy to collect and are recycled at a rate of about 80 percent", whereas "the small consumer NiCd batteries are frequently discarded by the public (U.S. GS, 2004)". Danish experience from 2004 with separate collection of small NiCd-batteries supported by a fee arrangement indicates a collection efficiency at about 50 percent. The percentage is estimated considering the effect of household practices of prolonged storage of batteries after end-of-life (the so-called "hoarding effect"), which may delay delivery of worn-out batteries by several years (Maag and Hansen*.,* 2005). The experience in both countries is that a significant part of the batteries will be disposed of with municipal solid waste.

533. Table 8-8 provides other examples of collection rates for spent NiCd batteries from selected European countries. Presented indicative collection rates based on NiCd sales range from 0.5 - 59 percent in these countries; some of which have made significant investments in separate battery collection schemes. Note that comparing collected amounts with sales from one year only yields indicative collection rates, because collectable NiCd batteries were generally sold several years earlier, where sales may have been lower or higher. Collection rates in percent of spent portable NiCd batteries "available for collection" - ranging from 46 - 70 percent - are also presented for selected countries where such estimates could be developed (Bio Intellegence, 2003). The difference between rates based on sold NiCd amounts and rates based on NiCd batteries "available for collection" is that the latter is an attempt to take into consideration the hoarding effect mentioned above. Note that the estimated collection rates based on NiCd batteries "available for collection" are based on the assumption that all discarded NiCd batteries will be collected either separately or with controlled municipal solid waste collection (Bio Intellegence, 2003). This may be close to reality in the countries assessed, but is likely not a valid assumption in many developing countries, where significant parts of the generated general waste may be dumped or incinerated informally. Such hoarded NiCd batteries will ultimately either be collected with waste (separately or with municipal waste), or be lost to the environment, meaning that over time the observed collection rates based on accumulated NiCd sales should in principle illustrate the actual accumulated collection efficiency.

Table 8-8 Reported collection rates for spent portable NiCd batteries in selected European countries (data from European Commission, 2003and Bio Intellegence, 2003).

Country	Collection rate in percent of sales in 2002 2)	Collection rate in percent of spent portable NiCd batteries "available for collection" 1)
Austria	44%	70%
Belgium	59%	-
France	16%	64%
Germany	39%	67%
Netherlands	32%	69%
Sweden	55%	-
Spain	14%	-
United Kingdom	0.5%	-

1) This way of assessing the collection rate is an attempt to take into consideration the so-called hoarding effect (prolonged storage by users after end-of-battery-life). The presented estimates are based on the assumption that all discarded NiCd batteries will be collected either separately or with controlled municipal solid waste collection (MSW). This may be close to reality in the countries assessed, but will not be a valid assumption in many developing countries, where significant parts of the generated waste may be dumped or incinerated informally.

2) Data in this column were presented in this way in the references cited. Comparing current collection with current sales gives only an indicative illustration of collection efficiency, as currently collectable amounts generally reflects sales from earlier years, which may have been higher or lower than current sales.

534. In the European situation most, or all, of the spent NiCd batteries collected separately are recycled for re-marketing of the metals (including cadmium; Bio Intellegence, 2003).

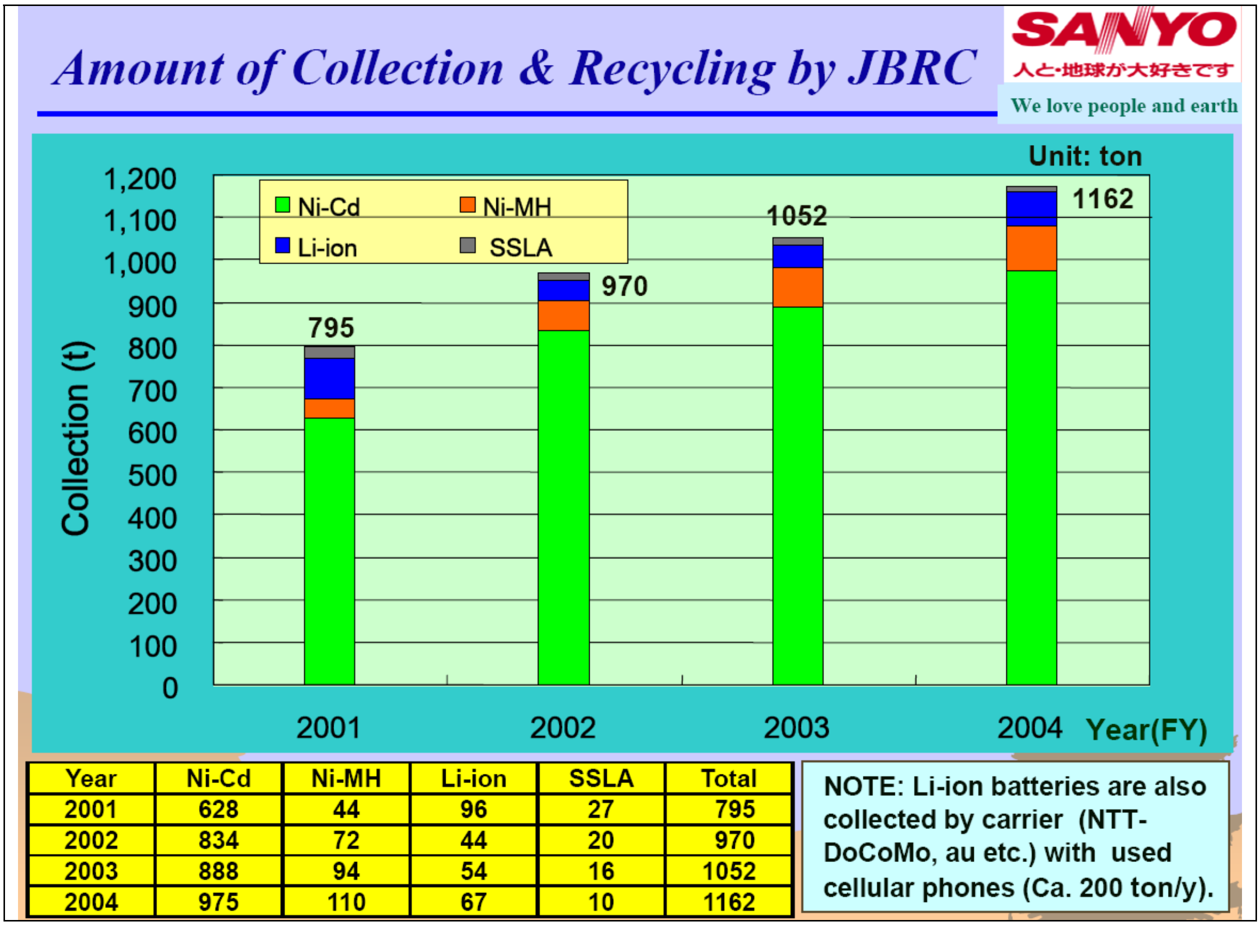
535. Cadmium releases to the environment from waste management may happen in several steps of the waste management chain. Three dominant sources of short term releases of cadmium from treatment of municipal waste under controlled circumstances - namely air and water releases from municipal waste incineration and leachate releases from landfills - were assessed for the industry association "Recharge" for the European situation (Euras, 2005). They found that air emissions from incineration of MSW only contributed 2.6 percent to the total reported cadmium emissions to the atmosphere in the EU (oil and coal combustions and ferrous metal production being the main sources of releases to the atmosphere). With regard to aquatic releases, the contribution of landfilling and incinerating MSW was also assessed as minor (2.3 percent of total reported releases). Based on their assessment of reviewed data, they found that NiCd batteries contributed with about 17 percent of the cadmium contents in municipal waste in the countries included, meaning that NiCd batteries only contributed with approximately 0.5 percent to overall cadmium emissions to air and water in the EU. The data used in the study appear to reflect extremely high separate collection rates (as compared to EU NiCd sales as well as to collection rates corrected for the hoarding effect), the relevance of which appear questionable in the global context. The study did not take other long term cadmium releases than leachate into consideration from landfills.

