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RISK REDUCTION MONOGRAPH NO. 5:

CADMIUM

BACKGROUND AND NATIONAL EXPERIENCE WITH REDUCING RISK

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Paris 1995

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OECD Environment Monograph Series No. 104

RISK REDUCTION MONOGRAPH NO. 5:

CADMIUM

Background and National Experience with Reducing Risk

Environment Directorate

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Also published in this series:

Risk Reduction Monograph No. 1: Lead

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RISK REDUCTION MONOGRAPHS

Risk Reduction Monograph No. 5: Cadmium – Background and National Experience with Reducing Risk is the fifth in a series of OECD documents concerned with risk reduction activities for specific chemicals or groups of chemicals. The Risk Reduction Monographs contain sections on: the commercial life cycle; the environmental life cycle, including sources of environmental releases, pathways, and estimations of exposure; risk reduction and control measures; and international and national positions on the perceived risk.

Risk Reduction Monographs are part of the Environment Monograph series, which makes selected technical reports prepared by the OECD Environment Directorate available to a wide readership. Copies are available at no charge, in limited quantities, from the OECD Environment Directorate, Environmental Health and Safety Division, 2 rue André-Pascal, 75775 Paris Cedex 16, France.

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FOREWORD

Background

In 1990, the Council of the OECD adopted a Decision-Recommendation on the Co-operative Investigation and Risk Reduction of Existing Chemicals [C(90) 163/Final]. This OECD Council Act is aimed at the reduction of risks from chemicals to the environment, and/or to the health of the general public or workers. It is based on the premise that international co-operation in risk reduction activities can enhance the technical and institutional aspects of risk management in Member countries through burden-sharing and a reduction of duplicative efforts. Furthermore, such activities can lead to a more effective use of the knowledge about risks that is being generated through, for example, national chemicals reviews and assessments; the OECD co-operative investigation of existing chemicals; and the work of other international organizations conducting hazard and risk evaluations, such as the United Nations' International Programme on Chemical Safety (IPCS).

International co-operation can provide a forum for the exchange of views on risk reduction strategies, thus increasing mutual understanding and facilitating the harmonization of programmes being undertaken at the national level. By means of this forum, technical barriers to trade can also be prevented.

The OECD's approach to risk reduction

The risk reduction process normally begins at the national level. However, the international character of the use and marketing of chemicals, and the mobility of certain chemicals in the environment, give risk reduction activities an international dimension.

The OECD's approach to risk reduction relies on the sharing and exchange of information on the management of specific chemicals. Readily available information concerning national risk reduction strategies can make comparative analyses possible. Where common interests emerge, the development and implementation of measured and consistent responses to unacceptable health and/or environmental risks can be facilitated.

In this context, risk reduction activities can take into account all stages of a chemical's commercial and environmental life cycles, beginning with the natural resources needed to produce it and extending through the chemical's uses to its eventual disposal. The chemical's health and environmental effects can be considered, together with exposure via all routes and media to different populations.

OECD work on cadmium risk reduction

OECD Member countries chose cadmium as one of the five chemicals (or groups of chemicals) to be included in the initial pilot project on co-operative risk reduction. France served as the lead country on this project, including initiation of information collection efforts in 1992. All drafts of the Risk Reduction Monograph, including this final version, were developed by either Kimmo Louekari or Hugo van Looy, consultants to the OECD.

The Joint Meeting of the Chemicals Group and the Management Committee of the Special Programme on the Control of Chemicals recommended that this document be derestricted. It is being made public under the authority of the Secretary-General.

EXECUTIVE SUMMARY

The main purposes of this document are:

- to provide a summary of information regarding the uses of cadmium, its environmental releases and fate in the environment, environmental and human exposures, and the way OECD Member countries perceive the risks associated with exposure to cadmium; and

- to describe the actions Member countries have taken, or contemplate taking, to reduce risks associated with exposure to cadmium.

The document brings together information provided by Member countries and industrial organizations from 1991 to 1994. It represents a snapshot of recent thinking in respect of the risks posed by cadmium, and ways considered and actions undertaken to reduce risk. It is intended to be merely a basis for further consideration of the feasibility of concerted international action, and it is not claimed to be an exhaustive study of the possibilities that exist for reducing the risk of cadmium. For instance, the use of alternatives to cadmium in products, and the use of alternative processes, are not developed as such in the document. Several Member countries have drawn attention to possibilities of substitution (see Chapter 5).

Chapter Summaries

1. Cadmium Production and Uses

Cadmium production in the western world in 1993 was about 15,000 tonnes. As it is a by-product of zinc, the production of cadmium is more dependent on zinc refining than on market demand. Over 10 per cent of current cadmium production is from secondary sources, including ferrous and non-ferrous metal refining dusts, recovery from electronic scrap and electroplating sludge, and recycling of nickel-cadmium (NiCd) batteries. Further growth in primary refined metal production and secondary production (recycling) is forecast until the year 2000.

Cadmium prices, following a boom in the mid to late 1980s, had fallen to an all-time low of 40-50 US cents per pound at the time this document was written. Consumption and commercial use of cadmium followed a growth trend from 0.4 per cent a year in 1983 to 4.2 per cent a year in the late 1980s and early 1990s, with the exception of 1990. Cadmium is used principally in rechargeable batteries, in pigments for colouring plastics, in heat/light stabilizers for polyvinylchloride, as a metallic coating, and in certain alloys or electronic compounds. Production of nickel-cadmium (NiCd) batteries for a wide range of applications currently accounts for about 60 per cent of consumption of the metal.

2. Sources of Environmental Contamination, and Fate and Occurrence of Cadmium in the Environment

Cadmium is widely distributed in the earth's crust. Weathering and erosion, and transport by rivers and air, result in fluxes in the global cadmium cycle. Surface and deep sea volcanic activity contribute to cadmium releases.

Cadmium is also released from anthropogenic activities. Account has to be taken of releases associated with the manufacture, use and disposal of cadmium products, as well as releases from industrial and agricultural activities involving materials which contain cadmium in trace quantities. The development of a quantitative inventory of cadmium emissions to the environment is difficult, and this is reflected in the limited amount of data on emissions in this document.

Worldwide, between 15,000 and 17,000 tonnes of cadmium per year is transformed into products belonging mainly to five categories: batteries, coatings, pigments, stabilizers and alloys. The use of these products does not result in direct releases of cadmium to the environment, nor in significant exposures of populations to cadmium. However, the manufacture and disposal of these products have potential for releasing cadmium to the environment.

The significance of releases during manufacture is dependent upon the process utilized and the emission control techniques applied. Releases from the processes may occur to both air and water. Manufacturing wastes such as process scraps, sludges and filter cakes may also be generated. These wastes are sent either for recycling or to disposal. Partitioning between environmental compartments varies considerably, depending on product types and the individual processes employed. For example, cadmium electroplating processes may result in aqueous emissions and generate wastes such as sludges and filter cakes, but produce negligible atmospheric emissions. Releases associated with the disposal of cadmium products will be dependent upon the form of product, the techniques employed for disposal, and the extent of recycling practised.

The most significant releases arise from the production of non-ferrous metals, iron and steel, the combustion of fossil fuel, the production and use of phosphate fertilizers, and the application of manure and sewage sludge to agricultural land. Cadmium is a natural component of the raw materials used in these processes. The relative importance of these sources varies among OECD countries, depending on the level of industrial or agricultural activity and pollution control.

Following its release to the environment, cadmium is distributed and transported within and between the environmental compartments. Emissions of cadmium to the atmosphere are an important transport pathway leading to its precipitation and deposition onto soil, vegetation and surface water.

Cadmium entering fresh water is rapidly adsorbed on particulate matter. Although sediment is the ultimate sink for cadmium, natural or man-induced changes in the physico-chemical conditions in water can result in remobilization of cadmium.

Cadmium is rather immobile in soil. Soil pH is the most important factor controlling the stability and solubility of cadmium in the soil environment. This factor and others are important considerations in determining the availability of cadmium for plant uptake, or its capacity for transfer to other environmental compartments.

Plant species differ widely in their ability to absorb, accumulate and tolerate cadmium. Leafy crops are capable of accumulating cadmium to relatively high levels. The cadmium concentrations in plants can arise from the uptake from soils or direct deposition on leaves. In general, cadmium concentrations are lower in seed, tuber and fruit tissues relative to leafy tissue.

3. Human Exposure

Food constitutes the main source of exposure for the general population, with the major contribution coming from plants. The cadmium content of food depends upon the food type, the major sources of dietary intake being leafy vegetables, grains and cereals. In the vast majority of countries, the average dietary intake of cadmium is below the provisional tolerable weekly intake (PTWI) established by FAO/WHO. Because of the lack of comparable data, it is difficult to draw any conclusion on trends over time in average dietary intake.

While intake from drinking water and inhalation of ambient air are not important routes of exposure for the general population, lung absorption through the inhalation of workplace air is the major route of exposure for workers.

Several factors may lead to above or below average human exposure or uptake, notably smoking (an important source of cadmium uptake), high food consumption and preference for particular foods, localized contamination, nutrient deficiencies, and low bioavailability of cadmium from certain foods.

4. International and National Positions on the Risks from Cadmium

This chapter contains international assessments of the risks to human health and the environment from cadmium. These assessments are taken directly from Chapters 1, 9 and 10 of each of the International Programme on Chemical Safety (IPCS) Environmental Health Criteria documents on cadmium (Nos. 134 and 135). The International Agency for Research on Cancer (IARC) evaluation of the carcinogenicity of cadmium and cadmium compounds is also provided, as well as the Forty-first Report of the Joint FAO/WHO Expert Committee on Food Additives (section on cadmium).

Also presented in this chapter are Member country statements in regard to national positions on risks from cadmium. These statements essentially present the rationale for any actions the country has taken or contemplates taking to address the effects associated with environmental or human exposure to cadmium. The risk assessments and risk characterizations that have led countries to take action have a national character. Countries develop positions on the need for risk reduction activities only after they have analysed the hazard and the significance of certain exposures and have factored in local social, economic and political considerations. These positions are usually arrived at after considerable debate on the numerous factors involved, and thus are not consistent across Member countries.

5. Mechanisms for Risk Reduction

Many Member countries have taken steps to reduce unacceptable human and ecosystem risks from exposure to cadmium. Requests for information on cadmium risk reduction activities were made to all Member countries. The submissions received contain discussions of steps taken in the past to reduce cadmium exposure, as well as current activities and future measures contemplated.

The measures taken to reduce exposure to cadmium vary from country to country. The general base line consists of mostly comparable environmental quality criteria, and permissible levels, to limit emissions to air, water, soil and food. Many countries control the input of cadmium to the environment from contaminated products, e.g. fertilizer, sludge and manure. Measures to reduce or ban the use of cadmium in products show considerable variability between countries. In many countries, regulations or voluntary programmes are aimed at the labelling, collection and recycling of NiCd batteries.

Some national risk reduction measures are shown in the tables in Annex A. Absence of information on a particular Member country does not mean that risk reduction activities have not taken place in that country.

EXPOSE DE SYNTHESE

Le présent document a pour principaux objectifs :

- de résumer les informations relatives aux utilisations du cadmium, à ses rejets et à son devenir dans l'environnement, à l'exposition qui s'ensuit pour l'environnement et pour l'être humain, ainsi qu'à la façon dont les pays Membres de l'OCDE perçoivent les risques associés à l'exposition au cadmium ; et

- de décrire les dispositions que les pays Membres ont prises ou envisagent de prendre afin de réduire les risques associés à l'exposition au cadmium.

Ce document s'inspire des informations fournies entre 1991 et 1994 par les pays Membres et les organismes professionnels, et doit être considéré comme un «instantané» des réflexions récentes sur les risques liés au cadmium et des activités poursuivies pendant cette période. Il ne prétend pas constituer une étude complète de toutes les possibilities qui permettent de réduire les risques du cadmium, mais plutôt fournir des éléments suffisants pour approfondir l'examen des possibilités d'action internationale concertée. Ainsi la substitution du cadmium dans les produits et procédés n'est past traitée en soi dans le document. Plusieurs pays Membres ont mis en relief les possibilités de substitution (voir Chapitre 5).

Résumé des différents chapitres

1. Production et utilisations du cadmium

La production de cadmium dans le monde occidental était d'environ 15 000 tonnes en 1993. Le cadmium étant un sous-produit du zinc, sa production dépend donc davantage de l'affinage de celui-ci que des besoins du marché. Plus de 10 pour cent du cadmium actuellement produit proviennent de sources secondaires, notamment poussières d'affinage des métaux ferreux et non ferreux, valorisation de déchets électroniques et de boues de galvanoplastie et recyclage de batteries nickel-cadmium (Ni Cd). D'après les prévisions, la production de métal primaire affiné et la production secondaire (recyclage) devraient continuer d'augmenter d'ici l'an 2000.

Après une forte hausse pendant la deuxième moitié des années 80, les prix du cadmium ont chuté jusqu'à leur plus bas niveau historique, soit 40 à 50 cents des Etats-Unis la livre (453,6 grammes) au moment de la rédaction du présent document. La consommation et l'utilisation commerciale du cadmium ont connu, sauf en 1990, une augmentation annuelle de plus en plus forte, de 0,4 pour cent en 1983 à 4,2 pour cent à la fin des années 80 et au début des années 90. Le cadmium est essentiellement utilisé dans les accumulateurs rechargeables, les pigments servant à la coloration des matières plastiques, les stabilisateurs du chlorure de polyvinyle vis-à-vis de la chaleur ou de la lumière, comme revêtement métallique et pour certains alliages ou composants électroniques. La production de batteries nickel-cadmium pour une large gamme d'applications représente actuellement environ 60 pour cent de la consommation du métal.

