

Nordic Council of Ministers

Cadmium Review

January 2003



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COUNCIL OF MINISTERS

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1 Introduction

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

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

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

This report has been prepared by COWI A/S on behalf of the Nordic Council of Ministers.

2 Summary

Cadmium is a heavy metal with a high toxicity. Cadmium is toxic at very low exposure levels and has acute and chronic effects on health and environment. Cadmium is not degradable in nature and will thus, once released to the environment, stay in circulation. New releases add to the already existing deposits of cadmium in the environment. Cadmium and cadmium compounds are, compared to other heavy metals, relatively water soluble. They are therefore also more mobile in e.g. soil, generally more bioavailable and tend to bioaccumulate.

Chronic cadmium exposure produces a wide variety of acute and chronic effects in humans. Cadmium accumulates in the human body and especially in the kidneys. According to the current knowledge kidney damage (renal tubular damage) is probably the critical health effect. Other effects of cadmium exposure are disturbances of calcium metabolism, hypercalciuria and formation of stones in the kidney. High exposure can lead to lung cancer and prostate cancer.

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

- Atmospheric deposition seems continuously to cause the content of cadmium in agricultural top soil to increase, which by time will be reflected in an increased human intake by foodstuffs and therefore in an increased human risk of kidney damages and other effects related to cadmium.
- In the marine environment levels of cadmium may significantly exceed background levels causing a potential for serious effects on marine animals and in particular birds and mammals.
- Significant quantities of cadmium are continuously stockpiled in landfills and other deposits and represent a significant potential for future releases to the environment.

The dominant sources of atmospheric emission will vary depending on the region or country considered. Non-ferrous metal production as well as combustion of coal and oil and waste incineration should be considered important sources. Important sources of cadmium input to the marine environment include atmospheric deposition, domestic waste water and industrial discharges.

Emissions to air as well as water on an international scale seem to be lowering due to improved flue gas and waste water treatment.

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

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

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

The current low world market price of cadmium motivates the development of new applications that by time may develop into new sources of emissions to the environment not covered by existing regulation.

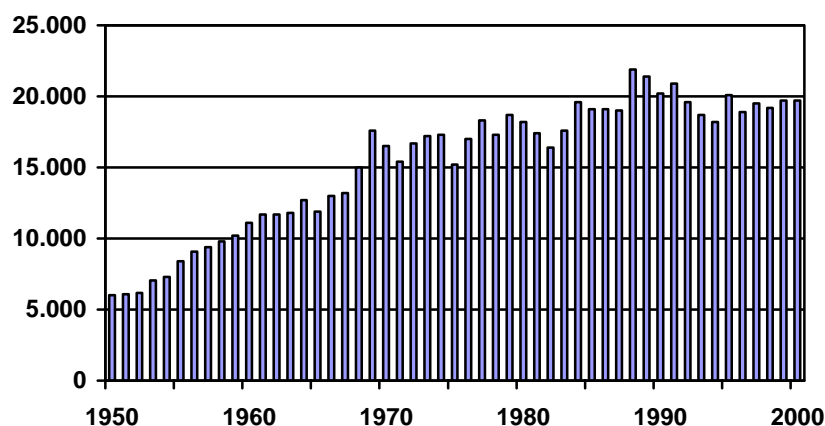
3 General Description

3.1 Global Production

Cadmium is produced mainly as a by-product from mining, smelting, and refining sulphide ores of zinc, 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 per cent with an average of 0.23 per cent. Small amounts of cadmium, about 10-15% of consumption, are produced from secondary sources, mainly from dust generated by recycling of iron and steel scrap. /OECD 1994/

The global cadmium production increased with a factor of four from 1950 to 1990 (Figure 3.1). In the recent decade the production has slightly decreased.

Figure 3.1 Global cadmium refinery production 1950-2000 /USGS 2002b/



Mine production and reserves by country is shown in table 3.1. The reserves are estimated at 600,000 tonnes resembling 30 years production at today level.