536. Ecuador reports in its submission that batteries represent an estimated 48 percent of the cadmium in waste in the country (Ecuador's submission, 2006). Madagascar reports in its submission that 100 millions of batteries (all types of batteries) are consumed annually in Madagascar. In the absence of a collection system the batteries are mixed up with household wastes without sorting or spread in the nature (Madagascar's submission, 2005).

537. **Fate of discarded batteries in Yaounde, Cameroon** – A study undertaken by Tetsopgang and Kuepouo (2008) highlighted the mismanagement of discarded dry batteries in Yaoundé, Cameroon. This study pointed out that these discarded dry batteries are sources of hazardous substances like mer-

cury or cadmium to the environment. Given the problems highlighted, a sound management system of discarded dry batteries that could be applicable to other Sub-Saharan countries is proposed in the study. The management system proposed includes an import fee system, better regulations in term of life-cycle responsibility for local trademarks and better labeling (Tetsopgang and Kuepouo, 2008).

538. Spent rechargeable batteries, including NiCd batteries are collected in many OECD countries. Figure 8-5 shows amounts of collected rechargeable batteries in Japan in 2001-2004 (collected by JBRC, Japan Rechargeable Battery Recycling Center). The figure shows that substantial amounts have been collected; as comparable consumption data for Japan have however not been found for this study, the collection efficiency cannot be estimated.



Year	Ni-Cd	Ni-MH	Li-ion	SSLA	Total
2001	628	44	96	27	795
2002	834	72	44	20	970
2003	888	94	54	16	1052
2004	975	110	67	10	1162

NOTE: Li-ion batteries are also collected by carrier (NTT-DoCoMo, au etc.) with used cellular phones (Ca. 200 ton/y).

Figure 8-5 Amounts of rechargeable batteries collected by Japan Rechargeable Battery Collection Center (JBRC) in 2001-2004 (Sanyo, 2005).

539. **Cadmium wastes in Trinidad and Tobago.** In Trinidad and Tobago, for the period 2004 – 2008 the main sources of cadmium derived from the recently concluded National Hazardous Waste Inventory include sources of spend lithium/cadmium batteries and electronic waste. The main methods for disposal identified are incineration, land filling and recycling (Trinidad and Tobago’s submission, 2010).

9 Initiatives for preventing or controlling releases and limiting exposures

540. The information presented in this chapter on initiatives and actions for management and control of releases and exposures of cadmium 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.

541. Initiatives for preventing or controlling releases and limiting exposures take place at different levels. The current chapter briefly describes initiatives specifically addressing cadmium at four levels:

- National initiatives;
- International conventions and treaties;
- International organisations and programmes;
- Sub-regional and regional initiatives.

9.1 National initiatives

Overview of existing national initiatives

542. Table 9-1 gives an overview of types of implemented measures of importance to management and control of cadmium, as related to releases from point sources and 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 cadmium products and processes from which cadmium is emitted.

Common features of existing national initiatives

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

544. Legislation provides an impetus and a framework for the safe management of chemicals, including cadmium and cadmium 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 cadmium; 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.

545. Although legislation is a key component of many initiatives, safe management of cadmium may also include efforts to reduce the volume of cadmium 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 cadmium.

Table 9-1 Overview of implemented measures of importance to cadmium, 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 cadmium from raw materials		
POINT SOURCES	Apply emission control technologies to limit emissions of dust and adhered pollutants (including cadmium) from combustion of fossil fuels and processing of mineral materials	Implemented in most countries
	Prevent or limit the release of heavy metals (including cadmium) from industrial processes to the wastewater treatment system	Implemented in many countries
	Require use of best available technology to reduce or prevent cadmium releases	Implemented in some countries, especially OECD countries
PRODUCTS	Prevent or limit products containing cadmium from being marketed nationally	General bans implemented in a few countries only. Bans or limits on specific products are more widespread, such as some types of pigments or cadmium plating
	Limit the allowable content of cadmium present as impurities in high-volume materials - for example phosphate fertilizers	Implemented in many countries - in particular OECD countries
	Limit the allowed contents of cadmium in commercial foodstuffs and feed.	Implemented in some countries, especially OECD countries. WHO guidelines used by some countries.
Disposal phase of life cycle		
Prevent cadmium in products and process waste from being released directly to the environment, by efficient waste collection		Implemented in many countries, especially OECD countries
Prevent cadmium 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, especially OECD countries
Prevent or limit cadmium releases to the environment from incineration (and possibly other treatment) of household waste, hazardous waste and medical waste by emission control technologies		Implemented or implementation ongoing in many countries.
Set limit values for allowable cadmium contents in sewage sludge and other organic waste products used for land application		Implemented in many countries
Set limit values for cadmium in solid incineration residues used in road-building, construction and other applications		Implemented in a few OECD countries

546. The overall aims of existing initiatives on cadmium are to reduce or prevent the release of cadmium to the environment and avoid direct/indirect impact 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 cadmium 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 cadmium 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. Actions and regulations to control cadmium-containing products, such as fertilizers, plastics, batteries, vehicles, electrical and electronic equipment etc.;

D. Other standards, actions and programmes, such as regulations or guidance on exposures to cadmium in the workplace, requirements for information and reporting on use and releases of cadmium in industry, and consumer safety measures.

547. Based on the information reviewed for this report, it appears that, no country has so far developed a comprehensive legislation covering the all life-cycle stages of cadmium. 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 cadmium. Often, legislation related to production, marketing and use of cadmium and cadmium-containing products is specific to cadmium, 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.

548. 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 lack thereof, of initiatives and legislation on cadmium in a country must be seen in connection with the use and release patterns of that country, and that the need to address specific risks to health and the environment posed by these uses or releases varies.

Common types of national initiatives

549. 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. In this description, EU legislation is also referred to as national legislation, although EU legislation must be implemented in all of its 25 Member States, representing the dominant part of the cadmium consumed in Europe.

550. A more detailed compilation of national initiatives, including legislation, in each individual country is contained in a separate Appendix to this review, entitled “Overview of existing and future national actions, including legislation, relevant to cadmium”. 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 for most of the types of measures described in this section.

A. Environmental media standards and guidelines, specifying a maximum acceptable or tolerable cadmium concentration for different media

551. **Water, air and soil -** In order to limit the general population’s exposure to cadmium and cadmium compounds, a number of countries have established standards setting maximum acceptable concentration limits for cadmium in a number of different media, such as water (drinking water, surface waters, groundwater etc.), 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 cadmium in natural waters of max. 0.01 ppm (Iran's submission, 2005), while the republic of Moldova has established a standard for cadmium and its compounds in air of residential areas of 0.0003 $\mu g/m^3$ (Moldova's submission, 2005).