2. Sources de contamination de l'environnement, devenir et présence du cadmium dans l'environnement

Le cadmium est largement répandu dans la croûte terrestre. Les processus naturels d'altération et d'érosion et de transport par les fleuves et dans l'air se traduisent par des flux au sein du cycle général du cadmium. Le volcanisme en surface et au fond des océans contribue à libérer du cadmium.

Du cadmium est, en outre, émis au cours d'activités humaines. Il faut tenir compte, à cet égard, des rejets liés à la fabrication, à l'utilisation et à l'élimination de produits contenant du cadmium, et aussi des rejets dûs aux activités industrielles et agricoles mettant en jeu des matières qui contiennent du cadmium à l'état de traces. La mise au point d'un inventaire quantitatif des émissions de cadmium dans l'environnement comporte des difficultés qui expliquent le volume limité de données sur les émissions figurant dans le présent rapport.

Dans le monde entier, entre 15 000 et 17 000 tonnes de cadmium sont transformées chaque année en produits appartenant essentiellement à cinq catégories : batteries, revêtements, pigments, stabilisateurs et alliages. L'utilisation de ces produits n'entraîne pas de rejets directs de cadmium dans l'environnement ni une exposition importante des populations à ce métal. Cependant, la fabrication et l'élimination de tels produits sont susceptibles de libérer du cadmium dans l'environnement.

L'ampleur des rejets au cours de la fabrication de produits dépend du procédé appliqué et des techniques servant à contrôler les émissions. Les rejets au cours des procédés peuvent se faire aussi bien vers l'air que vers l'eau. Des déchets de fabrication tels que résidus de traitement, boues et gâteaux de filtration peuvent également être produits. Ces déchets sont envoyés soit au recyclage, soit à l'élimination. La répartition entre les différents milieux de l'environnement est extrêmement variable et dépend des catégories de produits et du procédé mis en oeuvre pour chacun. Par exemple, les procédés de galvanoplastie au cadmium peuvent entraîner des émissions dans l'eau et produire des déchets, comme des boues et des gâteaux de filtration, mais n'entraînent que des émissions atmosphériques négligeables. Les rejets associés à l'élimination de produits contenant du cadmium dépendront de la forme de ces produits, des techniques utilisées pour leur élimination et de l'ampleur du recyclage effectué.

Les rejets les plus importants se produisent lors de la production de métaux non ferreux, de la production de fer et d'acier, de la consommation de combustibles fossiles, de la production et de l'utilisation d'engrais phosphatés et de l'application de fumier et de boues d'épuration sur des terres agricoles. Le cadmium est un composant naturel des matières premières mises en oeuvre dans ces opérations. L'importance relative de ces sources varie d'un pays de l'OCDE à l'autre, suivant l'ampleur de l'activité industrielle ou agricole et l'intensité de la lutte contre la pollution.

Après avoir été émis dans l'environnement, le cadmium se répartit entre les divers compartiments de l'environnement et est transporté de l'un à l'autre. Les émissions de cadmium dans l'atmosphère constituent une voie de transfert importante qui aboutit à des précipitations et à des dépôts de ce métal sur les sols, les végétaux et les eaux de surface.

Le cadmium pénétrant dans l'eau douce est rapidement adsorbé sur des particules. Si les sédiments constituent le piège ultime du cadmium, des modifications de l'état physico-chimique de l'eau, spontanées ou induites par l'homme, peuvent entraîner une remobilisation du cadmium.

Le cadmium est plutôt immobile dans le sol. Le pH du sol est le facteur le plus important dont dépendent la stabilité et la solubilité du cadmium dans le milieu pédologique. Ce facteur constitue l'un des éléments déterminants pour établir dans quelle mesure le cadmium est susceptible d'être absorbé par les végétaux ou transféré vers d'autres compartiments de l'environnement.

La capacité d'absorber, d'accumuler et de tolérer le cadmium varie considérablement d'une espèce végétale à l'autre. Les plantes cultivés pour leur feuilles sont capables d'accumuler du cadmium à des concentrations relativement élevées. Ces concentrations dans les végétaux peuvent résulter de l'absorption à partir du sol ou du dépôt direct sur les feuilles. En général, les concentrations du cadmium dans les tissus des graines, des tubercules et des fruits sont plus faibles que dans les tissus des feuilles.

3. Exposition humaine

L'alimentation constitue la principale source d'exposition pour la population en général, la majeure partie du cadmium venant des végétaux. La teneur en cadmium des denrées alimentaires dépend de la nature de ces denrées, les principales sources de l'absorption alimentaire étant les légumes-feuilles, les graines et les céréales. Dans la grande majorité des pays, la quantité moyenne de cadmium absorbée par l'alimentation est inférieure à la dose hebdomadaire tolérable provisoire (DHTP) établie par la FAO et l'OMS. Etant donné l'absence de données comparables, il est difficile de tirer une conclusion quelconque sur l'évolution dans le temps de ces quantités moyennes.

L'ingestion d'eau de boisson et l'inhalation de l'air ambiant ne représentent pas des voies importantes d'exposition pour l'ensemble de la population ; l'absorption par les poumons lors de l'inhalation d'air sur les lieux de travail constitue la principale voie d'exposition des travailleurs.

Plusieurs facteurs peuvent augmenter ou diminuer l'exposition de l'homme, ou les quantités moyennes absorbées, notamment le tabagisme (importante source d'absorption du cadmium), la consommation élevée de denrées alimentaires et la préférence pour des aliments précis, la contamination localisée, les carences en éléments nutritifs et la faible biodisponiblité du cadmium à partir de certaines denrées alimentaires.

4. Positions adoptées au niveau international et national quant aux risques imputables au cadmium

Ce chapitre continet des évaluations des risques liés au cadmium acceptées au plan international et établies par le Programme international sur la sécurité des substances chimiques (PISSC). Les évaluations réproduits ci-après sont celles qui figurent aux chapitres 1, 9 et 10 de chacun des deux Critères d'hygiène de l'environnement sur le cadmium (numéros 134 et 135) du PISSC. L'évaluation de la cancérogénicité du cadmium et de ses derives établie par le Centre international de recherche sur le cancer (CIRC) ainsi que la section sur le cadmium contenue dans le 41ème Rapport du Joint FAO/WHO Expert Committee ou Food Additives sont également reproduites.

On trouvera également dans ce chapitre des déclarations provenant de pays Membres relatifs à l'attitude adoptée par les divers pays vis-à-vis des risques liés au cadmium. Pour l'essentiel, ces déclarations donnent les raisons à la base de toute disposition prise par un pays donné pour faire face aux effets associés à l'exposition de l'environnement ou de l'être humain au cadmium.

Les évaluations et les descriptions nationales des risques qui ont conduit les pays à prendre des mesures ont un caractère profondément national. Les pays n'ont défini leur position sur la nécessité de lancer des activités de réduction des risques qu'après avoir analysé le danger que présentaient certaines expositions, ainsi que leur ampleur, et avoir pris en compte des considérations locales d'ordre social, économique et politique. Comme ces positions sont habituellement établies après un débat approfondi sur les nombreux facteurs impliqués, il ne faut par conséquent pas s'attendre à ce qu'elles soient homogènes entre les différents pays Membres.

5. Dispositifs pour la réduction des risques

De nombreux pays Membres ont pris des mesures pour réduire les risques inacceptables que l'exposition au cadmium fait courir à l'homme et aux écosystèmes. Tous les pays Membres ont été invités à fournir des informations sur les activités visant à la réduction des risques associés au cadmium. Les réponses reçues comportent l'examen des mesures prises auparavant pour réduire l'exposition au cadmium, ainsi que des activités en cours et des mesures envisagées à l'avenir.

Les mesures prises en vue de réduire l'exposition au cadmium varient d'un pays à l'autre. Le niveau de base général comporte des critères de qualité de l'environnement, comparables pour la plupart, et des concentrations admissibles, afin de limiter les émissions dans l'eau, dans l'air, dans le sol et dans les denrées alimentaires. De nombreux pays luttent contre les rejets de cadmium dans l'environnement à partir de produits contaminés, tels qu'engrais, boues et fumier. Les mesures visant à réduire ou à interdire l'utilisation de cadmium dans les produits s'avèrent extrêmement variables d'un pays à l'autre. Dans de nombreux pays, des réglementations ou des programmes volontaires ont pour objectif l'étiquetage, la collecte et le recyclage des batteries nickel-cadmium.

Une série de tableaux récapitulant quelques mesures nationales de réduction des risques figure en annexe à ce chapitre. L'absence d'informations pour un pays Membre donné ne signifie pas que ce pays ne consacre pas d'activités à la réduction des risques.

CHAPTER 1

CADMIUM PRODUCTION AND USES

Between 1981 and 1989, the production and consumption of refined cadmium metal in the western world showed a general increase (Yates 1992). Both production and consumption of cadmium metal decreased slightly in the early 1990s. In 1993, production was about 15,000 tonnes and consumption was about 16,500 tonnes. The difference probably reflects the use of cadmium from world stocks or from secondary production. Further growth of 3 per cent a year in refined metal production and consumption is forecast for 1992-1996 (Yates 1992).

1.1 Production

Cadmium is obtained as a by-product of zinc refining. Cadmium minerals do not occur in concentrations and quantities sufficient to justify mining them in their own right. Greenockite (CdS), the only cadmium mineral of importance, is found in association with zinc as a minor constituent of zinc concentrate, and in some lead or complex copper-lead-zinc ores, nearly always associated with zinc sulphide.

It is not possible to produce refined zinc metal without generating cadmium as a by-product (Yates 1992). 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. Since the average zinc content of these concentrates is 55 per cent, approximately 3 kg of cadmium will be produced for every tonne of refined zinc. Cadmium output is therefore much more dependent on zinc production than on demand for cadmium, and the best way to forecast cadmium supply is to apply an approximate cadmium/zinc ratio to the forecast of zinc production. If cadmium demand is reduced below supply, surplus material must be managed to avoid contamination of the environment. Cadmium producers are able to adjust output somewhat by selecting concentrates. The feed materials for primary cadmium production are mainly fume and dust, collected as flue dust in baghouses during the pyrometallurgical processing of zinc, and residues resulting from electrolytic zinc production (Ary 1992).

Production of refined cadmium in the western world[1] in 1993 was around 15,000 tonnes. The world pattern of refined cadmium metal production is detailed in **Table 1.1**. Japan is the largest producer, treating concentrates from South America, Asia and Australia as well as from its own mines. Production in countries with economies in transition was estimated to be around 4500 tonnes in 1990, but fell to 3000 tonnes more recently with more than half produced in countries that were formerly part of the Soviet Union. The evolution of cadmium production in the western world between 1980 and 1993 is shown in **Figure 1.1**.

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[1] "Western world" here does not include Central and Eastern European countries.

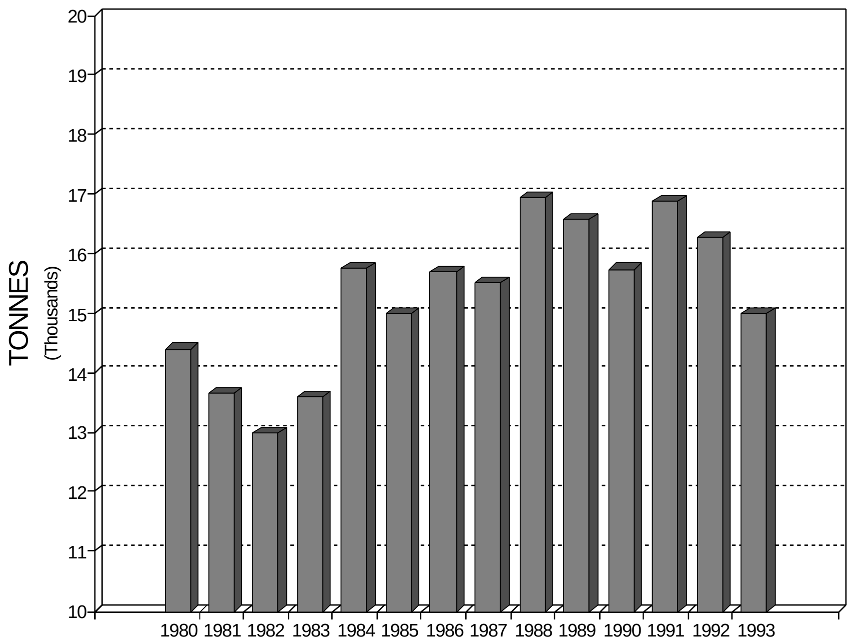
Table 1.1 Cadmium Production in 1990 and 1993

Country	1990	1993
Japan	2451	2808
Canada	1458	1945
Belgium	1958	1573
United States	1912	1139
Germany	973	1069
Australia	638	996
Finland	568	785
Mexico	1213	612
Italy	691	584
South Korea	568	568
Netherlands	590	526
United Kingdom	438	458
Yugoslavia	362	362
Spain	262	329
India	277	248
Peru	359	240
Norway	286	213
(Africa)	266	178
France	188	139
Brazil	135	135
Argentina	55	55
Turkey	46	21
Total	**15,736**	**14,981**

Figures in metric tonnes

Source: World Bureau of Metal Statistics

Figure 1.1 Cadmium Production in the Western World, 1980-1993



Source: World Bureau of Metal Statistics

1.2 Secondary production and recycling

Secondary cadmium production is in the range of 1500-2000 tonnes a year, approximately 10-15 per cent of total current production in the western world.

Cadmium is relatively easy to recycle. It can be separated from other materials in a comparatively uncomplicated fashion, with fairly low energy expenditure. Cadmium volatilizes at comparatively low temperatures, making it easy to separate from metals with higher melting points using high-temperature recovery processes. It is also active chemically and electrochemically, and thus can be readily removed using hydrometallurgical techniques.