Estimated world resources of cadmium were about 6 million tons based on zinc resources containing about 0.3% cadmium /USGS 2002a/. Zinc-bearing coals also contain large sub-economic resources of cadmium.

Table 3.1 Mine production and reserves by country, 2000/2001 /USGS 2002a/

Country	Mine production 2000 Tonnes	Reserves 1) 2001 Tonnes
Japan	2,472	10,000
China	2,200	13,000
United States	1,890	90,000
Belgium	1,400	-
Canada	1,390	55,000
Mexico	1,350	35,000
Kazakhstan	1,060	25,000
Germany	1,000	6,000
Russia	925	16,000
Australia	552	110,000
Other countries	5,460	240,000
World (rounded)	19,700	600,000

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

The restrictions on the use of cadmium have caused the world market price of cadmium to fall steeply since 1990 (see table 3.2).

Table 3.2 World market prices of cadmium /HELCOM 2002/

Year	1985	1990	1993	1998
\$/pound	1.21	3.38	0.45	0.28

3.2 End Uses

The general trend in the 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. Batteries accounted in 1990 for 55% of the total Western World consumption and for about 73% of the estimated EU consumption in 2000 (table 3.3). Although the use of cadmium for pigments, PVC stabilisers and plating in some countries by and large has been phased out, these applications at the EU level still account for a significant part of the total cadmium consumption in 2000.

Table 3.3 *Cadmium consumption by end-uses in Western World 1990 (derived from /OECD 1993/) and the EU about 2000 (derived from /Scoullas et al 2001/)*

Application	Western World 1990 ¹⁾		EU about 2000 ²⁾	
	tonnes Cd/year	%	tonnes Cd/year	%
Ni-Cd batteries	9,100	55	1,900	73
Pigments	3,300	20	300-350	12
Stabilisers	1,650	10	150	6
Plating	1,320	8	200	8
Alloys	500	3	30-40	1
Other	660	4	-	-
Total	16,500	100	1,930-1,990	100

- 1) The figures in tonnes are calculated from the distribution represented in percentages in the reference.
- 2) The figures for consumption are derived from a diagram showing the Cd flows in EU. The flow diagram is indicated as a preliminary draft. The report text states that Ni-Cd batteries account for 78% of the total consumption of end products. The consumption is here calculated from the flow diagrams indication of consumption, import and export of cadmium with batteries.

The immediate future of the cadmium industry rests largely with the NiCd battery market, which is the only market that continues to grow, especially for certain uses, such as in power tools and telecommunication devices /USGS 2002c/. Following declines in recent years, coating and pigment markets for cadmium have stabilized. The stabilizer and alloy markets are expected to diminish and eventually close due to substitution by cadmium-free products. However, several new applications of cadmium batteries such as in electric and hybrid electric vehicles, remote area power storage systems, and solar cells could become significant cadmium markets. The present very low world market price of cadmium (see table 3.2) could well encourage development of new fields of application.

4 Environmental Exposure and Effects

4.1 Sources and Emissions

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

Natural sources

The major natural sources for mobilisations of cadmium from the earth's crust are volcanoes and weathering of rocks. The atmospheric emission from volcanoes in 1983 is estimated at 140-1,500 tonnes /Nriagu 1989/. The weathering of rocks releases cadmium to soils and aquatic systems. This process plays a significant role in the global cadmium cycle, but only rarely results in elevated concentrations in any environmental compartment.

Within the biosphere the cadmium is translocated by different processes. The major sources for emission to air from natural sources are volcanoes, airborne soil particles, sea spray, biogenic material and forest fires. Total emission to air from natural sources is estimated at about 150-2,600 tonnes; these figures may be compared to an estimated total global anthropogenic air emission in 1995 of approximately 3,000 tonnes (see table 4.1).