552. WHO has developed guidelines for drinking water quality (WHO, 2006) and air quality, (WHO, 2000) designed to 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 cadmium. 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 account. In certain circumstances there may be valid reasons to pursue policies that will result in standards for pollutant concentrations that are set above or below the guideline values.

553. **Foodstuffs -** In order to limit the general population's exposure to cadmium and cadmium compounds, some countries - e.g. the EU - have established standards setting maximum acceptable concentration limits in a number of foodstuffs. Standards exist for a wide range of different foodstuffs.

554. The FAO/WHO Codex Alimentarius Commission has also set guideline levels (maximum levels) for cadmium in various foodstuffs (see Chapter 3)

555. The FAO/WHO Codex Alimentarius Commission has recently adopted new standards for marine bivalve molluscs (excluding oysters and scallops), cephalopods (without viscera) and in polished rice.

556. **Exposure -** The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has established a provisional tolerable weekly intake (PTWI) for cadmium of 7 µg/kg body weight per week (WHO, 2001). This PTWI and other similar exposure reference or guidance levels are discussed in more detail in Chapter 3.

B. Environmental source controls/regulations that control cadmium releases into the environment

557. **Emission limits for air and water point sources -** Many countries have legislation prescribing maximum allowable releases of cadmium (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 wastes, respectively.

558. In the EU, several Community Directives exist which together limit cadmium pollution of inland surface, territorial and internal coastal waters and set Community-wide standards regarding discharges of cadmium for a considerable number of industrial sectors. In addition, the new Water Framework Directive has been approved, laying down an integrated EU strategy for harmonised water quality standards and controls. Cadmium is one of the "priority hazardous substance" covered, and releases to the aquatic environment are to be phased out within 20 years.

559. Also, a 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 for existing installations as from 28 December 2005.

560. **Best available techniques**[7] **-** 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.

561. 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., 2008; OECD, 1994).

562. Another example is the European Community Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. It requires the application of best avail-

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[7] 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. BAT is increasingly used in regional forums (such as EU and the Aarhus Protocol to the LRTAP Convention) and global forums (such as the Stockholm Convention) where it is well defined and well accepted.

able 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. As part of the implementation of the Directive, reference documents on best available techniques (BREF) are developed for different sectors, e.g. non-ferrous metal industry (EIPPCB, 2006).

563. Another recently prepared report “Assessment of technological developments: Best Available Techniques (BAT) and limit values” includes information on cadmium. 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.

564. **Utilisation of waste and wastewater treatment residues -** Legislation exists prescribing maximum allowable concentrations of cadmium, often together with other pollutants, in wastewater sludge and other waste materials to be used as fertilizers on agricultural land or soil improvement material.

565. As examples, Denmark has established a limit value for wastes applied for agricultural purposes of 100 mg Cd per kg P (corresponding to 43 mg Cd per kg P_2O_5) or 0.8 mg Cd/kg dry weight (Danish EPA, 2003) while Finland has established a limit value of 3 mg Cd/kg dry weight (Loukari *et al.*, 2000).

566. **Waste treatment –** In a number of countries, for example members of the EU, legislation prescribes separate collection and disposal arrangements specifically addressing nickel-cadmium batteries (NiCd-batteries). The aim of such legislation is to prevent or minimise the diffuse spreading of cadmium and limit the amount of cadmium 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 (OECD, 1994).

C. Product control regulations for cadmium-containing products

567. Regulatory measures limiting or preventing several products containing cadmium from being marketed nationally, and in some cases also prohibiting import and export, have been implemented in some countries throughout the world. Such measures may include economic incentives.

568. **Batteries -** Some countries (e.g. Denmark and Sweden) have worked towards minimizing NiCd battery consumption by introducing, among other means, import fee systems which also have the role of covering society's costs for separate collection and treatment of waste batteries (Maag and Skaarup, 2005; European Commission, 2003). In the revised (2006) Battery Directive of the European Union (2003/0282/COD, the sale of NiCd batteries has been banned EU-wide, except for a number of specified uses (e.g. power tools, the single largest use). The Directive calls for the collection and recycling of all types of batteries and imposes a marketing restriction on portable Ni-Cd batteries for certain applications and exempts from this marketing restriction the following applications: emergency and alarm system, medical, military and space and cordless power tools. A recent EU directive (Directive 2006/66/EC) on batteries and accumulators and waste batteries and accumulators explicitly addresses the question of cadmium and lead (Sweden’s submission,2007).

569. **Phosphate fertilizers -** Limits on the content of cadmium in phosphate fertilizers has been established in a number of countries. The aim of these restrictions is generally to limit the supply of cadmium to agricultural soils. Limits on the content of cadmium in phosphate fertilizers have been established by a number of countries. As examples, limit values for cadmium in fertilizers has been established in Austria (75 mg Cd/kg P_2O_5), Finland (21.5 mg Cd/kg P_2O_5) and Sweden (43 mg Cd/kg P_2O_5). In Australia, all states are aiming for a maximum permitted concentration of cadmium in phosphate fertilizers of 300 mg Cd/kg phosphorus (corresponding to 128 mg Cd/kg P_2O_5) (Australia's submission,

2005). Information regarding the management of risk of cadmium in phosphate fertilizer can be obtained in the document mentioned by WPI (WPI submission, 2009).

570. **Pesticides -** According to ATSDR (2006), use of cadmium and cadmium compounds in pesticides is not allowed in the U.S.

571. **Pigments and stabilisers in plastics and metal plating -** some countries have established a ban on the use of cadmium in plastics (mainly bulk plastics), and for certain metal plating applications. The ban was originally established in Sweden back in 1982 and later followed by Denmark, the Netherlands and EU (OECD, 1994). The ban was driven by the need to eliminate the dominant sources of cadmium (at that time) from waste incineration plants and scrap based steel plants.

572. **Tableware, ceramic objects intended for food contact and toys etc. -** Leaching of cadmium from certain articles intended to be in contact with food such as tableware, or that are otherwise accessible to children or older persons (by chewing, sucking) which may dissolve cadmium used in the product, is restricted 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.

573. **Electrical and electronic equipment -** EU Directive 2002/95/EC (Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment - the RoHS Directive - bans import and sale of electrical and electronic equipment, which contains cadmium, lead, mercury, hexavalent chromium, polybrominated biphenyls (PBB) or polybrominated diphenylethers (PBDE) above certain threshold concentrations with implementation from 1 July 2006. The ban also covers spare parts for the equipment in question. For cadmium, a threshold of 0.01 percent by weight for the individual homogeneous parts of the product has been established.

574. 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

575. Equipment for specific military purposes, medical devices and monitoring and control equipment is exempted from the Directive. Furthermore, a few specific applications of cadmium - e.g. cadmium plating on electrical contacts, are exempted from the ban.

576. **Cosmetics** - According to Directive76/768/EEU (and its amendments 2000/6/EU and 2000/11/EC) cadmium and its compounds are not allowed as ingredients in cosmetics that are marketed within the European Community.

577. **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 of all Member States as well as of third countries, and also to ensure the functioning of the internal market 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.