The nature of the cadmium products which are recycled depends on the cadmium content of the waste material, the amounts and types of other metals in the cadmium-containing waste, and the geographic area. Nickel-cadmium (NiCd) batteries contain the highest consistent levels of cadmium in used products, generally 10-20 per cent by weight. Process wastes such as filter cakes, electroplating sludge, and baghouse dusts from lead and copper smelting operations are highly variable in cadmium content. However, this is usually between 5 and 50 per cent and they often contain a number of other non-ferrous metals. Electric arc furnace (EAF) dust, swarf and grindings are low cadmium content (<1 per cent) residues which are processed in high volumes and often also contain the other low melting elements lead and zinc.

In pyrometallurgical recycling processes, cadmium-containing wastes or used products are mechanically treated to expose cadmium, heated at a low temperature to drive off moisture and organic compounds, and then heated to above 800°C to volatilize the cadmium. The vapour is then condensed, either as cadmium oxide or metal, and collected for final processing into high purity material suitable for use in industry. In hydrometallurgical processes the cadmium-containing wastes are dissolved in a suitable reagent, usually a strong acid, and then subjected to a series of wet chemical reactions designed to successively remove impurities. The final cadmium product is normally a cadmium sulphate, chloride or nitrate solution from which high purity cadmium may be electrochemically obtained. Ion exchange techniques have been utilized in some hydrometallurgical recycling schemes, depending on the nature of other impurities present.

Both hydrometallurgical and pyrometallurgical recycling techniques are capable of efficiently removing cadmium from these various wastes or used products and producing high purity secondary materials. However, the technical and economic details will depend on the other metal impurities present, their concentration levels, and their current market prices. Thus the economics of NiCd battery recycling depend very much on current nickel and cadmium prices, while the economics of recycling electroplating sludges may depend more on the current prices of non-ferrous metals such as copper, zinc, nickel and other metals which are electroplated in substantial quantities. Low nickel and cadmium prices in some countries have discouraged NiCd battery recycling recently.

Cadmium recycling in general has developed furthest in the major industrialized countries, which have the most advanced NiCd battery and metal producing technologies. Japan, the United States, and several European countries have organized active NiCd battery collection programmes to facilitate the recycling of these batteries. Portable cells are more difficult to collect for recycling; however, manufacturers of NiCd-powered appliances are now designing them so that their batteries may be easily removed for recycling, while battery manufacturers are marking battery types for ease of identification. A recent evaluation of built-in NiCd batteries on the Belgian market found that 64 per cent were easily removable (those in camcorders, portable telephones, power tools, etc.) and 22 per cent were difficult for the consumer to remove for safety reasons (those in electric shavers, computers, etc.) (Lechenet and Van Assche 1992).

Because of the varied sources of cadmium wastes, and the varied lifetimes of cadmium products, it is very difficult to estimate the rates at which cadmium is currently being recycled. The most widely used methods generally attempt to establish the amount of cadmium available for recycling and then to determine how much of the amount available is actually recycled. Thus the amounts of cadmium consumed in the various types of NiCd batteries, for example, must be related to their lifetimes to establish a measure of the relative proportion recycled. Similar assumptions are necessary regarding the lifetimes of other cadmium products such as coatings, pigments, stabilizers and alloys, depending on the product in which they are used and the service to which they are subjected.

These difficulties notwithstanding, overall NiCd battery recycling rates in Japan and the United States have recently been estimated at 20 and 20-30 per cent respectively and are increasing. Recycling rates in Europe vary from country to country, depending on specific national programmes. Recycling of industrial NiCd batteries is believed to occur at a rate of approximately 80 per cent. However, because of their much smaller size and wider dispersion, portable NiCd batteries are recycled at a rate of 10 per cent. Both regulatory pressures in regard to used batteries, and the development of industry-led collection programmes, are giving added impetus to the recycling of portable NiCd batteries in Japan, Europe and the United States.

1.3 Cadmium prices

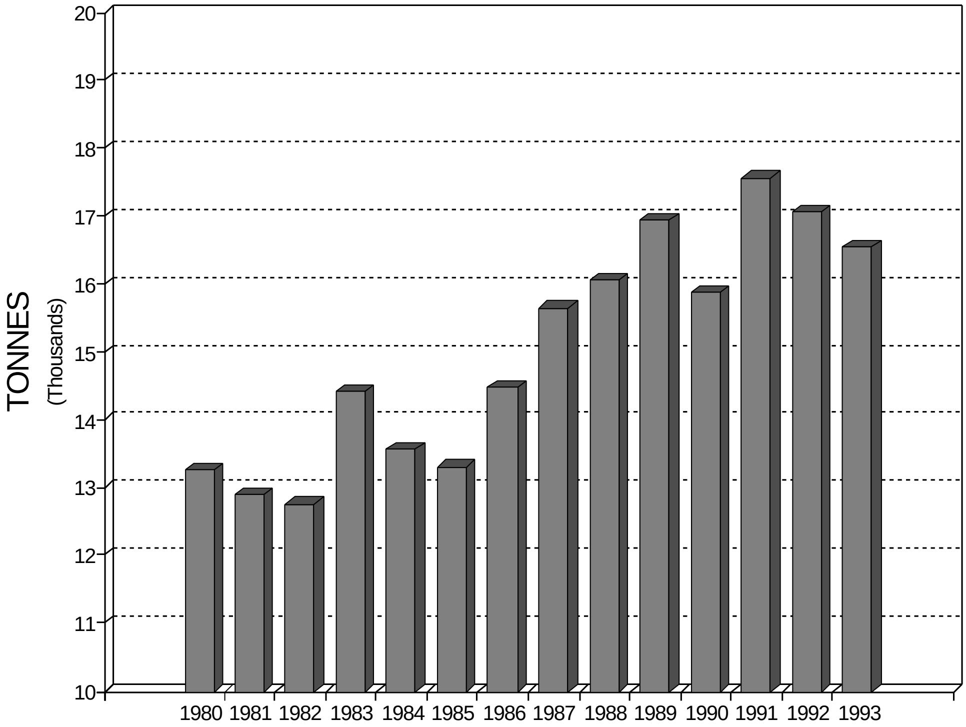
The price of cadmium on the world market showed an increasing trend until 1989. In 1979, the price of a pound of cadmium was approximately US$ 1.00; by 1988, it was almost eight times higher. The price increase has been attributed to tight supply, speculative trading, and high demand for nickel-cadmium batteries, particularly in Japan (Ary 1992). By 1992, in conjunction with the global recession and possibly other factors, prices had fallen, ranging from US$ 1.10 to 1.30. They reached an all-time low of 40 to 50 US cents in 1993. Market fluctuations and volatile prices have an important influence on recycling and secondary production.

1.4 Consumption and commercial uses

The evolution of total western world consumption of cadmium is shown in **Figure 1.2**. Current consumption of cadmium in the western world is around 16,500 tonnes a year. Japan is by far the greatest user of cadmium, followed by the United States, Belgium, the United Kingdom, France and Germany. Consumption in countries with economies in transition is estimated at around 3500 tonnes, two-thirds of which is consumed in the countries that were formerly part of the Soviet Union. Regional cadmium consumption patterns in 1984 and 1991 are shown in **Figure 1.3**.

Cadmium has five principal areas of application. Their significance in relation to total consumption of cadmium in the western world is shown in **Table 1.2**. Nickel-cadmium batteries are by far the most significant application (see Section 1.4.1). In the production of NiCd batteries worldwide, 3000 tonnes of cadmium was used in 1980 and 9000 tonnes in 1990. All other cadmium uses decreased from 10,000 tonnes in 1980 to 7500 tonnes in 1990, a 25 per cent decline. Small amounts of cadmium are used in a variety of miscellaneous applications including photoconductive and photovoltaic cells, nuclear engineering and other battery types.

Figure 1.2 Commercial Use or Consumption of Cadmium in the Western World, 1980-1993



Source: World Bureau of Metal Statistics

Figure 1.3 Regional Consumption of Cadmium

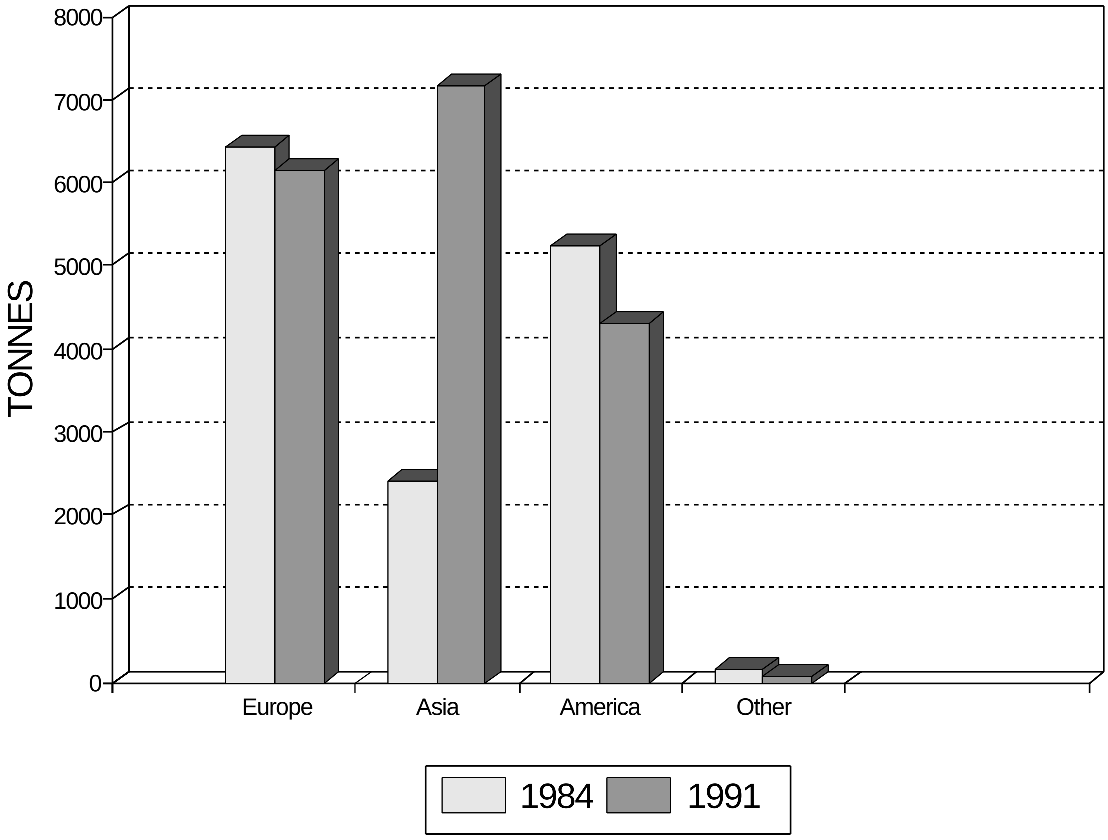


Table 1.2 Cadmium Consumption in the Western World by Application (1990)

Application	% total consumption
Nickel-cadmium batteries	55
Cadmium pigments	20
Cadmium-bearing stabilizers	10
Cadmium coatings	8
Cadmium-containing alloys	3
Miscellaneous uses	4

Source: Cadmium Association (estimate)

1.4.1 Nickel-cadmium batteries

Nickel-cadmium (NiCd) batteries are rechargeable or secondary power sources characterized by high energy and power output, long life, low maintenance, and a high tolerance to electrical and mechanical abuse. Approximately 75 per cent are used for portable applications such as power tools, cordless appliances, cellular telephones, and portable computers. The remaining 25 per cent are of the larger type and are used in industrial applications such as emergency lighting, railroad signalling and switching systems, and stand-by power, as well as in aerospace applications.

The use of cadmium in portable rechargeable batteries grew strongly during the "cordless revolution" from 1985-1990. Growth has continued in the 1990s, but is expected to be moderated by the adoption of new battery systems with higher energy capacities for certain applications such as portable computers and cellular telephones. Present growth rates for portable NiCd cells range from 5 to 10 per cent a year, while the growth rate for industrial NiCd cells is placed at 2-4 per cent a year.

NiCd battery technology has also been considered for powering electric vehicles. The evolution of the electric vehicle market could lead to the production of 90,000 such vehicles in the United States, 60,000 in France and 300,000 EU-wide by 1998. To date, the development of electric vehicle technology has principally been based on the lead-acid battery, mainly because of its relatively low cost. Increased production will lead to a significant decrease in the cost of the NiCd battery. Based solely on the difference in the cost of raw materials, however, NiCd batteries will still be approximately twice as expensive as lead-acid batteries. Lead-acid batteries will thus continue to play an important role in the electric vehicle market. Nonetheless, the NiCd share of this market is expected to increase steadily to 20 per cent in 1995 (Cornu 1992).

1.4.2 Pigments

A wide range of bright red, orange and yellow pigments for plastics, ceramics, glass, enamels and artist's colours are based on the insoluble compound cadmium sulphide (CdS). These pigments are utilized primarily because of their high heat resistance, long-term stability, chemical resistance and colour brightness. About 85 per cent of cadmium pigments are used in engineering plastics which require high temperature processing. At these temperatures, no other pigments will retain their bright red, orange or yellow colours. Ceramics, glass and enamels, which are also processed at high temperature, require cadmium pigments for a variety of colours including red, orange and yellow. In some applications of pigments, cadmium can be replaced by zinc and sulphur can be replaced by selenium.

1.4.3 Stabilizers for PVC

Organic cadmium compounds, generally laurates or stearates used in combination with barium sulphate, are utilized in either solid or liquid form to stabilize polyvinyl chloride (PVC) during processing and protect against long-term weathering or ultraviolet light degradation during service. Cadmium-based stabilizers are used in PVC applications such as pipes and gutters, window and door frames, cable shielding, roofing, swimming pool covers, and numerous other applications where long-term weathering and UV resistance is required to prolong the life of a product.