Anthropogenic sources

As mentioned in the previous chapter 19,700 tonnes of cadmium was in 2000 extracted from the earth's crust by man and brought into circulation in the technosphere. Beside this a significant amount of cadmium ended up in metal extraction residues or was mobilised as impurity by extraction of other minerals like coal and lime.

The most comprehensive assessment of the global anthropogenic cadmium emission dates back to 1983. From 1983 to mid 1990's the total emission of cadmium to air decreased from about 7,600 tonnes (medium estimates of /Nriagu & Pacyna 1988/) to 3,000 tonnes (table 4.1). According to the assessment, by far the major source of cadmium emission to the air is non-ferrous metal production.

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).

In countries with extensive waste incineration the pattern may be significantly different. In Denmark, waste incineration accounts for 50% of the total air emission and combustion of oil products accounts for 35% of the total /Drivsholm et al 2000/. However, the picture of other countries may be quite different. In the US, combustion of coal and oil is assumed to be responsible for around 76% of the total emission of cadmium to air, whereas waste incineration counts for around 7% of the total emission /OECD 1994/.

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

Economic sector	Air emission (tonnes)	%
Stationary fossil fuel combustion	691	23
Non-ferrous metal production	2,171	73
Iron and steel production	64	2.0
Cement production	17	0.6
Waste disposal (incineration)	40	1.3
Total	2,983	
Total, 1983 emission	7,570	

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

Natural versus anthropogenic sources - long range transport

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

The global significance of anthropogenic versus natural emissions can be seen in the ice core records from the Greenland Ice Sheet. Cadmium deposition in the 1960s and 1970s was eight times higher than in pre-industrial times /AMAP 2002/.

Release of cadmium to waste and soil

The only comprehensive assessment of global cadmium releases to soil and landfills dates back to 1983 (see table 4.2). As stated the total direct contribution to the land environment come up to 2,500-15,500 tonnes per year with atmospheric deposition as the dominating source, whereas an extra 7,500-29,500 tonnes per year are assumed directed to landfills and various deposits in form of discarded products and production waste. A more recent estimate addressing sources of cadmium to waste disposal in Europe is presented in table 4.3.

Considering cadmium in waste inclusive of residues of waste treatment processes a basic question is when and to what extent this cadmium will be mobilised and further released to the environment. Although the mobility of cadmium inside landfills is low, and a complete wash-out of cadmium may require hundreds to thousands of years and in some cases even more, no evidence exist that landfills can be regarded as a permanent containment of cadmium.

Cadmium balances for farmland in Denmark, the Netherlands and Sweden shows accumulation of cadmium in top soil. Yearly accumulation rate has been

calculated as 0.3% for Denmark and 0.6-0.7% for the Netherlands. In all cases the dominant sources are atmospheric deposition and commercial phosphate fertilizers. /OECD 1994/.

The picture that cadmium is accumulating in top agricultural soils is supported by risks assessments related to cadmium in phosphate fertilisers undertaken by several European countries. In Austria, Denmark, Greece, Ireland, and UK the present content of cadmium in fertilisers is causing the content of cadmium in top soil to increase. The increase in these countries over 100 years is estimated to 4 - 43%. For Finland and Sweden using fertilisers with a very low cadmium content ($<7 \text{ mg Cd/kg P}_2\text{O}_5$) the picture is different, as the change over 100 years is estimated to minus 75% to plus 11%. The data from Belgium also differs, as Belgium using fertilisers with a medium cadmium content ($\sim 33 \text{ mg Cd/kg P}_2\text{O}_5$) estimates a change over 60 years of minus 75% to 120%. /Hutton & de Meeus 2001/.