578. **Vehicles -** European Community Directive 2000/53/EC on end-of-life vehicles lays down measures that aim at prevention of waste from vehicles and promotion of reuse, recycling and other forms of recovery of end-of-life vehicles and their components so as to reduce the disposal of waste, as well as the improvement in the environmental performance of all of the economic operators involved in

the life-cycle of vehicles. According to Article 4 of this Directive, cadmium, *inter alia*, is restricted in materials and components of vehicles. Materials and components of vehicles put on the market after 1 July 2003 shall not contain cadmium.

579. **Other products -** In Denmark, it is prohibited for occupational health reasons to use cadmium solders containing more than 0.1 percent cadmium. It is also not allowed to use cadmium pigments for products other than ceramics, glass, dental cement and art (Drivsholm *et al.,* 2000).

580. 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 stopped selling all cadmium stabilisers in the European Union, Norway and Switzerland from March 2001 (ESPA, 2001).

D. Other standards and programmes

581. **Occupational health and safety -** A number of countries have implemented measures to ensure occupational safety and health of workers and regulate exposures to cadmium 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.

582. **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.

9.2 International Conventions and Treaties

9.2.1 The Convention on Long-Range Transboundary Air Pollution and its 1998 Aarhus Protocol on Heavy Metals (LRTAP Convention)

583. 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 regarding the Convention 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 cadmium

584. The Executive Body of the Convention adopted the Protocol on Heavy Metals on 24 June 1998 in Aarhus, Denmark. It targets three heavy 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 limit values for emissions from stationary sources and suggests best available techniques for these sources. Emission levels are 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.

585. Article 3 of the 1998 Århus Protocol on Heavy Metals describes the basic obligations set out in the Protocol; below is a summary of those especially relevant to cadmium:

A) **Reduction of total annual emissions of cadmium 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 (by December 2011). The standards for best available techniques are given as examples in Annex III to the Protocol. The Annex specifies a number of control techniques that address cadmium 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 limit values for particulate emissions from combustion plants, cement industry, waste incinerators and a number of sources within the metallurgical industry.

586. 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 cadmium containing batteries, cadmium as surface treatment, stabiliser and colouring agent, cadmium in electrical and electronic equipment and heavy metals in packaging, sewage sludge and vehicles.

Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe

587. 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 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 cadmium, and particulate matter. For further information is referred to EMEP's website at http://www.emep.int/index.html;

9.2.2 The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)

588. 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 cadmium

589. 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 implementa-

tion 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.

590. 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.

591. 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 cadmium and cadmium 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 cadmium was endorsed by OSPAR in 2002 and updated in 2004 (OSPAR, 2002) and in 2010 (OSPAR, 2010). The actions recommended there are taken into account, when appropriate, in the work of OSPAR.

592. Quality Status Report summarises advances and trends in the last 10 years for the OSPAR areas of work. Chapter 5 on Hazardous Substances covers the monitoring information and levels of cadmium in environmental compartments and biota, among other aspects (QSR, 2010).

593. The following OSPAR Decisions and Recommendations, applicable under the OSPAR Convention, are related to cadmium and related industries.

594. **Substitution of cadmium**

- PARCOM Recommendation 84/2 for Reducing Cadmium Pollution. This Recommendation requires Contracting Parties to respect the scope which exists for the substitution of cadmium by other materials particularly in the fields of electroplating, pigments and stabilisers. The Commission agreed that the risks resulting from the use of cadmium in soldering and alloys were a minor problem.

- PARCOM Recommendation 92/4 on the Reduction of Emissions from the Electroplating Industry. This Recommendation requires the substitution, if technically possible, of hazardous substances; a maximum concentration in specific waste water streams of 0,2 mg cadmium/l; and to implement technical measures to treat specific in-plant waste water streams that are particularly hazardous (e.g. cadmium, mercury and chlorinated solvents).

595. **Batteries and accumulators**

PARCOM Decision 90/2 on Programmes and Measures for Mercury and Cadmium Containing Batteries. This Decision recognises the need for further measures to reduce inputs of mercury and cadmium to Convention waters, and agrees to the recovery and disposal of batteries and accumulators containing more than 0,025% cadmium by weight. To this end, among other measures:

- batteries and, where appropriate, appliances into which cadmium is incorporated should be labelled with a recovery symbol;

- the public should be informed about the danger of uncontrolled disposal of spent batteries and the labelling of such batteries;

- consideration should be given to establishing economic incentives to encourage the recycling of batteries. It is the aim for the collection and recycling of all batteries larger than 500 g and

- for the collection of at least 80% of smaller batteries.

596. **Primary iron and steel industry**

- PARCOM Recommendation 91/2 on the Definition of Best Available Technology in the Primary Iron and Steel Industry. This Recommendation covers non-specific emissions, sinter plants, pellet plants, coke plants, blast furnaces and basic oxygen furnaces.
- PARCOM Recommendation 92/2 Concerning Limitation of Pollution from New Primary Iron and Steel Production Installations. This recommendation focuses on sinter plants, coke plants, blast furnaces and basic oxygen furnaces. Waste gases containing dust should be collected and be subjected to dedusting. After dedusting, the gases should not contain more than 50 mg dust/m3. If the dust contains hazardous substances (more than 0,2% cadmium) lower standards should be achieved.
- PARCOM Recommendation 93/1 on the Limitation of Pollution from Existing Primary Iron and Steel Production Installations. This Recommendation focuses on sinter plants, coke plants, blast furnaces. Waste gases containing dust should be collected and be subjected to dedusting. After dedusting, the gases should not contain more than 50 mg dust/m3. If the dust contains hazardous substances (more than 0,2% cadmium) lower standards should be achieved.

597. **Secondary iron and steel industry**

- PARCOM Recommendation 90/1 on the Definition of the Best Available Technology for Secondary Iron and Steel Plants.
- PARCOM Recommendation 91/3 on Measures to Be Taken and Investigations to Be Carried out in Order to Reduce Pollution from Secondary Iron and Steel Production. This Recommendation reflects the necessity of measures for the reduction of heavy metal contamination in scrap in order to avoid further pollution with inter alia cadmium.
- PARCOM Recommendation 92/3 Concerning Limitation of Pollution from New Secondary Steel Production and Polling Mills. In relation to aqueous discharges, waste water flow from pickling and plating should be reduced as far as possible. Discharges of metals from pickling plants should be limited to 0,2 mg cadmium/l as maximum concentration in effluent water (unfiltered samples).

598. **Limitation of pollution from other industrial sources**

- PARCOM Decision 85/2 on Programmes and Measures on Limit Values and Quality Objectives for Cadmium Discharges.
- PARCOM Recommendation 97/2 on Measures to Be Taken to Limit Emissions of Heavy Metals and Persistent Organic Pollutants Due to Large Combustion Plants (_50 MWth).
- PARCOM Recommendation 98/1 concerning Best Available Techniques and Best Environmental Practice for the Primary Non-ferrous Metal Industry.
- PARCOM Recommendation 2001/1 for the Management of Produced Water from Offshore Installations.

599. There are several measures applicable under OSPAR to control cadmium emissions, discharges and losses from specific sectors. Furthermore, OSPAR measures on Best Available Techniques (BATs) for various industrial installations, as well as offshore gas and oil installations, will also help to limit discharges, emissions and losses of cadmium.