1.4.4 Coatings

Metallic cadmium and cadmium alloy coatings are utilized where a combination of excellent corrosion resistance, particularly in salt solutions, and either a low coefficient of friction, low electrical resistivity, or good brazing characteristics are required. Most applications are for aerospace or industrial fasteners, electrical parts, automotive systems, military equipment, or marine/offshore installations where a high degree of safety or reliability is required. While a number of zinc alloy coatings can produce corrosion resistance equivalent to that of cadmium, none has cadmium's low friction coefficient, electrical properties or brazability. Cadmium coatings today are generally utilized only in those applications which require a combination of corrosion resistance and these other properties.

In recent years, cadmium coatings have been increasingly recycled through the remelting of cadmium-coated scrap steel. The large amounts of electric arc furnace (EAF) dust which are now recycled rather than landfilled contain lead, zinc and cadmium. In the United States, recent estimates place the recycling rate of cadmium coatings at 35-50 per cent. This rate is expected to increase as recycling of EAF dust becomes more widespread.

1.4.5 Alloys

Cadmium is used as an alloying element in a wide variety of other non-ferrous metals to produce special properties. It is added to copper in small amounts to increase strength without reducing electrical conductivity. It is added to low melting point brazing and soldering alloys to reduce melting temperatures and improve surface tension characteristics. This enhances the flow and wetting properties of brazing alloys. Cadmium is used in some low melting point alloys in sprinkler systems, bimetallic alloys for temperature sensing and control, nuclear reactor control rods, and a number of other low-volume but highly specialized applications.

1.4.6 Electronic compounds

Several high-purity cadmium compounds, such as cadmium sulphide, cadmium selenide (CdSe) and cadmium telluride (CdTe), have unusual semiconducting, optical or electronic properties which make them useful for a wide variety of electronic applications. One of the most promising is cadmium telluride, used in photovoltaic devices to convert sunlight directly to electricity. Very thin coatings of CdTe can be applied through a wide variety of processes to produce systems with relatively good conversion efficiency and low cost compared with other systems. These compounds must be highly purified to be effective, are applied in very thin coatings, are relatively expensive, and can readily be recycled within non-ferrous metal processes (e.g. copper production) which require glass as a flux agent (Ullal 1992). Thus these uses, which may include electronic switches, gates and sensors, as well as photovoltaic conversion devices, are expected to consume only very small amounts of cadmium and to be largely recycled.

CHAPTER 2

SOURCES OF ENVIRONMENTAL CONTAMINATION, AND FATE AND OCCURRENCE OF CADMIUM IN THE ENVIRONMENT

2.1 Natural sources

Cadmium is widely distributed in the earth's crust at an average concentration of about 0.1-0.2 mg/kg and is commonly found in association with zinc. Higher levels are present in sedimentary rocks: marine phosphates often contain about 15 mg/kg (GESAMP 1984). Weathering and erosion result in the transport by rivers of large quantities of cadmium to oceans, which is a major flux of the global cadmium cycle.

Marine black shales and slates have frequently been found to contain anomalously high concentrations of cadmium (<240 mg/kg). Soils developed on these cadmium-rich black shales also have naturally elevated concentrations of over 22 mg/kg, as found in soils on both the Monterey shales in California and the carboniferous shales in the Pennine Hills in the United Kingdom (Alloway 1990).

In background areas away from ore bodies, surface soil concentrations of cadmium typically range between 0.1 and 0.4 mg/kg (Page et al. 1981). The median cadmium concentration in non-volcanic soil ranges from 0.1 to 1 mg/kg, but levels of up to 4.5 mg/kg have been found in volcanic soil (Korte 1983).

Volcanic activity is an important natural source of atmospheric cadmium release. The annual global flux from this source has been estimated to be 820 tonnes (Nriagu 1989). Deep sea volcanism is also a source of environmental cadmium release, but the role of this process in the global cadmium cycle remains to be quantified.

The average cadmium content of sea water is about 5-20 ng/litre in open seas, while concentrations measured in European rivers roughly varied from 20 to 100 ng/litre (Jensen and Bro-Rasmussen 1992). Cadmium levels of up to 5 mg/kg have been reported in river and lake sediments, and from 0.03 to 1 mg/kg in marine sediments (Korte 1983).

The vertical distribution of dissolved cadmium in ocean waters is characterized by surface depletion and deep water enrichment, which corresponds to the pattern of nutrient concentrations in these areas (Boyle et al. 1976). This distribution is considered to result from the absorption of cadmium by phytoplankton in surface waters and its transport to the depths, incorporation to biological debris, and subsequent release. In contrast, cadmium is enriched in the surface waters of areas of upwelling and this also leads to elevated levels in plankton unconnected with human activity (Martin and Broenkow 1975, Boyle et al. 1976). Oceanic sediments underlying these areas of high productivity can contain markedly elevated cadmium levels as a result of inputs associated with biological debris (Simpson 1981).

In remote, uninhabited areas cadmium concentrations in air are usually less than 1 ng/m^3 (Korte 1983). Recent levels in European rural areas vary from 0.1 to 0.5 ng/m^3 (Jensen and Bro-Rasmussen 1992).

2.2 Anthropogenic sources

To assess the importance of environmental contamination by cadmium from anthropogenic sources, account has to be taken of releases associated with the manufacture, use and disposal of cadmium products, as well as releases from industrial processes involving raw materials which contain cadmium in trace quantities. Frequently the products and by-products of these processes enter the environment in large volumes: for example, those from the refining of non-ferrous metals, the production of iron and steel, the combustion of fossil fuels, the production and use of phosphate fertilizer, the production of cement, the application of sewage sludge, the incineration of domestic waste, and the disposal of industrial and domestic wastes.

As a result of the complexity of the environmental life cycle and the great number and variability of the input data (e.g. regional differences in cadmium content of raw materials, differences in technology applied, etc.), the development of a quantitative inventory of cadmium emissions to the environment is an immense task.

Several studies containing estimations of cadmium emissions, whether on a global scale or addressing a geographical region, specific environmental compartment or sectorial industrial activity, have been published (ERL 1990, Nriagu 1979, 1989, Nriagu and Pacyna 1988). For estimating man-made emissions, emission factors are applied to levels of activity. In establishing emission factors, a number of simplifying assumptions are made concerning the concentration of cadmium in raw materials, conversion factors, and partitioning between environmental compartments. An obvious limitation of the methodology is due to the difficulty of choosing realistic emission factors which cover the wide variety of current situations and take into account the current state of technological progress.

This document does not pretend to present a global or even OECD-wide quantitative inventory of cadmium releases. In that respect it is, rather, descriptive. However, data provided by countries are presented and allow certain current situations to be assessed.

2.2.1 Cadmium products

Between 15,000 and 17,000 tonnes of cadmium per year is transformed into products belonging mainly to five categories: batteries, coatings, pigments, stabilizers and alloys. Direct releases of cadmium to the environment, or significant exposures of populations to cadmium, are unlikely from the use of these products. The manufacture and disposal of these products, however, have potential for releasing cadmium to the environment.

The significance of releases during manufacture is dependent upon the processes utilized and the emission control techniques. Releases from these processes may mainly occur to both air and water, but solid manufacturing wastes such as process scraps, sludges and filter cakes may also be generated. Solid wastes are sent for either recycling or disposal.

Environmental partitioning of the emissions varies considerably, according to product types and the individual processes employed. For example, cadmium electroplating may result in aqueous emissions and generate wastes such as sludges or filter cakes, but produce negligible atmospheric emissions.

Releases associated with the disposal of these products will depend upon the form of product and the techniques employed for disposal. The quantity of cadmium products entering the waste stream depends on the lifetime of the product, and their collection rates for recycling.

The consumption pattern for cadmium used in the manufacture of products varies considerably from one country to another. However, the use patterns for cadmium products does not greatly vary throughout OECD countries. Patterns of cadmium consumption will largely dictate patterns of release associated with manufacture, while patterns of product use will be of importance when considering releases from the disposal of those products.

Although the amount of cadmium used in batteries is much greater than that used in pigments, stabilizers and plating, the latter uses cause the major part of the cadmium flow to waste deposits at present. This is due to differences in product life span, the time lag between purchase and disposal, and the fact that pigment and stabilizer applications were prominent in the 1970s and 1980s. The difference between consumption and disposal of cadmium in batteries can be explained by the recent growth in NiCd battery production, as well as the time lag between the manufacture and disposal of NiCd batteries. There may also be some stockpiling of used batteries, with a view to later recycling.

2.2.2 Products containing cadmium as an impurity

2.2.2.1 Production of non-ferrous metals

Cadmium is a naturally occurring constituent in all zinc, lead and copper ores, and cadmium emissions may occur in all industrial production of those metals. Zinc ores are the primary source of cadmium production. In zinc production most of the cadmium is deliberately removed and subsequently refined into cadmium metal. Residual levels of cadmium in lead are much lower. They are generally recovered as baghouse dust and subsequently sent to cadmium refineries for recovery. Cadmium levels in copper refining are still lower, but the volumes processed are much higher. For primary production of zinc, lead and copper, the principal emissions are likely to be contained in the high volumes of solid wastes such as jarosite, goethite or slag, generally landfilled under controlled conditions.

The residual cadmium levels in zinc, lead and copper alloys are quite low, and significant emissions are not generally expected from the processing of these alloys. A few specialty alloys, with deliberate additions of cadmium to obtain specific properties, are produced in very low volumes and could result in limited cadmium emissions.

2.2.2.2 Production of iron and steel

Cadmium emissions may occur at several stages in the production of iron and steel, including both primary and secondary steelmaking. Emissions to air, water and landfill may result from several of the input materials and processes for converting iron ore, coke and limestone/fluorspar to iron, for producing refined steel from pig iron, or for secondary production of steel from scrap steel. Although the cadmium levels in most input materials for steelmaking processes are quite low, the volumes of materials handled are very high and there is a potential for significant cadmium emissions to the environment. In secondary steelmaking, cadmium emissions arise from impurities in leaded and galvanized steels or other impurities in the scrap steel or slag-making materials. Emission control devices capture much of the possible emissions of cadmium to air and water, e.g. electric arc furnace (EAF) dust, baghouse dust and filter cakes from wet scrubbers. Cadmium and other non-ferrous metals are recovered from these devices and sent for recycling.

2.2.2.3 Fossil fuel combustion

Cadmium, like many other trace elements, is a natural constituent of fossil fuels such as coal, oil and peat. The cadmium content of coal varies from 1 µg/g (lignite) to 2 µg/g (bituminous coals) (Hutton 1982). The cadmium content of crude oil is lower than that of coal, and an average value of 0.05 µg/g has been suggested (Hutton 1982). Natural gas does not contain significant quantities of cadmium and is considered to be a negligible source of cadmium emissions.

Although the cadmium level in fuels may be quite low, the volumes burned in power plants and other combustion sources, including mobile sources, are high and thus could lead to significant cadmium air emissions. Most of the cadmium from the combustion of fossil fuels will be contained in the fly ash and will be captured by emission control devices such as precipitators and scrubbers. A small portion of the cadmium may be present in the slag or bottom ash produced by the fuel burning process. Most of this slag is landfilled or immobilized in cement or asphalt-type products.

2.2.2.4 Mineral fertilizers and liming

Crop production requires primarily nitrogen, phosphorus and potassium. Some other elements are also necessary. One of these is calcium, used in carbonate form for soil pH adjustment (liming). Phosphate fertilizers introduce into soils a portion of the cadmium contained in the original rock phosphate. Igneous phosphates, such as those from South Africa or Russia, are very low in cadmium; sedimentary phosphates tend to contain more. West African phosphate rocks contain between 45 and 90 ppm of cadmium, while those from the Maghreb and the Near East contain 10-70 ppm. Phosphate rocks from the United States contain 5-100 ppm of cadmium, depending on the deposit, and those from the Pacific Islands around 70 ppm.

In the case of phosphate fertilizers, the important factors contributing to the amount of cadmium distributed are the amount of fertilizer used (which depends on agricultural practice and type of crop) and the Cd/P_2O_5 (mg of cadmium/kg of P_2O_5) ratio of the fertilizer (which depends on the fertilizer manufacturing process and the rock phosphate source).

Cd/P_2O_5 ratios vary from 1 to 5 for Kola or Palabora rocks to over 200 for Naru, Senegal, or the state of Idaho in the United States. Rock processing is a practical necessity since crops in most cases cannot use the phosphate ion directly from the rock, where it is locked in an insoluble or very sparsely soluble form. Therefore, some solubilization process must be used to produce efficient phosphate fertilizers and the preferred means is to use mineral acids. This in turn may or may not change the Cd/P_2O_5 ratio of the final product. Nitric acid solubilization leading to nitrophosphates does not change the ratio. Sulphuric acid solubilization does not change the ratio when superphosphate is produced, but always changes the ratio when phosphoric acid is produced for further processing to soluble phosphate fertilizers, such as DAP (diammonium phosphate) or MAP (monoammonium phosphate) or soluble calcium phosphates. This change is a 20 per cent lowering of the ratio, but may differ depending on the type of process used. Thus a rock phosphate having a Cd/P_2O_5 ratio of 100 would give rise to a compound phosphate fertilizer having a Cd/P_2O_5 ratio of 80 when the manufacturing process involved the use of phosphoric acid. The ratio difference in cadmium content between raw material and finished product will be found in the gypsum produced as a by-product of the phosphoric acid production.