Table 4.2 *Global cadmium releases to land in 1983 (derived from /Nriagu & Pacyna 1988/)*

Source category	1000 tonnes	% of discharge to land
Agricultural and food wastes	0-3	6
Animal wastes, manure	0.2-1.2	3
Logging and other wood wastes	0-2.2	4
Urban refuse	0.88-7.5	15
Municipal sewage sludge	0.02-0.34	0.7
Miscellaneous organic wastes including excreta	0-0.01	0.0
Solid wastes, metal manufacturing	0-0.08	0.1
Coal fly ash, bottom fly ash	1.5-13	26
Fertilizer	0.03-0.25	0.5
Peat (agricultural and fuel use)	0-0.11	0.2
Wastage of commercial products	0.78-1.6	4
Atmospheric fall-out	2.2-8.4	19
Total to soil	5,6-38	
Mine tailings	2.7-4.1	12
Smelter slags and wastes	1.6-3.3	9
Total discharge on land	10-45	

Table 4.3 Sources of cadmium to waste disposal in the EU about 2000¹⁾ (derived from /Scoullou et al 2001/)

	Tonnes/year *2	% 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	

- 1) The table text in the report designate the geographic area "Europe", but the figures refers according to the report text only to the EU.
- 1) 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.

Releases to water environments

The total direct releases to water inclusive atmospheric deposition in 1983 was estimated at 2,100-17,000 tonnes /Nriagu & Pacyna 1988/. Of these atmospheric deposition accounted for 900-3,600 tonnes. Other major sources were domestic wastewater, non-ferrous metal smelting and refining, and manufacturing of chemicals and metals.

Cadmium levels of up to 5 mg/kg have been reported in sediments from river and lakes, and from 0.03 - 1 mg/kg in marine sediments. The average cadmium content of seawater is about 5-20 ng/l in open seas, while concentrations of 80 - 250 ng/l has been reported in French and Norwegian coastal zones. Concentrations measured in European rivers roughly varies from 10 to 100 ng/l. /OSPAR 2002/.

4.2 Environmental Effects

Cadmium and cadmium compounds are, compared to other heavy metals, relatively water soluble. They are therefore also more mobile in e.g. soil, generally more bioavailable and tend to bioaccumulate.

Cadmium is readily accumulated by many organisms, particularly by microorganisms and molluscs where the bioconcentration factors are in the order of thousands. Soil invertebrates also concentrate cadmium markedly. Most organisms show low to moderate concentration factors of less than 100.

In animals, cadmium concentrates in the internal organs rather than in muscle or fat. It is typically higher in kidney than in liver, and higher in liver than in muscle. Cadmium levels usually increase with age.

Cadmium is not essential for plant or animal life.

The following information has largely been extracted from the IPCS monographs /WHO 1992a; WHO 1992b/ unless otherwise indicated.

Birds and mammals

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.

Seabirds in general are known to accumulate high levels of cadmium. Kidney damages have been reported in wild colonies of pelagic sea birds having cadmium level of 60-480 µg/g in the kidney /WHO 1992b/. Seabirds and marine mammals in Greenland have high levels of cadmium, but researchers have found no evidence of effects in a study of selected ringed seal specimens with very high cadmium levels in their kidneys. /AMAP 2002/

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.

Microorganisms

Cadmium is toxic to a wide range of microorganisms as demonstrated by laboratory experiments. However, the presence of sediment, high concentrations of dissolved salts or organic matter in the test vessels all reduces the toxic impact. The main effect is on growth and replication. The most affected soil microorganisms are fungi, some species being eliminated after exposure to cadmium in soil. There is selection for resistant strains of microorganisms after low exposure to the metal in soil.

Other aquatic organisms

In aquatic systems, cadmium is most readily absorbed by organisms directly from the water in its free ionic form Cd (II) /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 of animals. In fish it causes lack of calcium (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/. 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.