600. **Cadmium discharges from industrial sources** - *PARCOM Decision 85/2 on Programmes and Measures on Limit Values and Quality Objectives for Cadmium Discharges* sets limit values for cadmium discharges for a number of industrial processes: Manufacture of cadmium compounds, manufac-

ture of pigments, manufacture of stabilizers, manufacture of primary and secondary batteries, electroplating and manufacture of phosphoric acid and/or phosphate fertilizer from phosphate rock. The emission standards set by the Parties must not exceed the limit values, except where a Contracting Party applies quality objectives in conformity with Annexes II and IV of the decision.

601. **Cadmium in batteries** - *PARCOM Decision 90/2 on Programmes and Measures for Mercury and Cadmium-Containing Batteries* lays down various measures dealing with the recovery, disposal, marketing and use of certain mercury and cadmium batteries.

602. **Cadmium in electroplating, pigments and stabilisers** - In *PARCOM Recommendation 84/2 for Reducing Cadmium Pollution* The Commission agreed that, in taking measures to eliminate pollution of Convention waters by cadmium, Parties should take into account the scope which exists for the substitution of cadmium by other materials, particularly in the fields of electroplating, pigments and stabilisers, and it was agreed that further research to define the pathways and reduce the cadmium content in fertilizers should be encouraged.

603. Moreover, 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 cadmium among other substances. The following recommendations are of particular importance concerning the reduction of cadmium emission:

604. **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.

605. **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)

606. 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.

The HELCOM Strategy to Implement its Objective with regard to Hazardous Substances, and its relevance to cadmium

607. 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 cadmium and its compounds.

608. The following valid (April 2006) HELCOM recommendations specifically relate to cadmium :

- 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 17/6 (adopted 12 March 1996): Reduction of pollution from discharges into water, emissions into the atmosphere and phosphogypsum from the production of fertilizers.
- HELCOM Recommendation 18/2 (adopted 12 March 1997): Offshore activities.
- HELCOM Recommendation 19/5 (adopted 26 March 1998): HELCOM objective with regard to hazardous substances.
- 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 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

609. The HELCOM strategy on hazardous substances, including cadmium, 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

610. 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 Convention was signed on June 29 1994, in Sofia, Bulgaria, by eleven of the Danube Riparian States – Austria, Bulgaria, Croatia, the Czech Republic, Germany, Hungary, Moldova, Romania, Slovakia, Slovenia and Ukraine – and the European Community, and duly came into force in October 1998, when it was ratified by the ninth signatory.

611. 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 sustainably 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.

612. For further information regarding the convention refer to ICPDR's website - http://www.icpdr.org/.

613. Cadmium and cadmium 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)

614. 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/.

The Basel Convention's relevance to cadmium

615. According to Article 1, paragraph 1 (a) of the Convention, cadmium 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 cadmium 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.

616. Annex IX provides a list of waste not falling under article 1,1(a) of the Convention. Waste containing cadmium may be found under the following Annex IX categories (the list below is not meant to be considered exhaustive):

A1010 - Metal wastes and waste consisting of alloys of any of the following: (…), Cadmium, (…);
A1020 - Waste having as constituents or contaminants, excluding metal waste in massive form, any of the following: (…) Cadmium, cadmium 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;
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);
A3120 - Fluff - light fraction from shredding;
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).

617. The Basel Secretariat has published a number of guidelines on management of hazardous waste including lead (available from the web-site), among these "Technical guidelines on the environmentally sound recycling/reclamation of metals and metals compounds" and "Basel Convention technical guidelines on hazardous waste physicochemical treatment (D9) / biological treatment (D8)".

9.3 International organizations and programmes

9.3.1 The International Agency for Research on Cancer (IARC)

618. 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/.

619. 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.

620. In 1993, IARC published Volume 58 of the IARC Monographs on cadmium and cadmium compounds (evaluated as a group). In its overall evaluation of carcinogenicity to humans, cadmium and cadmium compounds were classified (evaluated as a group) in Group 1 (carcinogenic to humans).

9.3.2 International Labour Organization (ILO)

621. 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.

622. 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.

623. 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)

624. The International Programme on Chemical Safety, IPCS, was established in 1980 as a cooperative 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.

625. 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.

- IPCS has published the following Environmental Health Criteria relevant to cadmium:
  - EHC 134 (1992): *Cadmium*;
  - EHC 135 (1989); *Cadmium - environmental aspects.*

626. 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 (WHO, 1972). These documents are all available on the IPCS website at http://www.who.int/pcs/pcs_pubs.html.

9.3.4 World Health Organisation (WHO)

627. 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.

628. 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).

629. 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 cadmium, in food, their contribution to total human exposure, and significance with regard to public health and trade.

630. 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 cadmium (WHO, 2006) and Air Quality Guidelines for Europe (WHO, 2000).

9.3.5 The Organization of Economic Cooperation and Development (OECD)

631. 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.

632. 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.

633. In 1990, the Council of the OECD adopted a Decision-Recommendation on the Cooperative Investigation and Risk Reduction of Existing Chemicals. OECD Member countries chose cadmium as one of the five chemicals (or groups of chemicals) to be included in the initial pilot project on cooperative risk reduction. France served as the lead country on the review for cadmium and included the initiation of information-collection efforts in 1992. The Risk Reduction Monograph No. 5: *Cadmium* was published in 1994 (OECD, 1994). The Monograph provides a summary of information regarding releases of cadmium to the environment, environmental and human exposures, and the way OECD Member countries perceived the risks associated with exposure to cadmium, and describes the actions member-countries and industry had taken, or contemplated taking, to reduce risks associated with exposure to cadmium.

634. In 1995, two OECD workshops on *Fertilizers as a Source of Cadmium* and *Sources of Cadmium in the Environment*, were held in Saltsjöbaden in Sweden. The presentations and results of the

workshops are reported in two proceedings (OECD, 1996a; OECD, 1996b). One of the main conclusions was the need to improve the collection and recycling rates for nickel-cadmium batteries.

635. To facilitate this, a workshop on *Effective Collection and Recycling of Nickel-Cadmium Batteries* was held in Lyon, France in 1997. The presentations at the workshop are reported in proceedings (OECD, 1997). The workshop identified elements of a successful programme and other actions that will facilitate better collection and recycling rates.

636. Another workshop was held on 8-10 December, 1998 in Mexico during which specific proposals for improving the collection and recycling rates of these batteries were developed. This included a proposed label for these batteries that could be used throughout OECD countries, and a proposed guidance document for developing collection and recycling programmes. OECD countries are currently examining these proposals.

637. OECD has developed a web-site that lists NiCd battery collection facilities by country at http://www.oecd.org/document/4/0,2340,en_2649_34365_1945092_1_1_1_1,00.html.

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)

638. 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.

639. The programme has a special section for recommendations regarding heavy metals, including cadmium. 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 cadmium, 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 Industrial Development Organization (UNIDO)

640. 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.

9.3.8 The World Bank Group

641. 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/.

642. The World Bank’s portfolio of projects with clear environmental objectives currently amounts to $US 10.7 billion (2005). Some of the activities including pollutants control may be of relevance to cadmium, but no activities specifically addressing cadmium have been identified.

9.4 Sub-regional and regional initiatives

9.4.1 Arctic Council

643. 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;

644. 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.

645. 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".