In summary, contamination of the environment due to fertilizers and their manufacture may occur:

- in water, through manufacturing losses and disposal of by-product gypsum to sea;
- in soil, through the use of fertilizers on agricultural land and the disposal of by-product gypsum to landfill;
- in air, through losses of dust during fertilizer manufacture (these losses, however, are thought to be negligible and not to contribute significantly to atmospheric deposition).

The use of lime in agriculture can be a small additional source of cadmium to soils. There is a selective use of lime, directed towards soils with a low pH. Where lime is used, it may add higher amounts of cadmium to agricultural soils. However, liming elevates soil pH and immobilizes cadmium, making it less available to plants (Louekari 1991).

2.2.2.5 Manure and compost

It has been suggested that the addition of farmyard manure to agricultural land may contribute to the cadmium content of soils. Little is known concerning the cadmium content of composts originating from municipal refuse. Increasing quantities of manure and compost are being used in agriculture, largely as a result of restrictions on disposal aimed at preventing the release of nitrogen to waterways. Experiments have shown that up to 16 grams of cadmium/hectare per year may be added from an application of 35 tonnes of manure/hectare (fresh weight) per year (Johnston and Jones 1993). However, farmyard manure application rates of 35 tonnes/hectare are some five to seven times higher than normal rates of application. The cadmium content of animal manure varies from 0.3 to 1.8 mg/kg of dry matter. Furthermore, animal manure has a very heterogeneous composition with dry matter content varying from 25-60 per cent in farmyard manure to 3-15 per cent in less concentrated slurry. Therefore, at normal rates of application of animal manure, up to 3 grams of cadmium per hectare may be added per year. Some cadmium will be subject to recirculation on the farm, although additional cadmium can be introduced through imported feeding stuffs.

2.2.2.6 Sewage sludge

Sewage sludge, whether originating from domestic or from industrial wastewater treatment plants, contains cadmium. The cadmium content varies according to the type of treatment plant and its location.

When sewage sludge is used as a fertilizer on agricultural land, it can lead to inputs as high as 80 grams of cadmium/hectare per year over limited areas (Hutton and Symon 1986, Tjell et al. 1981). Although the problem of metal contaminants in sewage sludges is well recognized, bans on disposal at sea may lead to an increasing need for land disposal sites or an increased spreading on agricultural land. Furthermore, it is anticipated that volumes of sewage sludge generated will increase as a result of more stringent regulations on water quality and treatment.

2.2.2.7 Cement production

Cadmium is present as a trace contaminant in the raw materials used in cement manufacture. Cadmium content in these raw materials has been suggested to be around 2.0 ppm. Emissions may result from the feed system, the kiln system, and the clinker-cooling and handling system. The partitioning of emissions will be dependent upon the production process, type of fuel, and type of fuel-firing system employed. The nature and extent of emission control equipment will also affect partitioning of emissions. Cadmium emissions to the atmosphere in the form of dusts are probable and will depend on efficiencies in dust collection. Direct emissions to water are unlikely.

2.2.3 Incineration of municipal waste

Municipal waste may contain cadmium products, or materials in which cadmium is present as an impurity. The incineration of these wastes has potential for release of cadmium through stack emissions and landfilling of ashes (for the latter, see Section 2.2.4).

Studies concerning the fate and distribution of cadmium in municipal waste incineration have been carried out in North America. A study concerning a modern energy-from-waste facility in Canada demonstrated that 99.8 to 99.9 per cent of cadmium introduced to the incinerator was caught in the boiler and the air pollution control equipment (Chandler 1992, Rigo, Chandler and Sawell 1993).

2.2.4 Release from landfills

The leaching of cadmium from disposed solid waste is dependent on many factors, e.g. physico-chemical properties of the cadmium-containing products, pH of the liquid phase of the landfill, rainwater, temperature changes. In principle, the amount of cadmium released from landfills can be decreased substantially through modern waste treatment techniques, e.g. an impermeable liner in the landfill and leachate treatment, either on-site or in a separate wastewater treatment plant. It is not known at the moment how much of the industrial and household waste in OECD countries is disposed according to environmentally sound practices.

2.2.4.1 Availability of cadmium in solid waste

Results of laboratory experiments on leaching of cadmium from pigmented plastics have been interpreted as showing that these products would not contribute significantly to cadmium leachate from landfills (Wilson et al. 1982).

Cadmium assays of incinerator ash in the United States have suggested that landfilled ash could pose a hazard to human health and the environment if cadmium were allowed to leach from landfills into groundwater (Cathcart 1990). In laboratory experiments using extraction procedures, leachates exceeding drinking water standards were found. However, the pH used was probably below that of landfills where neutral or basic conditions prevail (Francis and White 1987, Ujihara and Gough 1989, CORRE project 1990). In other extraction experiments, which simulated landfill conditions more closely, drinking water standards were not exceeded (CORRE project 1990). In general, if refuse ash is disposed in ash monofills, the leachate is more apt to remain alkaline and therefore contain lower concentrations of metals. If co-disposed with municipal solid waste, the pH could be lower, in which case the amounts of metals leached would be higher (Francis and White 1987, Ujihara 1989). Stabilization treatment of ash, e.g. pozzuolana cementation, has proven very efficient in reducing the mobility of cadmium in ash samples (Stokely and Newland 1992).

It is clear that leaching of cadmium from products in landfills or in soil can be studied. But standardized procedures for such studies, which are not available at present, are needed.

2.2.4.2 Contamination from landfills

Extensive monitoring data on environmental contamination by cadmium from landfills are not available.

Domestic and industrial cadmium-containing waste can be brought to three sorts of landfills – industrial, municipal or mixed. Large differences in cadmium content and leachability exist between these types of landfill. The contamination observed seems to be caused by old and uncontrolled landfills, whereas the cadmium concentration in leachates from controlled, state-of-the-art industrial or municipal landfills is often below the limit of detection. It can be assumed that cadmium concentrations in leachate are reduced in subsequent transport to ground and surface water, by sorption on particles, and through dilution. Data providing support for this hypothesis have been presented (Assmuth and Strandberg 1993).

In Canada, a study was commissioned by Environment Canada to assess means of reducing the entry of specific metals in the environment via the municipal solid waste stream (Sentar Consultants Ltd. 1993). The study used recent data from Canada and the United States to characterize the levels of metallic elements in the waste stream. From the waste groups that were defined (paper, plastics, organics, metals, glass, inorganic appliances, household appliances), five major components were identified: newsprint, corrugated containers, plastic film, yard and garden waste, and ferrous cans.

The concentration of cadmium (g/tonne) in the five major components (based on data from Canada and the United States) is as follows:

newsprint	0.002
corrugated containers	0.009
plastic film	0.206
yard and garden waste	0.549
ferrous cans	0.541

The amount of cadmium (tonnes/year) in Municipal Solid Waste landfilled in Canada is estimated below (Stanley Industrial Engineering Ltd. 1992):

newsprint	0.8
corrugated containers	8.2
plastic film	52.7
yard and garden waste	376.3
ferrous cans	128.6

Leachate from four municipal solid waste landfills in Ontario, Canada, all contained cadmium concentrations exceeding the acceptable level for potable water, which was 5 µg/litre. The landfills were of the mixed type, accepting domestic, commercial and industrial waste (Bolton et al. 1991).

The average cadmium concentrations in landfill leachate in four states in the United States (Alaska, Delaware, Florida and Oregon) varied from 1.65 to 27.7 µg/litre, while pH varied from 5.34 to 6.43. The number of sampling points per state varied from 33 to 115. Thus concentrations of leachate that exceed drinking water standard and ecotoxic levels were found in some areas in the United States. In general, landfill leachate quality had improved since 1980, probably due to better waste management and landfill practices (AWD Technologies 1993).

In a study on one uncontrolled municipal landfill in Denmark containing municipal and industrial waste, demolition waste, and 3 per cent hazardous waste, no elevated cadmium content in leachate was observed. The cadmium concentration in twelve samples was below the limit of detection, 0.2 µg/l (Andersen 1991).

2.2.5 Contaminated sites

Near non-ferrous metal industries, the soil concentration can be over 6 mg cadmium/kg (dry weight). Concentrations of about 3 mg/kg d.w. have been measured in an area of 75 km^2 around the zinc industries in Northern Limburg and the Antwerp Kempen in Belgium. In these areas, maximum groundwater concentrations of 400 µg cadmium/litre have been measured (Werkgroep Zware Metalen 1986).

Soils at former sewage treatment facilities have shown particularly high cadmium levels, which have called for remedial measures (Musgrove 1991).

Concentrations of <360 mg cadmium/kg soil have been found in vegetable garden soils of houses built on old zinc-lead mine workings in the village of Shipham in the United Kingdom (Morgan and Sims 1988).

2.3 Country data

The data on cadmium releases in this section have been submitted by Member countries. These data are often not published. The trend of cadmium releases, as well as the contribution of different branches of industry, are elucidated by the following information.

2.3.1 Belgium (see **Table 2.1**)

2.3.2 Canada

Complete quantitative inventories of cadmium releases from all known or potential anthropogenic sources in Canada are not available. The available data compiled by Environment Canada indicate that an estimated total of 147 tonnes of cadmium is released annually to the Canadian atmosphere (predominantly as particulate cadmium oxide) (see **Table 2.2**), while 12 tonnes is released into aquatic environments (as hydrated cadmium ion or in ionic complexes). Approximately 340 tonnes of cadmium in slag, sludge, and solid waste is estimated to be disposed of on land. Although land disposal accounts for most of the total cadmium waste, the nature of this material and the amount that is bioavailable are unknown. According to 1988 estimates (MacLatchy 1992), base metal smelters (primarily lead-zinc) accounted for the largest percentage (approximately 82 per cent) of total cadmium released to the Canadian environment; however, due to the application of improved cleaning technology, current levels have dropped significantly.

2.3.3 Denmark (see **Table 2.3**).

2.3.4 Finland

Between 1980 and 1989, cadmium releases from air emissions produced by non-ferrous metal production and waste incineration, water discharges from the production of iron and steel, and solid wastes from the production of fertilizers and waste incineration have decreased, whereas cadmium releases from solid waste produced by the combustion of coal and oil have increased (**Table 2.4**). The increase is probably due to the improved treatment of flue gas, resulting in greater amounts of cadmium-containing ash. Other changes in cadmium releases are insignificant and/or based on incomparable and unreliable data.

A zinc mine, a zinc refinery and a copper refinery are the largest sources of cadmium discharges to water. Their total load was about 0.2 tonnes in 1992. As an example, the permission given to the refinery at Kokkola establishes a limit of 0.1 tonnes/year discharges to water. In 1992 the actual discharge was about 0.04 tonnes. The permission given to enterprises includes a provision that the company has to monitor the discharged amounts of cadmium and the concentrations of cadmium in the receiving water bodies and sediments.

Releases from a copper refinery in Harjavalta have caused contamination of soil and groundwater where the drinking water standard (5 µg/litre) was exceeded.

Cadmium emissions to air amounted to approximately three to four tonnes in 1992. About half of this amount came from zinc, copper and nickel refining.

Table 2.1 Releases of Cadmium in Belgium (tonnes/year)

Source	1985	1990
Air emissions		
· combustion of coal	>0.2	0.1
· combustion of oil	>1.21	1.21
· production of lead	3.5	1.95
· production of copper	0.10	<0.10
· cadmium metal, oxides, salts	>0.5	0.36
· production of iron and steel	>2.7	2.7
· production of cement	>0.48	0.48
· incineration of household waste	>1.7	1.7
· other	?	?
Total	>10.4	> 8.6
Water discharge		
· production of lead	<0.15	<0.1
· production of copper	0.090	<0.090
· cadmium metal, oxides, salts	1.64	<1.81
· production of iron and steel	>3.5	3.5
· production of phosphates	>14.2	>1.75
· cadmium processing	>0.068	>0.068
· household waste	<0.5	0.5
· other	?	?
Total	>20.1	>7.8
Solid wastes and disposed		
products	>3.6	3.6
· combustion of coal	19.7	10.7
· production of lead	0.29	<0.29
· production of copper	69.0	77.0
· cadmium metal, oxides, salts	>25.4	25.4
· production of iron and steel	> 9.8	9.8
· production of cement	>9.0	9.0
· production of phosphates	6.2	<6.2
· fertilizers containing phosphates	1.0	1.0
· fertilizers without phosphates	>2.0	2.0
· cattle feed containing phosphates	>40.4	40.4
· household waste handling	?	?
· other		
Total	>186	>185

Reference: C. Plasman and G. Verreet, Ministry of Public Health and Environment, 1992 (in Dutch)

Table 2.2 Estimated Anthropogenic Air Emissions of Cadmium in Canada (tonnes/year)*

Metal production	
· production of non-ferrous metal	120
· production of iron and steel	5
Stationary fuel combustion	
· power generation	12
· commercial, residential and industrial heating	1
Transportation	
· rail	1
· marine	1
· road	2
· tire wear	<0.1
Solid waste disposal	
· incineration	5
Total	**147.1**

** other anthropogenic sources to air have not been estimated*

Table 2.3 Emissions of Cadmium to the Environment, Cadmium in Waste Products, and Reuse of Cadmium-containing Waste Products in Denmark (tonnes/year)

Compartment	1980	1990	Future trend
Air	5.0	2.0	downward tendency
Water	5.7	0.7	weak downward tendency
Soil	8.4	5.3*	weak downward tendency
Waste deposits	32.3	30.6	weak downward tendency
Reuse	no estimate	5.8	upward tendency
Total	**51.4**	**44.4**	**downward tendency**

** amount due to fertilizer: 2.6 tonnes*

Reference: A. Jensen and J. Markussen, Danish EPA, 1993 (in Danish)

Table 2.4 Emissions of Cadmium in Finland in 1980 and 1988-89 (tonnes/year)

Source	1980	1988/89
Air emissions		
· combustion of coal and oil	0.5-1.0	0.95
· production of non-ferrous metals (zinc, copper and cadmium)	6.0[1]	4.85
· production of iron and steel	0.25-0.3	0.4
· waste incineration	0.8	0.02
Total	7.6-8.1	6.2
Water discharges		
· production of non-ferrous metals	0.12-0.25	0.12
· production of iron and steel	0.25-0.8	<0.01
· production of fertilizers	–	<0.01
· cadmium plating	<0.01	<0.01
· production of sulphuric acid	0.2	0.3
Total	0.57	0.52
Solid wastes and disposed products		
· combustion of coal and oil[2]	1.6	4.8
· production of non-ferrous metals	–	135.5[3]
· production of iron and steel	–	3.5
· production of fertilizers[4]	1.5	0.2
· waste incineration	2.8	0.9[5]
· cadmium plating	0.02	<0.01
· waste to landfills	3.8-15.1	1.5
Total		146.4

– = data not available

Notes:

[1] This is an estimate. There is a great annual variation; in 1992 the emission was approximately 2.4 tonnes.