In studies of lake trout exposed to different levels of cadmium, researchers found that cadmium affected foraging behavior, resulting in lower success at catching prey. Decreased thyroid function as a result of cadmium exposure has also been documented. Both responses indicate a low response threshold for cadmium caused behavioural changes. /AMAP 2002/

Other terrestrial organisms

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/. Terrestrial invertebrates are relatively insensitive to the toxic effects of cadmium, probably due to effective sequestration mechanisms in specific organs. Terrestrial snails are affected sublethally by cadmium; the main effect is on food consumption and dormancy, but only at very high dose levels. Cadmium even at high dosage does not lethally affect birds, although kidney damage occurs. Cadmium has been reported in field studies to be responsible for changes in species composition in populations of microorganisms and some aquatic invertebrates. Leaf litter decomposition is greatly reduced by heavy metal pollution, and cadmium has been identified as the most potent causative agent for this effect.

5 Human Exposure and Health Effects

5.1 Human Exposure

The major route of exposure to cadmium for the non-smoking general population is via food; the contribution from other pathways to total uptake is small. Tobacco is an important source of cadmium uptake in smokers, as tobacco plants like other plants accumulate cadmium from the soil.

Data from experimental animals and humans have shown that absorption via lungs is higher than gastrointestinal absorption (via the stomach). Up to 50% of the inhaled cadmium may be absorbed. The gastrointestinal absorption of cadmium is influenced by the type of diet and nutritional status. On average, 5% of the total oral intake of cadmium is absorbed. /WHO 1992a/.

A major part of cadmium in the human diet comes from agricultural products. The pathway of human exposure from agricultural crops is susceptible to increases in soil cadmium as increase in soil cadmium contents result in an increase in the uptake of cadmium by plants. The most important sources of cadmium to agricultural soils are atmospheric deposition and direct inputs through, for example, the application of phosphate fertilizers and other soil amendment products. Some of the regulative focal points in many countries have been decreasing the cadmium content of fertilisers and restriction on the input of cadmium to farmland by application of sewage sludge and other waste products.

Average daily intakes from food in most areas not polluted with cadmium are 10-40 µg /WHO 1992a/. In polluted areas the value has been found to be several hundred µg per day. In non-polluted areas, uptake from heavy smoking may equal cadmium intake from food. The World Health Organisation (WHO) has established a provisional tolerable weekly intake of 7 µg/kg body weight. This PTWI value corresponds to a daily tolerable intake level of 70 µg of cadmium for the average 70-kg man and 60 µg of cadmium per day for the average 60-kg woman. The PTWI value may be considered in the light of the fact, that in certain areas where the estimated cadmium intake has been 140-260 µg/day, effects in the form of increased low molecular weight proteinuria have been seen in some individuals following long-term exposure /WHO 1992a/.

It should thus be recognised, that the margin between the actual intake of cadmium by the general population and the PTWI as well as cadmium intakes causing effects is small, frequently less than 10-fold, and may be even smaller for smokers.

A result of the decreasing air emissions of cadmium may be decreasing atmospheric deposition, which lead to reduced intake of cadmium by food. The Danish National Food Agency found that the cadmium content of food was reasonably constant between 1980 and 1990. In Belgium and the Netherlands, the cadmium content of foodstuff actually decreased during the 1980s. /OECD 1994/. It should, however, be recognised that decreasing air emissions does not

necessarily lead to a decrease in total plant cadmium in the longer term perspective because of continuing accumulation of cadmium in top soil that over time will cause plant uptake from soil to increase.

A drinking-water guideline value for cadmium of 0.003 mg/litre is established based on an allocation of 10% of the PTWI to drinking-water /WHO 1993/.

5.2 Health Effects

Cadmium accumulates in the human body and especially in the kidneys. According to the current knowledge kidney damage (renal tubular damage) is probably the critical health effect, both in the general population and in occupational exposed workers /Järup *et al* 1998/. The accumulation of cadmium in the kidney (in the renal cortex) leads to dysfunction of the kidney with impaired reabsorption of, for instance, proteins, glucose, and amino acids. It is estimated that 1% of all smoking women in Sweden with low body iron stores may today experience adverse kidney effects due to the cadmium load /Järup *et al* 1998/.