646. 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 cadmium, 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

647. 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/

648. The Strategy establishes reduction challenges for an initial list of 12 persistent toxic substances targeted for virtual elimination (List I). Cadmium and cadmium compounds are not among these, but are included in the list of level II substances. Level II substances are those for which one country or the other has grounds to indicate its persistence in the environment, potential for bioaccumulation and toxicity. These grounds have not as yet been sufficiently considered by both nations such that they can agree to set joint challenge goals for these substances at this time. Until and unless these substances are placed on the Level I list, the governments encourage stakeholders to undertake pollution prevention activities to reduce levels in the environment of those substances nominated jointly by both countries, and to conform with the laws and policies of each country with respect to those substances nominated by only one country.

9.4.3 The North Sea Conferences

649. 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/

650. In 1990, ambitious targets were agreed on to reduce inputs of 36 hazardous substances, including cadmium, 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).

9.4.4 South Asia Cooperative Environment Programme (SACEP)

651. 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.

652. 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.

653. The declaration does not specifically address heavy metals, but includes the development and adoption of strategies to prevent and minimise air pollution.

9.4.5 International commissions for the protection of rivers

654. 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 activites, the contracting parties cooperate in

the commissions to prevent the pollution of the rivers and their drainage areas with hazardous substances.

10 Data and information gaps

10.1 National research and information gaps

655. 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

656. 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 cadmium. The latest global inventory of atmospheric emission is based on 1995 data whereas global releases to land and water concern 1983 data. The lack of adequate emission inventories is the main reason that cadmium has not been included in available (northern) hemispheric atmospheric transport models;
- 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;
- More data on the releases of cadmium from natural sources and their significance for regional and long-range transport. Very different release estimates have been presented is previous studies;
- Currently only regional atmospheric transport of cadmium is included in existing atmospheric transport models. Usable hemispheric models exist, but cadmium cannot be included in the models because adequate emission data are missing. Cadmium needs to be included in the models based on suitable emission data. Also, there is a need to develop atmospheric transport models for the Southern hemisphere - regional, hemispheric and/or global models - to better understand the regional and intercontinental atmospheric transport of cadmium;

- Ocean transport of cadmium in general is poorly understood and seems to warrant more investigation; inclusion of cadmium in existing ocean transport models would be one element in establishing a better understanding of the long-range transport of cadmium with ocean currents;
- The release inventory database needs to be improved in the developed regions,:
    - 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 cadmium pollution levels;
    - Improve data quality of national release inventories;
- Develop guidelines for monitoring activities (air, soil, precipitation, human blood etc.);
- The sources of cadmium to the waste are not well investigated (except for some data on NiCd batteries), and could warrant further investigation, because waste handling is an important part of the life cycle as regards potential long term releases. This is even more so true in the developing regions where waste data on cadmium are extremely scarce;
- Certain aspects of cadmium toxicity have been noted in EU risk assessment work on cadmium:
    - Further information is needed to better document the possible effect of low doses of cadmium-oxide (CdO) on neurobehavioral performances suggested in experimental animals, especially on the developing brain;
    - Dermal exposure to cadmium metal is possible when wearing (low price) jewellery and it cannot be excluded that consumer exposure may represent a cause of concern as regards carcinogenicity/genotoxicity and possibly reprotoxicity. This may warrant further investigation;
- The extent of risks to humans from exposure from cadmium is not fully understood in the global perspective.
- The substance flows as a consequence of trade and waste disposal, mainly in developing and transition countries are major causes of human exposure to cadmium. There are gaps on cadmium flows so research in this area is necessary in order to set priorities to global action to reduce risks.

657. **Data gaps between developed and developing countries** - 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 Acronyms and abbreviations

AD	Anno Domini (years after Christ in the Christian calendar)
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
Cd	Symbol for cadmium in the Periodic Table
CORINAIR	CORe INventory of AIR emissions (in the EU)
DRPC	Danube River Protection Convention
DTIE	Division of Technology, Industry, and Economics
EC	European Community
EC_{50}	Effective concentration of substance that causes 50 percent of the maximum response
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (under the LRTAP Convention)
EPER	European Pollutant Emission Register
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 desulfurization; process of/equipment for primarily minimizing emissions of sulfur 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

ILZSG	International Lead and Zinc Study Group
IMPROVE	Interagency Monitoring of Protected Visual Environments
IPCS	International Programme on Chemical Safety
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
LC_{50}	Concentration of a chemical which causes the death of 50 percent of a group of test organisms
LRTAP Convention	Convention on Long-Range Transboundary Air Pollution
LOEC	Lowest Observed Effect Concentration
MAC	Maximum Acceptable Concentration
MACT	Maximum Achievable Control Technology
MPC	Maximum Permissible Concentration
MSC-E	Meteorological Synthesizing Centre – East (associated with the LRTAP Convention)
MSW	Municipal solid waste
MSWI	Municipal solid waste incinerator
NABO	Swiss Soil Monitoring Network (Nationale Bodenbeobachtung)
NATA	National-Scale Air Toxics Assessment
NGO	Non-governmental organization
Ni	Symbol for nickel in the Periodic Table
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
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
PTE	Potentially toxic elements
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.
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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Annex 1 Cadmium in soils

658. 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 lead is provided are thus excluded in this table.

ID	**Country**	**Soil type**	**Description (from reference)**	**In this study categorised as**	**mg Cd/kg**				**Reference [8]**
					min	**max**	**mean**	**median**	
3	Canada	-	Mean concentrations of cadmium in several studies of rural, urban, and agricultural soils from across Canada (more than 350 sites in total) ranged from 0.56 to 1.1 mg/kg (Bewers *et al*., 1987, as cited by Canada's submission, 2005).	Topsoils - unspecified	0.56	1.1	-	-	Government of Canada, 1994
4	Canada	-	High levels of cadmium have been reported in the vicinity of industrial plants and urban areas, especially near known sources of cadmium. Garden soils collected up to 12.8 km away from a copper/zinc smelter in Flin Flon, Manitoba, contained a mean concentration of cadmium of 5.2 mg/kg (3.2 to 13 mg/kg) (Pip, 1991, as cited by Canada's submission, 2005).	Highly contaminated soils	3.2	13	-	-	Government of Canada, 1994
5	Canada	-	Cadmium levels in peat samples collected from 1.0 to 3.7 km away from a copper smelter (Rouyn-Noranda, Quebec) ranged from 54 to 66 mg/kg (mean not reported) (Dumontet *et al*., 1990, as cited by Canada's submission, 2005).	Highly contaminated soils	54	66	-	-	Government of Canada, 1994
6	Canada	-	Cadmium levels in samples collected 25 to 43 km away from a copper smelter (Rouyn-Noranda, Quebec) contained between 5.5 to 7.8 mg/kg (Dumontet *et al*., 1990, as cited by Canada's submission, 2005).	Highly contaminated soils	5.5	7.8	-	-	Government of Canada, 1994
7	Canada	-	The mean concentration of cadmium (n = 5) in soil next to a paint manufacturing plant in Vancouver, British Columbia, was 10.7 mg/kg (0.23 to 37.2 mg/kg) (Golder Assoc. Ltd., 1989, as cited by Canada's submission, 2005).	Highly contaminated soils	0.23	37.2	10.7	-	Government of Canada, 1994
8	Canada	-	Bisessar (1982, as cited by Canada's submission, 2005) reported that concentrations of cadmium in surface soils in the immediate vicinity of an urban secondary lead smelter in Ontario in 1976 ranged from 151 to 26 mg Cd/kg dry weight at	Highly contaminated soils	26	150	-	-	Government of Canada, 1994