[2] Cadmium in the fly ash of power plants is either used in production of cement (about 50 per cent) or taken to municipal or other landfills.

[3] Jarosite from zinc refining contains 124 tonnes of cadmium.

[4] Waste gypsum from fertilizer production contains cadmium.

[5] The biggest waste incineration plant was closed in the early 1980s.

2.3.5 Germany

Table 2.5 Emissions of Cadmium to Air in Germany (original German Federal States)

Source of air emissions	Tonnes of cadmium/year		
	1985	**1990**	**1995**
Combustion of coal and oil	4.8	0.7	0.5
Iron and steel industry	7.93	4.9	2.69
Cement, glass and ceramics manufacturing	0.87	0.95	0.19
Non-ferrous metal industry	5	3	2
Hazardous and municipal waste incineration	3.3	0.5	0.1
Total	**21.9**	**10.05**	**5.48**

Source: TÜV Rheinland

Cadmium in solid wastes and disposed products (tonnes/year 1986):

Household waste disposed to landfills	235
Industrial waste disposed to landfills	226
Utilization of residues	158

Cadmium emissions to soil (tonnes/year 1991):

Fertilizers	20.4
Sewage sludge	2.4
Atmospheric deposition	41.5

Cadmium discharged to water (tonnes/year 1988):

Production of iron and steel, cadmium processing, and production of coke	4.5

Report of the Enquete-Kommission Schutz des Menschen und der Umwelt (Teil Cadmium) 1993. The figures given apply only to the original German Federal States (alte Bundesländer).

In 1985, 6.6 tonnes of cadmium was discharged by wastewater into German rivers and the North Sea. The objective for 1995 is a reduction of about 47 per cent (3.8 tonnes). About 5.2 tonnes was emitted from fugitive sources. These emissions will be reduced drastically in 1995. For the former GDR (new German Federal States), cadmium emissions into the river Elbe were about 13.1 tonnes in 1985. A reduction of about 50 per cent is the objective for 1995 (Report of the Bundesregierung on the realization of the conclusions of the Third International Conference on the Protection of the North Sea.

2.3.6 The Netherlands

Recent evaluation of cadmium emissions by the RIVM (Dutch National Institute for Public Health and the Environment), and the goals for emission reduction by the NEPP (National Environment Policy Plan), gives the following data:

Table 2.6 Emissions of Cadmium in the Netherlands (tonnes/year)

Source	1985	1990	2000 goal	2010 goal
Air emissions				
· industry	1.6	1.5	0.5	0.3
· refineries[a]	1	1	-	0.1
· incineration of household waste	0.7	0.6	-	-
Total	4	3 (-25%)	(-70%)	(-70%)
Water discharge				
· industry	16	4	1.6	1.6
· consumers	0.7	0.7	-	-
· miscellaneous	1	1	-	-
Total	18	6 (-65%)	(-70%)	(-70%)
Soil (agricultural)[b]				
· animal manure	4.5	4.5	-	-
· fertilizer	7	3	-	-
Total	12	8 (-35%)	(-70%)	-

[a] *estimate*
[b] *compared to 1986*

(from Nationale Milieuverkenning 1993-2015 by RIVM)

Cadmium in waste

40 million tonnes of waste is currently produced each year. This includes all categories, except for dredge spoil and excess manure. Waste currently contributes 98 tonnes a year to cadmium pollution.

The emission of cadmium caused by incineration of waste in 2000 will be 80 per cent less than in 1985. This is due to implementation of the cadmium decree, the development of an effective system of collection for NiCd batteries, and the recycling of plastic/polymer materials containing cadmium.

Table 2.7 Emissions of Cadmium Due to Incineration of Household and Industrial Waste in the Netherlands

Year	1985	1990	1995	2000	2010
Quantity of waste burned in millions of tonnes/year	2.45	2.7	4.3	6	8.4
cadmium emission in tonnes/year from burning waste	0.662	0.609	0.060	0.099	0.12

2.3.7 Norway

Cadmium emissions from smelters, incinerators, etc. have been reduced. Total emissions of cadmium to air were reduced from 1.5 tonnes in 1985 to 1.2 tonnes in 1991, and emissions of cadmium to water were reduced from 27 tonnes in 1985 to 1.5 tonnes in 1992.

The total amount of cadmium in solid waste in 1989 was about 5-6 tonnes (household) and 20-30 tonnes (industrial). Most solid waste from industry was deposited at special sites.

About 100,000 tonnes of sewage sludge (dry weight) per year is disposed of in Norway, over 50 per cent according to modern landfill techniques (agriculture and green areas). The rest is deposited.

2.3.8 Sweden

Cadmium emissions from point sources have been reduced considerably, from about 50 tonnes per year in the early 1970s to less than 5 tonnes per year at present. Waste contains at present about 100-200 tonnes of cadmium annually.

Table 2.8 Emissions of Cadmium from Point Sources in Sweden

Point sources, total emissions in tonnes of cadmium	1977-78	1985	1990	1995*	2000*
To air	12	5	2	1.4	0.8
To water	4	3	2.1	1.9	1.1

** estimate*

The total airborne deposition of cadmium in Sweden was about 20 tonnes in 1990.

Airborne deposition of cadmium (in mg/m^2/year):

	l990	1991
Northern Sweden, medium value	0.02	0.01
Southern Sweden, medium value	0.08	0.05

The cadmium input to agricultural soils is about 4 tonnes/year currently. About 55 per cent of this amount comes from atmospheric deposition and 40 per cent from fertilizers. For fertilizers, this is a reduction to less than 20 per cent of the input in the early 1970s. However, the current total cadmium input still leads to cadmium accumulation. To reach a balance between cadmium input and output, a substantial (about 90 per cent) decrease in current input would be required.

Table 2.9 Emissions of Cadmium in Sweden

Main point sources in 1990	Tonnes of cadmium to air	Tonnes of cadmium to water
Ore-based steel works	0.1	
Scrap-based steel works	0.1	
Primary metal works	1.3	0.1
Secondary metal works	0.1	
Engineering industry		0.1
Mines		0.1
Waste from mines		1.0
Combustion of oil	0.1	
Combustion of wood and peat	0.3	
Municipal sewage treatment		0.2
Paper and pulp industry		0.6
Total	**2.0**	**2.1**

2.3.9 Switzerland

Table 2.10 shows the considerable reduction of cadmium air emissions since 1984, as well as a forecast to 1995. The contribution of industry and trade is the most important, followed by emissions from households. The emission from traffic is negligible.

Table 2.10 Reduction of Cadmium Emissions in Switzerland (tonnes)

	1984	1990	1995
Households	0.35 (8%)	0.34 (12%)	0.34 (18%)
Trade, industry, agriculture	4.3 (92%)	2.6 (88%)	1.6 (82%)
Total	4.7 (100%)	2.9 (100%)	1.9 (100%)
Total (if 1950 = 100)	**138**	**85**	**56**

In Switzerland, cadmium is emitted by the metal processing industry, by waste incineration plants, by burning of coal, and during the processing of, for example, pigments, stabilizers, accumulators or alloys. The reduction of emissions is shown in **Table 2.11**.

Table 2.11 Reduction of Cadmium Emission Factors in Specific Industries and Waste Incineration Plants in Switzerland

	1984	**1990**	**1995**
Non-ferrous metal foundries (grams/tonne metal)	5.0	2.5	0.25
Steel works (grams/tonne steel)	0.9	0.72	0.54
Hazardous waste incineration (grams/tonne hazardous waste)	3.6	2.4	1.2
Municipal waste incineration (grams/tonne waste)	1.1*	0.45	0.20

** The value of 1.1 grams/tonne waste is the weighted mean of all plants in Switzerland in 1984. The emission factors of different municipal waste incineration plants vary considerably (cadmium in grams/tonne of municipal waste).*

2.3.10 United States

Cadmium releases in the United States in 1989 are presented in **Tables 2.12 and 2.13**. The source of the data in Table 2.13 is the EPA's Toxics Release Inventory (TRI). Releases from power plants are not reported to TRI, which explains the difference between the two tables.

Cadmium in disposed products is not included in this inventory. Assuming a relatively low recycling rate, as in Europe, the total amount in disposed products, most of which are disposed to landfill, is about 3500 tonnes annually. Much of the cadmium remains safely in the products for many years, some may corrode or erode during use, some is recycled, and some is disposed of in the environment. Ultimately, most of the cadmium utilized in products produced many years ago reaches landfills.

Table 2.12 Air Emissions of Cadmium in the United States (tonnes/year)

Production of cadmium metal, batteries, stabilizers and pigments	6.1
Production of zinc, lead and copper	38.1
Production of iron and steel	unknown
Combustion of coal and oil	243.8
Waste incineration	21.8
Production of cement	13.0
Other	0.5
Total	**about 320**

Source: US EPA, Report by the Emission Inventory Branch, 1990

Table 2.13 Cadmium Releases in the United States (1989)

Releases	Tonnes of cadmium/year
Air	54
Water	2
Underground wells	0.4
Landfills and solid waste on-site	159
Releases to municipal landfills and wastewater treatment plants	8
Waste transferred to off-site location[1]	287

[1] *"Waste transferred to off-site location" includes treatment, disposal and recycling of cadmium-containing waste.*

Source: US EPA Toxics Release Inventory

2.3.11 European Union

In 1989, the European Commission asked Environmental Resources Ltd (ERL) to undertake a study to evaluate the sources of human and environmental contamination by cadmium in the EC. The report (ERL 1990) includes estimations of emissions arising during the manufacture of cadmium products, summarized in **Table 2.14**.

The authors of the ERL report made important points concerning the limitations of the data in that report, including the following:

1) ERL was largely unable to obtain data concerning emission control technologies in operation, which may introduce uncertainty in the emission estimates from manufacturing; and

2) The available data were rarely later than 1987. The data on emission factors were considerably earlier than 1987. In most cases the emission factors used were those published in 1984 by Yost and Greenkorn, and were based upon industrial processes in operation in North America in 1979.

Recent estimates of emissions from the manufacture of batteries, pigments, stabilizers and plating have been made by industry. These estimates are shown as "revised data" in Table 2.14.

These values are based on the analysis of actual cadmium concentrations in air emissions and water discharges from factories in EU countries, collated by industry organizations.

Table 2.14 Releases of Cadmium from the Manufacture of Products in the EU (tonnes/year)

Manufacturing process	Emissions to air		Emissions to water			Solid waste	
	ERL	Revised data	ERL	Revised data	Maximum allowed under Directive 83/513	ERL	Revised data
Batteries	11.4	4.03[1]	3.2	1.3[2]	4.05 (1989)	25.4	21.2[3]
Pigments	-	0.025[4]	21.0	0.11[4]	0.37 (1991)	-	2.6[4]
Stabilizers	-	-	1.0	-	0.13 (1993)	10.5	-
Coatings	-	-	19.7	0.25[5]	0.18 (1989)	66.0	4.8[6]

Sources: ERL 1990, Revised Data from Cadmium Association

Notes:

ERL data have been corrected where revised estimates/measurements are available for individual countries. Where revised data were not available for individual countries, original ERL estimates have been retained.

1 Includes corrected figures for UK (0.00), FRG (0.03). No revised data available for F and S; therefore ERL estimate of 3.8 tonnes and 0.2 respectively retained.

2 Includes corrected figures for UK (0.00), FRG (0.05). No revised data available for F and S; therefore ERL estimate of 1.2 and 0.05 respectively retained.

3 Includes corrected figures for UK (0.00). No revised data available for F, FRG and S; therefore ERL estimate of 12.4, 8.3 and 0.5 tonnes respectively retained.

4 Data based on Cadmium Association survey of the five cadmium pigment producers in the EU (Royal Society of Chemistry 1994).

5 Revised estimate based on 1988 emission factors presented by Elgersma (1992).

6 Revised estimate based on reduced consumption of cadmium in coatings in EU, and revised emission factors from Yost and Greenkorn report of 1984 which were the basis of ERL estimates.

Table 2.15 The Evolution of Emission Factors for Aqueous Emissions from the Manufacture of Products Containing Cadmium

Process	1970-1972	1973-1977	1978-1982	1983-1987	1988
Battery manufacture					
pocket plate	8	4	3	1.5	1
sintered plate	15	10-15	5-10	2-3	1
Pigment manufacture	10-20	4-10	1.5	0.5	0.3
Stabilizer manufacture	10-20	4-10	2.0	0.6	0.4
Electroplating	20-30	15-25	10-20	1-6	0.3

Factors expressed as g cadmium/kg cadmium processed

Source: Elgersma et al. 1992

Despite the difficulties presented by the limitations of the ERL study data and the limited amount of revised data available, it can be seen from Tables 2.14 and 2.15 that:

a) Significant decreases have been observed in emissions and emission factors for the manufacture of products containing cadmium in the approximate period 1970-1990;

b) The absolute levels of these emissions are comparatively very small in relation to total anthropogenic emissions.