Both human and animal studies indicate that skeletal damage (osteoporosis) may be a critical effect of cadmium exposure, but the significance of the effect in the Swedish population is according to /Järup *et al* 1998/ still unclear.

Lung changes primarily characterised by chronic obstructive airway disease may follow high occupational exposure (WHO 1992a). Early minor changes in ventilatory function tests may progress, with continued cadmium exposure, to respiratory insufficiency. An increased mortality rate from obstructive lung disease has been seen in workers with high exposure in the past.

Other effects of cadmium exposure are disturbances in calcium metabolism, hypercalciuria and formation of stones in the kidney.

The International Agency for Research on Cancer (IARC) classifies cadmium in Class 1 '*The agent (mixture) is carcinogenic to humans. The exposure circumstance entails exposures that are carcinogenic to humans.*' /IARC 1993/.

Occupational exposure is linked to lung cancer and prostate cancer. According to a recent review, the epidemiological data linking cadmium and lung cancer are much stronger than for prostate cancer, whereas links between cadmium and cancer in liver, kidney and stomach is considered equivocal /Waalkes 2000/.

6 International Regulation

6.1 International Conventions and Treaties

A number of international agreements have been established already in order to manage and control releases of cadmium to the environment and limit human and environmental exposure to cadmium. The relevant agreements is presented in table 6.1. It is noted that under the Rotterdam Convention a procedure for Prior Informed Consent to control import of unwanted chemicals that has been banned or severely restricted in the exporting country has been established. However, neither cadmium nor any cadmium compounds has so far been included in the procedure.

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

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

6.2 Legislation

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

Table 6.2 Legislation addressing cadmium or cadmium compounds in products /HELCOM 2002; OECD 1994/

Country/countries	Legislation
European Union*	<p>Ban of certain uses of cadmium and cadmium compounds as stabilisers in plastics, colorants in plastics and paint etc. Also ban on certain uses of cadmium-plating and on the use of cadmium in cosmetics.</p> <p>Restrictions on the content of cadmium in packaging materials. Batteries and accumulators containing more than 0.025% cadmium by weight must be labelled aimed at separation followed by recycling or special disposal.</p> <p>Limits on the release of cadmium from toys and ceramic articles intended to be in contact with foodstuffs.</p> <p>A general ban on the use of cadmium in new electrical and electronic equipment is planned to take effect as of July 1, 2006 /EU 2000a/. A ban on cadmium in vehicles except for certain applications is going to take effect as of July 1, 2003. /EU 2000b/.</p>
Estonia*	Ban on import/use of batteries and accumulators containing more than 0.025% cadmium by weight.
Denmark, Sweden*	Tax on batteries and accumulators containing more than 0.025% cadmium by weight.
Austria, Belgium, Denmark, Finland, Germany, Portugal, Norway and Sweden*	Limit on the content of cadmium in fertilizers.
Japan, Switzerland	Limit on the content of cadmium in fertilizers.
Canada	Limits on the release of cadmium from toys, ceramics and equipment
Australia	Limits on the release of cadmium from toys
USA	Legal arrangements on labelling and recycling of NiCd-batteries exist in several states. Cadmium is not allowed in pesticides //
Norway	Restrictions on use of cadmium in pigments, stabilizer and surface treatment. Limits on the content of cadmium in packaging and batteries.