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[8] 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 Cd/kg				Reference [8]
					min	max	mean	median	
			sites 15 to 180 metres from the smelter, respectively, compared with 5 mg/kg at a site 1000 metres from the smelter. Older data (1970 to 1980) also confirm that levels of cadmium in soils are higher in the vicinity of industrial operations and known cadmium sources (John, 1975; Lynch *et al*., 1980; Sergeant and Westlake, 1980, as cited by Canada's submission, 2005).						
9	Canada	-	Bisessar (1982, as cited by Canada's submission, 2005) reported that concentrations of cadmium in surface soils in the immediate vicinity of an urban secondary lead smelter in Ontario in 1976 ranged from 151 to 26 mg Cd/kg dry weight at sites 15 to 180 metres from the smelter, respectively, compared with 5 mg/kg at a site 1000 metres from the smelter. Older data (1970 to 1980) also confirm that levels of cadmium in soils are higher in the vicinity of industrial operations and known cadmium sources (John, 1975; Lynch *et al*., 1980; Sergeant and Westlake, 1980, as cited by Canada's submission, 2005).	Highly contaminated soils	-	-	5	-	Government of Canada, 1994
10	Canada	-	Cadmium: Natural mean concentrations for Ontaria topsoils (transcription from figure 3 from Canada's, submission, 2005).	Remote areas	-	-	3.5	-	Government of Canada, 1994
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	-	-	0.24	-	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	-	-	0.3	-	Czech Republic's submission, 2005
16	Denmark	-	Cadmium and lead concentrations in Danish natural topsoils, mg/kg dw.	Topsoils - unspecified	0.1	0.7	-	-	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	0.025	3.4	-	-	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	0.05	0.6	0.25	-	Tjell and Hovmand, 1978, as cited by Scott-Fordsmand and Pedersen, 1995
23	Japan	-	Cadmium in supposedly non-contaminated soil: The average composition of cadmium in supposedly non-contaminated domestic soil is estimated to be approximately several hundred ppb 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 measurement results of 0.3 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 0.33 to 0.44 mg/kg dw on the	Remote areas	-	-	0.3	-	Japan's submission, 2005

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Cd/kg				Reference [8]
					min	max	mean	median	
			average and 0.27 to 0.35 mg/kg dw as a median.						
26	Lithuania	All soils	Top layer, city soil	Topsoils - specified	-	-	0.4	-	Lithuania's submission, 2005
27	Lithuania	All soils	Top layer, city soil	Topsoils - specified	-	-	0.21	-	Lithuania's submission, 2005
37	Moldova	-	Analysis results on determination of Lead and Cadmium (mobile forms) in soils	Topsoils - unspecified	0.28	0.81	0.395098	-	Moldova's submission, 2005
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	-	-	-	-	Poland's submission, 2005
39	Poland	-	According to Poland's submission, 2005, the cadmium content in arable soil in Poland varies from 0.01 to 49.73 mg/kg, which after statistical rejection of the extreme values gives the average of 0.21 mg Cd /kg of soil (Trelak et.al. 1998 as cited by Poland's submission, 2005). The observed high cadmium 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 cadmium content in arable soil approaches average values, characterizing the average content of these metals in soil all over the world. Research carried out in 2000 showed that in Poland the share of soils with natural content of cadmium was 92 percent [Michna, Sztetke, 2001, as cited by Poland's submission, 2005]	Agricultural soils	0.01	49.73	0.21	-	Poland's submission, 2005
40	Togo	-	Mining soils	Highly contaminated soils	0.2	43	-	-	Togo's submission, 2005
44	USA	-	Unpolluted soil	Remote areas	-	-	0.25	-	ATSDR, 1999
45	USA	-	Hazardous waste sites	Highly contaminated soils	-	-	4	-	ATSDR, 1999
49	Canada	-	Topsoil	Topsoils - unspecified	0.4	1.7	0.9	-	Richardson *et al*., 2001
50	Canada	-	Agricultural soil (for Pb: Plowed agricultural soil)	Agricultural soils	0.11	0.43	-	-	Richardson *et al*., 2001
53	USA	-	Agricultural surface soil	Agricultural	0.01	2	0.265	-	Richardson *et al*., 2001

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Cd/kg				Reference [8]
					min	max	mean	median	
				soils					
56	England	-	Topsoil	Topsoils - unspecified	1	4	0.3	-	Richardson *et al*., 2001
57	England and Wales	-	Topsoil	Topsoils - unspecified	0.2	40.9	0.8	-	Richardson *et al*., 2001
58	England and Wales	-	Topsoil	Topsoils - unspecified	0.27	1.04	0.63	-	Richardson *et al*., 2001
59	Sweden	-	Topsoil	Topsoils - unspecified	0.03	2.3	0.22	-	Richardson *et al*., 2001
61	Denmark	-	Topsoil	Topsoils - unspecified	-	-	0.26	-	Richardson *et al*., 2001
62	Finland	-	Topsoil	Topsoils - unspecified	0.01	0.448	-	-	Richardson *et al*., 2001
78	Australia	-	Topsoil	Topsoils - unspecified	0.013	0.56	0.19	-	Richardson *et al*., 2001
79	New Zealand	-	Uncontaminated soil	Remote areas	-	-	-	-	Richardson *et al*., 2001
80	Scotland	-	Topsoil	Topsoils - unspecified	0.3	1.5	0.77	-	Richardson *et al*., 2001
81	Scotland	-	Topsoil	Topsoils - unspecified	0.25	1.4	0.66	-	Richardson *et al*., 2001
82	Norway	-	Topsoil	Topsoils - unspecified	0.02	3.7	0.57	-	Richardson *et al*., 2001
83	Trinidad and Tobago	-	(unspecified)	Highly contaminated soils	0.06	2.24	-	-	Trinidad and Tobago's submission, 2006
86	Uzbekistan	-	Polluted soil around industrial waste site, Navoi Region	Highly contaminated soils	-	-	1	-	Uzbekistan's submission, 2006
87	Uzbekistan	-	Polluted soil around industrial waste site, Fergana Region	Highly contaminated soils	-	-	0.75	-	Uzbekistan's submission, 2006
88	Uzbekistan	-	Polluted soil around industrial waste site, Fergana Region	Highly contaminated soils	-	-	1.55	-	Uzbekistan's submission, 2006
89	Uzbekistan	-	Polluted soil around industrial waste site, Namangan Region	Highly contaminated soils	-	-	1	-	Uzbekistan's submission, 2006
90	Uzbekistan	-	Polluted soil around industrial waste site, Namangan Region	Highly contaminated soils	-	-	0.75	-	Uzbekistan's submission, 2006
91	Finland	Coarse mineral soil	Cultivated fields	Remote areas	0.016	0.641	0.138	-	Finland's submission, 2006