Table 2.16 Emissions from Certain Processes and from Products Containing Impurities of Cadmium (metric tonnes)

Activity	Air	Revised data	Water	Revised data	Solid waste and land	Revised data
Non-ferrous metals: zinc, copper, lead	31.4	10.43[1]	27.3	15.5[2]	338	299[3]
Production of iron and steel	24.2		21.2		341	
Combustion of coal and oil	49.4				156, coal ash	
Production and use of fertilizers			30, gypsum	1.05[4]	96, gypsum 263, agriculture	<30,[4] gypsum <180,[4] agriculture
Sewage sludge					61, landfills 52, agriculture	
Production of cement	7				261	
Solid waste (household and industrial)	28, incinera-tion				1025	

(For notes to Table 2.16, see next page.)

Sources: ERL 1990, revised data from Cadmium Association

Notes to Table 2.16:

Revised data are based on revised entries for individual countries surveyed by ERL. Where revised entries are not available for individual countries, original ERL entries have been retained.

[1] Germany (FRG) – Rauhut (0.5)
France – Ministry of Environment (1.7)
United Kingdom – 1.5 (+ 0.5 copper)
other data – as for ERL

[2] France (4.2) – Ministry of Environment
Germany (FRG)(0.2) – Rauhut
Netherlands (0.03) for zinc – cadmium RIVM 1990
other data – as for ERL

[3] Germany (FRG) (48) – Rauhut
Netherlands (25t) – RIVM 1990 zinc
other data – as for ERL

[4] Revised data for 1992 from European Fertiliser Manufacturers Association (1994)

The annual emissions of cadmium in waste from the landfilling of jarosite or goethite are estimated to be around 300 tonnes per year in Europe (ERL 1990).

2.4 Summary and evaluation of country data

2.4.1 Releases to air

Based on the country data, data compiled by industry, and the ERL study, the four major sources of atmospheric releases (whose relative importance varies depending on the country) are:

- production of non-ferrous metals (zinc, lead and copper);
- production of iron and steel;
- combustion of fossil fuels;
- waste incineration.

Emissions from production of cadmium and manufacturing of cadmium products are relatively small in comparison with the four sources mentioned above. However, the treatment of waste from these products in, for example, incineration and secondary steelmaking can contribute to atmospheric emissions.

The production of non-ferrous metals is the greatest source of atmospheric releases in Germany, Canada, Sweden and Finland. A significant decrease in emissions (down 50 per cent) has been observed in Belgium, Denmark, Finland, Germany and Switzerland. This is due to the increased use of closed systems, and collection and treatment of exhaust gases.

Also, the emissions from waste incineration, from the combustion of fossil fuels, and from the steel industry have decreased in most of the countries on which data were presented above.

It has been observed that air emissions from the production of non-ferrous metals have contaminated agricultural soil and, in some cases, groundwater. In certain locations around smelters the atmospheric deposition has been reported to be about a hundred-fold as compared with the background levels (Scholl et al. 1985, Werkgroep Zware Metalen 1986). Similar local contamination has been observed near other point sources (production of iron and steel, waste incineration), although not in such concentrations as those observed near non-ferrous smelters. Combustion of fossil fuels has not been reported to cause local contamination by the atmospheric route.

In the United States, combustion of coal and oil is the predominant source of emissions.

2.4.2 Releases to water

Based on the data from Belgium, Finland, and Sweden, data compiled by industry, and the ERL study, the major sources of water discharges (whose relative importance varies depending on the country) are:

- production of non-ferrous metals (zinc, lead and copper);
- production of iron and steel;
- production of phosphate fertilizers and phosphoric acid, gypsum disposal;
- municipal sewage treatment.

Discharges from the production of cadmium and the manufacturing of cadmium products are relatively small in comparison with the four sources mentioned above.

A decreasing trend in the amount of cadmium discharged to water has been observed in Belgium, Finland, Sweden and Denmark.

2.4.3 Releases to land

Based on the country data, data compiled by industry, and the ERL study, the major sources of releases to land (whose relative importance varies depending on the country) are:

- production of phosphate fertilizers and phosphoric acid (gypsum);
- production of non-ferrous metals (zinc, lead and copper);
- production of iron and steel;
- combustion of fossil fuels;
- disposal of household waste;
- disposal of industrial waste.

Information on trends in the amount of cadmium in solid wastes is limited.

Due to improved treatment of flue gas and wastewater (e.g. in the production of non-ferrous metals, iron and steel, and in power plants) it is obvious that more cadmium is retained in ash and sludge, which can be recycled or sent to landfill.

The commercial use of cadmium in products has steadily increased since 1980, although a small decrease has been observed since 1991. It can therefore be anticipated that increasing amounts of cadmium may arise in solid waste, unless mitigated by recycling. The change in use pattern described in Chapter 1, showing a shift towards nickel-cadmium battery use, will provide opportunities to reduce, through greater recycling, the amount of cadmium reaching solid waste provided the collection of batteries is improved to more effective levels.

2.4.4 Direct input to agricultural soil

The available data on input of cadmium from fertilizers to agricultural soil (in tonnes/year) are: Belgium 3, Denmark 2.6, Germany 25, the Netherlands 3, and Sweden 1.5. The input from sewage sludge, when applied, is usually much higher than that from fertilizer use. The input of cadmium due to the use of manure is smaller, in general, than that due to fertilizers and sewage sludge. Locally, however, where animal manure is used, the amount of cadmium entering agricultural soil may be much higher than the inputs from all other sources. Information is given in Appendix 1 on cadmium levels in topsoil in Denmark, Germany and the Netherlands.

2.5 Fate and occurrence of cadmium in the environment

Following its release to the environment, cadmium is distributed and transported within and between the environmental compartments. Under certain conditions it can also be remobilized from sediment and soil, which are considered to be the sinks of cadmium in ecosystems.

2.5.1 Cadmium in the atmosphere

Emissions of cadmium to the atmosphere are an important transport pathway, leading to its precipitation and the deposition onto soil, vegetation and surface waters (IPCS 1992, Jensen and Bro-Rasmussen 1992). The atmosphere receives direct input from industrial processes such as the production of non-ferrous metals, production of iron and steel, fossil fuel combustion and waste incineration, and also from natural sources such as forest fires and volcanism. Deposited cadmium can be re-entrained into air with windblown dust. Emissions give rise to both local contamination and the deposition of cadmium in areas remote from the sources. Contamination due to long-range transport and precipitation on surface waters is difficult to quantify.

There is limited data on worldwide estimates of cadmium concentrations in ambient air. Levels reported in various countries for rural areas range from 0.1-4 ng/m^3, and for urban areas levels range from 2-150 ng/m^3 (IPCS 1992). The highest values of airborne cadmium recently measured at the edge of lead smelters in Belgium and Germany were 60 ng/m^3 and 29 ng/m^3, respectively (Thiessen and Lenelle 1991, Ewers 1990).

Cadmium released to the atmosphere is predominantly in the particulate form and can be transferred to other environmental compartments via wet or dry deposition. Cadmium compounds commonly found in the atmosphere (e.g. oxide, sulphide, sulphate and chloride) are stable, do not undergo chemical reactions quickly, and have relatively short tropospheric residence times (one to four weeks). Nearly all airborne cadmium originating from combustion sources is associated with aerosols and fine particles.

2.5.2 Cadmium in water

Cadmium is a natural, usually minor constituent of surface and groundwaters. Generally, cadmium may exist in water as the hydrated ion ($Cd^{2+} \cdot 6H_2O$); as inorganic complexes with CO_3^{2-}, OH^-, Cl^-, or SO_4^{2-}; or as organic complexes with humic acids.

Cadmium can enter aquatic systems through weathering and erosion of soils and bedrock, atmospheric fall-out, direct discharge from industrial operations, leakage from landfills and contaminated sites, and the dispersive use of sludge and fertilizers in agriculture. Much of the cadmium entering fresh waters from industrial sources is rapidly adsorbed by particulate matter, where it may settle out or remain suspended depending on local conditions. This can result in low concentrations of dissolved cadmium even in rivers that receive and transport large quantities of the metal (IPCS 1992). Sediment is a significant sink for cadmium emitted to the aquatic compartment. Depending on physico-chemical conditions (e.g. pH, suspended matter levels, redox potential, salinity) and on man-made interventions such as dredging, cadmium may be recirculated to the water column and hence become bioavailable. Acidification of lakes may result in enhanced mobilization of cadmium from sediments, and lead to increased levels in the overlying water.

Background average fresh water concentration of cadmium in Scandinavia is reported to be about 0.03 µg/litre. A median value of 0.8 µg/litre was reported for surface waters in Belgium during the period 1978-82. Values of around 0.1 µg/litre were reported in the late 1980s; some of the high values measured in the late 1970s may be due to analytical difficulties. These values are the total cadmium concentrations and do not necessarily represent the bioavailable fraction.

In 1988, the mean total cadmium concentration in the Schelde estuary was 0.447 µg/litre (Plasman and Verreet 1992), while the dissolved cadmium concentration was 0.02 µg/litre in the 1987 summer season and <0.01 in the 1987 winter season (Van Eck et al. 1990). The yearly mean total cadmium concentration in the Meuse at the Dutch/Belgian border was 0.5 µg/litre (CCRX 1991). Results of Ros and Sloof (1988) show that 10 to 40 per cent of cadmium was in dissolved form in the rivers Rhine, Meuse and Schelde. A Dutch national survey in 1990 showed that 87 per cent of the 937 sampling points had a cadmium concentration below the detection level (0.11 µg/litre), and only 2.4 per cent of the points exceeded the Dutch guidance value of 1.5 µg/litre (CCRX 1991).

2.5.3 Soil and agricultural land

Cadmium in soils is derived from natural and anthropogenic sources. The cadmium which occurs naturally in soils is derived mainly from underlying bedrock or transported parent material (e.g. glacial till and alluvium). Phosphates can be particularly rich in cadmium. Anthropogenic input of cadmium to soils can occur via aerial deposition, sewage sludge, manure, and phosphate fertilizer application.

In contrast to the water and air compartments, where it is very rapidly transported, cadmium is rather immobile in the soil. The major factors governing cadmium speciation, adsorption and distribution in soils are pH, soluble organic matter content, hydrous metal oxide content, clay content and type, presence of organic and inorganic ligands, and competition from other metal ions. Soil pH is the most important factor controlling the availability of cadmium; it affects the stability and solubility of cadmium complexes, as well as nearly all adsorption mechanisms (Haugen-Kozuyra 1993). The more acid the soil is, the more mobile the cadmium becomes, whereby it can be taken up by plants or leach more readily.

Cadmium concentrations in European agricultural soils have been reported as 0.06-0.5 mg/kg dry weight (d.w.), whereas the concentrations of cadmium in contaminated soils are very variable (Jensen and Bro-Rasmussen 1992). Surface soils sampled over 850,000 km^2 of the Canadian prairies and adjoining United States ranged in cadmium concentration from <0.2 to 3.8 mg/kg, with a mean of 0.28 mg/kg (Garrett 1994). A survey of soil samples collected from 5692 sites on a regular grid over England and Wales showed a range of cadmium concentrations of 0.2-40.9 mg/kg, with a mean of 0.8 mg/kg and a median concentration of 0.7 mg/kg (Mcgrath and Loveland 1992). In the United States, a survey of agricultural soils from 3045 locations selected on the basis of their being remote from obvious sources of contamination showed a range of <0.01 to 2.0 mg/kg cadmium, with a mean concentration of 0.265 mg/kg and a median concentration of 0.2 mg/kg (Holmgren et al. 1993).

The use of cadmium-containing fertilizers and sewage sludge, together with atmospheric deposition, is primarily responsible for the increase in the cadmium content of soils over the last 20 to 30 years in Europe (Jensen and Bro-Rasmussen 1992).

The input of cadmium on agricultural land through sewage sludge or manure only applies to a relatively small percentage of the total agricultural land and varies in EU countries. The long-term application of sludge to soil results in a marked increase in the soil metal content and causes cadmium concentrations in cultivated plants to increase up to a hundred-fold as compared with uncontaminated land (Juste 1992). Metals accumulate in the topsoil with no evidence of rapid downward movement, even many years after the termination of sludge application. Metals appear to remain in the zone of sludge incorporation (0-15 cm. depth) as a result of their absorption on hydrous oxides, clays and organic matter, the formation of insoluble salts, or the presence of residual sludge particles. In some cases, a limited metal movement to soils below the zone of sludge incorporation has been detected. The downward movement of metals increases with the loading rate (Juste 1992). Lateral movement was the main explanation for the progressive "disappearance" of metals from experimental plots.

For a wide range of crops grown on sludge-amended soils, the accumulation of cadmium varies by plant type. For example, the following plants accumulate cadmium in decreasing order: tobacco, lettuce, spinach, celery, cabbage (Haugen-Kozyra 1993).

Information on the cadmium balance in agricultural soils in different countries is presented in Appendix 1.

2.5.4 Plants

Cadmium is non-essential to plants. Soil pH is the principle factor governing the cadmium content of plants, while other factors include cadmium load and source, soil adsorptive capacity, the presence of interfering ions (e.g. zinc), and plant species (Haugen-Kozyra 1993). Cadmium is absorbed by both roots and leaves.