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

Table 5.3 Legislation addressing control of cadmium emission to air, water and soil environments /HELCOM 2002; OECD 1994/

Country/countries	Legislation
European Union*	Limits on emission to air from industrial processes and waste incineration. Limits on emission to water from certain industrial processes. Limit on content of cadmium in sludge to be used in agricultural land and for soil exposed to sludge.
Austria, Belgium, Luxembourg, Denmark, Finland, Germany, the Netherlands, Portugal, Sweden, Norway and UK*	Limits for Cd input to agricultural soil and/or content of Cd in soil below EU-limits.
Australia	Limit on emission to water and air (may differ between states of Australia).
Canada	Limit on emission to water from hazardous waste treatment and metal finishing. Limit on content of cadmium in sludge to be used in agricultural land
Japan	Limit on emission to water (mining and other drainage). Limit on emission to air.
Canada	Limit of input with sludge to agricultural land
USA	Limits for emission to air and water and input with sludge to agricultural land
Canada, Germany, the Netherlands, UK	Remediation criteria for soil concentration at contaminated sites
Norway	Limits on emission to air from industrial processes and waste incineration. Limits on emission to water from certain industrial processes.

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

6.3 Other Regulations

Many countries have legal standards for maximum concentration of cadmium in drinking water and quality standards for fresh water and marine waters etc. and have established cadmium threshold limits for air exposure in the working environment. Denmark has furthermore banned the use of cadmium solders for occupational health reasons /Nørgård 2003/.

Cadmium has been identified as a priority hazardous substance under the EC Water Framework directive and EC-regulation setting maximum levels of cadmium in foodstuffs has been established.

The OSPAR Commission recommends that cadmium is replaced by less hazardous substances, as waste disposal is expected to be a major anthropogenic source of cadmium releases to the environment. It is considered that the most effective way of reducing the cadmium content of waste is to remove it from the goods which will, in due cause, become waste. The OSPAR Commission

therefore invites the EU Commission to strengthen the existing regulation of cadmium. /OSPAR 2002/.

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 2002/.

A European risk assessment of cadmium metal and cadmium oxide is in the process of preparation with Belgium being the reporting country /BEL 2002/.

7 Substitution

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

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

Table 7.1 Options for substitution of cadmium with initial indication of level of expenses relative to Cd-technology (derived from Hansen et al. 2002)

Application	Alternatives	Level of expenses 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	Ag-Cd alloys are used for solders and jewellery. In “Indian silver” have been observed up to 30% cadmium /Drivsholm et al 2000/. Many alternative solders exist inclusive e.g. Sn-Ag solders. Alloys for jewellery may be substituted by pure silver.	“+” – The present use of cadmium in Ag-Cd alloys partly reflects the current low world market price on cadmium.	Quality jewellery is generally not based on Ag-Cd alloys. However, sterling silver may contain up to 5% cadmium /Scoullous et al 2001/.
Copper-cadmium alloys, solders and other alloys	Alternatives depend on application: Cu-Cd alloys may be replaced by pure copper Zn-Cd alloys for anti-corrosion anodes may be replaced by aluminium anodes Pb-Cd alloys for cable sheaths may be replaced by using 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 is 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/.

Application	Alternatives	Level of expenses relative to cadmium technology ¹⁾	Extension of alternatives
Ni-Cd batteries	Nickel-metal hydride, lithium-ion-polymer etc.	"-/+"? Although alternatives are typically more expensive to produce, they have technical benefits. E.g. life of battery is longer, as alternatives are not suffering from the so-called memory effect ²⁾ .	Ni-Cd still dominates very power consuming applications like portable electrical tools. For other applications alternatives are slowly taking over the market (Drivsholm et al 2000).
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 (reference is made to table 5.1 regarding PVC-stabilisers for lead).	? – No data are available. For best estimate please refer to table 5.1 regarding PVC-stabilisers for lead.	In both Austria, the Netherlands, Sweden and Denmark cadmium stabilisers have been more or less completely eliminated completely from the market from the early 1990's /Pearse 1995; Koot 1996; Jensen & Marcussen 1993; Öberg & Granath 1997/.
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.	"-/++" 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/.
Photovoltaic cells	Cadmium is used in modern thinfilm cells based on CdTe, but not in traditional crystalline cells.	"=/"	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 for this reason is shortened significantly /Drivsholm et al 2000/.

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