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Cd/kg				Reference [8]
					min	max	mean	median	
92	Finland	Clay soils	Cultivated fields	Remote areas	0.085	0.624	0.222	-	Finland's submission, 2006
93	Finland	Organic soils	Cultivated fields	Remote areas	0.073	0.748	0.298	-	Finland's submission, 2006
94	Finland	All soils	Cultivated fields	Remote areas	0.016	0.748	0.183	-	Finland's submission, 2006
95	Finland	Humus	Permanent national forest	Remote areas	0.07	1.13	0.36	0.34	Finland's submission, 2006
96	Finland	Podsol	Mainly forest land (<2mm)	Remote areas	0.1	7.88	0.15	-	Finland's submission, 2006
97	Finland	Podsol	Forest land (<1mm)	Remote areas	0.04	2.09	0.34	0.31	Finland's submission, 2006
98	Finland	Vertic cambisols	Topsoil, arable land, aqua regia	Agricultural soils	0.105	-	0.155	0.154	Finland's submission, 2006
99	Finland	Dystric cambisols	Topsoil, arable land, aqua regia	Agricultural soils	0.01	0.227	0.058	0.037	Finland's submission, 2006
100	Finland	Haplic podzols	Topsoil, arable land, aqua regia	Agricultural soils	0.019	0.238	0.067	0.071	Finland's submission, 2006
101	Finland	Fibric histosols	Topsoil, arable land, aqua regia	Agricultural soils	0.04	0.144	0.173	0.168	Finland's submission, 2006
104	Mongolia	-	Ulaanbaatar area, between 1996-1998 (unspecified)	Topsoils - unspecified	-	-	0.02	-	Mongolia's submission, 2006
105	Sweden	Till	Till. Fine fraction (<0.063 mm). Total contents XRF. Based on 24151 samples	Topsoils - unspecified	-	-	-	-	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	0.03	0.41	-	0.08	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	0.03	0.3	-	0.06	Sweden's submission, 2006
108	China	Rice soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	0.024	0.029			
109	China	Damp soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	0.046	0.19			
110	China	Drill soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	0.046	0.12			
111	China	Floss soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	0.046	0.19			
112	China	Black loamy soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	0.08	0.19			
113	China	Oasis soil	The background value of the cultivated soils. (uncontaminated rural soils)	Agricultural soils	0.024	0.19			
114	Norway	-	Agricultural soil (0-5 cm)	Agricultural soils	0.025	1.8	0.22	-	Norway's submission, 2006

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Cd/kg				Reference [8]
					min	max	mean	median	
115	Norway	-	Agricultural soil (> 40 cm)	Agricultural soils	0.14	2	0.17	-	Norway's submission, 2006
116	Switzerland	-	Grassland (extensive) (Swiss soil monitoring network site)	Topsoils - specified	0.081	2028	0.408	0.217	Switzerland's submission, 2006
117	Switzerland	-	Grassland (intensive) (Swiss soil monitoring network site)	Topsoils - specified	0.195	0.577	0.326	0.294	Switzerland's submission, 2006
118	Switzerland	-	Grassland (all)	Topsoils - specified	0.01	32400	0.503	0.32	Switzerland's submission, 2006
119	Switzerland	-	Agriculture (Swiss soil monitoring network site)	Agricultural soils	0.1	0.971	0.271	0.236	Switzerland's submission, 2006
120	Switzerland	-	Agriculture	Agricultural soils	0.005	23000	0.433	0.269	Switzerland's submission, 2006
121	Switzerland	-	Special crop (Swiss soil monitoring network site)	Agricultural soils	0.176	0.709	0.362	0.291	Switzerland's submission, 2006
122	Switzerland	-	Special crop	Agricultural soils	0.046	8115	0.388	0.277	Switzerland's submission, 2006
123	Switzerland	-	Town park (Swiss soil monitoring network site)	Topsoils - specified	0.19	0.496	0.345	0.347	Switzerland's submission, 2006
124	Switzerland	-	Town park	Topsoils - specified	0.06	19700	0.486	0.35	Switzerland's submission, 2006
125	Switzerland	-	Protected area (Swiss soil monitoring network site)	Topsoils - unspecified	0.218	0.768	0.389	0.304	Switzerland's submission, 2006
126	Switzerland	-	Protected area	Topsoils - unspecified	0.091	1976	0.415	0.35	Switzerland's submission, 2006
127	Switzerland	-	Decidious forest (Swiss soil monitoring network site)	Topsoils - specified	0.055	1066	0.358	0.282	Switzerland's submission, 2006
128	Switzerland	-	Decidious forest	Topsoils - specified	0.03	19400	0.553	0.267	Switzerland's submission, 2006
129	Switzerland	-	Coniferous forest (Swiss soil monitoring network site)	Topsoils - specified	0.053	1273	0.257	0.147	Switzerland's submission, 2006
130	Switzerland	-	Coniferous forest	Topsoils - specified	0.039	2800	0.237	0.168	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	-	-	≤0.12	-	Russian Federation's submission, 2006
132	Russian Federation	-	Background lead content near big industrial cities	Topsoils - specified	-	-	4.0-16	-	Russian Federation's submission, 2006
133	Russian Federation	-	Highly contaminated soils in the city territories	Topsoils - specified	-	-	2.0-35	-	Russian Federation's submission, 2006
134	Russian Federation	-	Soils of agricultural lands	Agricultural soils	-	-	0.45	-	Russian Federation's submission, 2006
135	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		-	-	21.294	16.000-	Lopez-Arias and Graucorbi, 2004

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Cd/kg				Reference [8]
					min	max	mean	median	
			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).						
136	Spain	Topsoils	535 samples belong to the 'grassland' category.	Grassland topsoil	-	-	25.806	21.000	Lopez-Arias and Graucorbi, 2004
137	Spain	Topsoils	2,397 samples belong to the 'arable land' category.	Arable land topsoil	-	-	20.287	16.000	Lopez-Arias and Graucorbi, 2004
	Switzerland		Grassland extensive (Swiss soil monitoring network site)	Grassland	0.081	2.028	0.408	0.217	Switzerland's submission 2007
	Switzerland		Grassland extensive (Swiss soil monitoring network site)	Grassland	0.195	0.577	0.326	0.294	Switzerland's submission 2007
	Switzerland		Grassland (all types)	Grassland	0.010	32.400	0.503	0.320	Switzerland's submission 2007
	Switzerland		Agriculture (Swiss soil monitoring network site)	Agriculture	0.100	0.971	0.271	0.236	Switzerland's submission 2007
	Switzerland		Agricultre	Agriculture	0.005	23.000	0.433	0.269	Switzerland's submission 2007
	Switzerland		Special crop (Swiss soil monitoring network site)		0.176	0.709	0.362	0.291	Switzerland's submission 2007
	Switzerland		Special corp		0.046	8.115	0.388	0.277	Switzerland's submission 2007
	Switzerland		Town park (Swiss soil monitoring network site)		0.190	0.496	0.345	0.347	Switzerland's submission 2007
	Switzerland		Town park		0.060	19.7	0.486	0.350	Switzerland's submission 2007
	Switzerland		Protected area (Swiss soil monitoring network site)		0.218	0.768	0.389	0.304	Switzerland's submission 2007
	Switzerland		Protected area		0.091	1.976	0.415	0.350	Switzerland's submission 2007
	Switzerland		Deciduous forest (Swiss soil monitoring network site)		0.055	1.066	0.358	0.282	Switzerland's submission 2007
	Switzerland		Deciduous forest		0.030	19.400	0.553	0.267	Switzerland's submission 2007

ID	Country	Soil type	Description (from reference)	In this study categorised as	mg Cd/kg				Reference [8]
					min	max	mean	median	
	Switzerland		Coniferous forest (Swiss soil monitoring network site)		0.053	1.273	0.257	0.147	Switzerland's submission 2007
	Switzerland		Coniferous forest		0.039	2.800	0.237	0.168	Switzerland's submission 2007