Plant species differ widely in their ability to absorb, accumulate and tolerate cadmium. Leafy vegetable crops are known to accumulate cadmium to the greatest extent. On average, lettuce contains 0.66 mg/kg d.w., while spinach contains 0.11 mg/kg d.w. Vegetable root crops, such as turnip and radish, are also capable of accumulating cadmium to relatively high levels. In general, cadmium concentrations are lower in the seed, tuber and fruit tissues, relative to leafy tissue, and this can be exemplified in the accumulations by lettuce, spinach, cabbage and tobacco (Haugen-Kozyra 1993).

For sensitive crops, the yield-dependent limit for cadmium content is about 1-5 mg/kg, depending on the soil type. In some contaminated soils in European countries, mean values ranging from 1 to 10 mg/kg have been reported. In a few cases, a significant long-term increase in cadmium has been demonstrated in harvested crops, corn leaves and wheat grains (Andersson et al. 1985, Jones et al. 1989, Jensen and Bro-Rasmussen 1992). The field studies and experiments to which Jensen and Bro-Rasmussen (1989) and Juste (1992) refer show that an increase in soil cadmium would increase the cadmium concentration in plants, with wheat and potato being examples of plants to which cadmium is easily transferred via the roots. The observed increase depends on the type of soil studied, and is proportionate to the increase in the cadmium content of the soil. However, the picture is not uniform. In some surveillance studies no particular trend was observed, and in certain areas the cadmium concentration in some foods has decreased (see Section 3.2.2).

According to studies in Germany (referred to by Juste 1992), a grain concentration of about 1 mg/kg was frequently found in winter wheat grown on soil where the total level of cadmium was near or above 2 mg/kg. This high cadmium concentration of 1 mg/kg in wheat is about twenty-fold, as compared with the average concentration. Total soil cadmium of 5-45 mg/kg resulted in 2.5 mg/kg of cadmium in sugar beets. In sugar beet and cereal leaves, the concentration was 3-18 mg/kg and 0.06-80 mg/kg dry weight, respectively.

In long-term experiments in the United States using the recommended levels of phosphorous for more than 50 years, Mortwedt and co-workers (1987, 1987) reported that cadmium in soil had increased over time, but corn, wheat and soybeans grown on these soils showed no increase in cadmium due to phosphorous fertilization. Similarly, an Australian study has shown that large applications of phosphorous fertilizer have had little or no effect on grain cadmium levels (Gartrell 1990). In general, the lower amount of fertilizer application in the United States and Australia as compared with Europe, as well as different soil parent material, could have affected these results.

In some but not all long-term field studies with sludge, cadmium uptake by corn decreases significantly with time following the termination of sludge application. Sludge application can elevate soil pH, which reduces metal bioavailability. A relatively high concentration of zinc in sludge, or in refining wastes or landfills, also reduces the uptake of cadmium by plants (Juste 1992). Similarly, interacting effects of metals co-deposited with cadmium around point sources, such as non-ferrous smelters, may reduce cadmium bioavailability and thus plant uptake. The amounts of cadmium in fertilizers and in sludge are not comparable in terms of cadmium accumulation in plants.

In addition to soil-plant transfer, a second important route of cadmium to plants is by direct deposition on leaves. In a study with agricultural crops from a rural area, it was found that 20-60 per cent of total plant cadmium originated from atmospheric deposition on plant surfaces with subsequent absorption and transport throughout the volume of the plant. In another study with grass cultures, it was found that 50 per cent of the atmospheric deposits on the leaves could be removed by washing (Jensen and Bro-Rasmussen 1992). Decreasing air emissions of cadmium, although diminishing the part played by foliar absorption, does not necessarily lead to a decrease in total plant cadmium because of the continuing accumulation of cadmium in soil from continuing atmospheric fall-out and from other sources.

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 foodstuffs actually decreased during the 1980s. The main reason for this favourable trend is the marked decrease in cadmium emissions to air, resulting in lower atmospheric cadmium levels and decreasing direct deposition from the atmosphere onto plants.

Cadmium concentrations in vegetables in different areas of Belgium are presented in **Table 2.17**. These data tend to support the results of other studies showing that an increase in soil cadmium is reflected in elevated cadmium in cultivated plants. The increase in plant concentration seems to be proportionate to the soil cadmium level in some cases, but not in others.

Although air emissions of cadmium have been reduced in many countries, trends for cadmium concentrations in plants and trends of cadmium exposure are not consistent. Trends vary depending on the relative importance of direct atmospheric deposition, and other factors that mitigate or contribute to the uptake of cadmium by plants.

Table 2.17 Mean Cadmium Content in Vegetables (Belgium)

Zone	Celery	Lettuce	Leek	Carrot	Potato
S	0.59	0.44	0.44	0.17	0.08
M	0.43	0.33	0.20	0.15	0.07
E	0.27	0.24	0.17	0.11	0.05
R	0.12	0.08	0.05	0.08	<0.02

(mg/kg f.w. in different zones of contamination)

S: Strongly contaminated soils (9 mg cadmium/kg d.w.)
M: Medium contaminated soils (4.1 mg cadmium/kg d.w.)
E: Enriched soils (1.7 mg cadmium/kg d.w.)
R: Reference soils (0.4 mg cadmium/kg d.w.)

Houtmeyers et al. 1985, 1986

CHAPTER 3

HUMAN EXPOSURE

Most of this chapter has been taken from IPCS Environmental Health Criteria document No. 134 on cadmium. More recent information submitted by Member countries has been added in the appropriate places.

3.1 Pathways of human exposure

The main pathways of cadmium from the environment to man are shown schematically in **Figure 3.1**. The major route of exposure to cadmium for the non-smoking general population is via food. Cadmium as a trace constituent is present in most food commodities, even in the absence of environmental contamination. Plants play a central role in the transfer of cadmium from the environment to man, and cadmium accumulated in certain foods of animal origin, such as offal, also indirectly originates from cadmium in vegetable fodder.

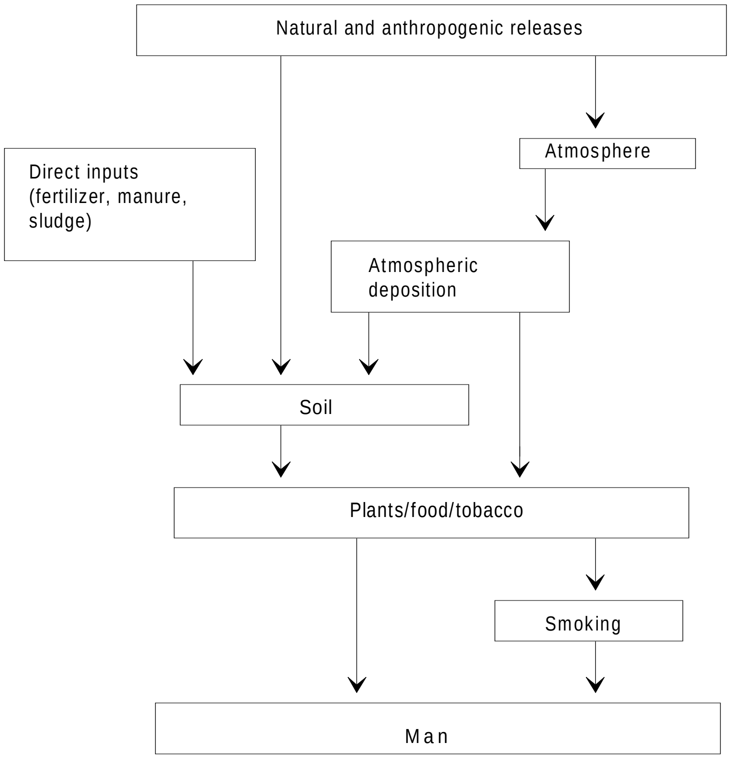
Plants absorb cadmium through two principal pathways: direct atmospheric deposition to exposed plant parts, such as leaves, cereals, and fruits, and absorption through root uptake and subsequent transport, especially to leaves and less so to fruits and seeds. Direct atmospheric deposition to plants is an important, yet often neglected, pathway of exposure. In rural areas, 20-60 per cent of total plant cadmium may originate from direct deposition. However, in urban and, especially, industrial areas atmospheric deposition will be by far the most dominant pathway (Jensen and Bro-Rasmussen 1992).

The two important sources of cadmium to agricultural soils are atmospheric deposition and direct inputs through, for example, the application of phosphate fertilizers.

The contribution from other pathways to total uptake is small. Tobacco is an important source of cadmium uptake in smokers.

In exposed workers, lung absorption of cadmium following inhalation of workplace air is the major route of exposure. Increased uptake in workers can also occur as a consequence of smoking.

Figure 3.1 Human Exposure Pathways



3.2 Exposure of the general population

3.2.1 Cadmium levels in ambient air, drinking water and tobacco

Assuming a cadmium concentration of 10 ng/m^3 in both indoor and outdoor air and a daily inhalation rate of 15 m^3 for an adult, the average intake of cadmium from the atmosphere would be 0.15 µg, of which about 25 per cent will be absorbed. Much higher air cadmium concentrations are found in areas close to major atmospheric point sources. However, these values can fluctuate widely as a result of changing emission characteristics and weather conditions. Typical levels of cadmium in ambient air are shown in **Table 3.1**.

Cadmium intake from drinking water, based on daily consumption of two litres, is usually less than 1 µg (IPCS, EHC 134).

Smoking a pack of 20 cigarettes daily can result in the inhalation of 2-4 µg cadmium, the amount varying considerably according to the country or origin of the tobacco (based on agricultural soil uptakes by tobacco plant). Of this amount, 25-50 per cent may be absorbed via the lungs, resulting in an uptake of 1-2 µg, a much larger amount than from air alone. Those who smoke two or more packs of cigarettes daily will absorb correspondingly greater quantities of cadmium.

Table 3.1 Typical Levels of Cadmium in Ambient Air

Type of area	Cadmium concentration range (ng/m^3)	Sampling period	Reference
Remote rural			
Pacific atoll	0.0025-0.0046	NR	Duce et al. (1983)
Europe	0.1-0.3	NR	Heindryckx et al. (1974)
Atlantic	.000006-.00062	NR	Duce et al. (1975)
Rural			
Belgium	1[a]	24h	Janssens and Dams (1974)
Federal Republic of Germany	0.1-1	<24h	Neeb and Wahdat (1974)
Japan	1-4	24h	Japanese Environment Agency (1974)
Urban			
Belgium	50[a]	24h	Jansens and Dams (1974)
Federal Republic of Germany	10-150	<24h	Neeb and Wahadat (1974)
Japan	3-6.3	1 year	Japanese Environment Agency (1974)
Poland	2-51	1 year	Just and Kelus (1971)
United States (New York)	3-23	1 year	Kneip et al. (1970)

[a] *mean value*
NR = not reported

Source: IPCS, EHC 134

3.2.2 Cadmium levels in food

Data on cadmium levels in a wide variety of foods are available for the period 1971 to 1985 from 21 countries (GEMS 1988). Very few countries monitored the same food consistently over several years. In addition, the specific foods monitored varied considerably from country to country. Because of this variability, comparisons between countries are rarely possible, although trends within a country may at times by established. The cadmium content of major foods in the United States and Europe is shown in **Tables 3.2 and 3.3**, respectively.

Cadmium levels in cereals, rice and potatoes seem to show no clear trend during the years 1972-85 in Australia, Canada, Germany, Japan and the United States (GEMS 1988) (**Figures 3.2 and 3.3**). The observed fluctuations in concentration may be due to the analytical difficulties and problems in executing a nationally representative sampling of foods. The concentration of cadmium varied with the nature of the cereal: for instance, in Germany levels of cadmium in rye were considerably lower than those in wheat. There was no apparent increase in cadmium levels from processing cereals into various products such as flour and bread. **Figure 3.4** shows some recent data on foodstuffs from Belgium and the Netherlands for comparison.

Levels of cadmium in Crustacea and Mollusca were appreciably higher than those in fish, with extremely high levels found in lobster and crab. Higher levels of cadmium are found in animal kidney and, as might be expected, are found to increase with increasing age of the animal. **Figure 3.5** shows data on pig kidney and mussels in the Netherlands through 1989.

Table 3.2 Cadmium Concentrations in the Major Types of Crops from Various Regions of the United States

Crop	Sample size	Cadmium concentration (µg/kg wet weight)		
		Median	Minimum	Maximum
Rice	166	4.5	<1	230
Peanuts	320	60	10	590
Soybeans	322	41	2	1,110
Wheat	288	30	<1.7	207
Potatoes	297	28	2	180
Carrots	207	17	2	130
Onions	230	9	1	54
Lettuce	150	17	1	160
Spinach	104	61	12	200
Tomatoes	231	14	2	48

Wolnik et al. 1983, 1985

Source: IPCS, EHC 134

Table 3.3 Cadmium Concentrations in Different Food Items from Various European Countries (µg/kg fresh weight)

Food group	United Kingdom 1983	Finland 1980	Sweden 1984	Denmark 1979	Netherlands 1988
Breads and cereals	20-30	20-40	31-32	30	25-35
Meat	<20-30	<5-5	2-3	6-30	10-40
Offal					
Pork kidney	450	180	190		1000
Pork liver	130	70	50		100
Fish	<15	<5-20	1-20	14	15
Eggs	<30	4	1	<10	2
Oils and dairy products	<20-30	3-20	1-23	<30	10-30
Sugars and preserves	<10	<10	3	30	5
Fresh fruit	<10	<2	1-2	11	5
Vegetables					
Cabbage	<10	5	4	10	
Cauliflower	<20	10	10		
Spinach	120	150	43		
Broccoli	10	10			
Legumes	<10-30	<2-30	1-4	15	
Lettuce	<60	50	29	43	
Potatoes	<30	30	16	30	30
Carrots	<50	30	41		

Year of publication is given in the table. Sampling of foods was made approximately two to three years earlier.

Source: IPCS, EHC 134

Figure 3.2 Median Levels of Cadmium in Cereals

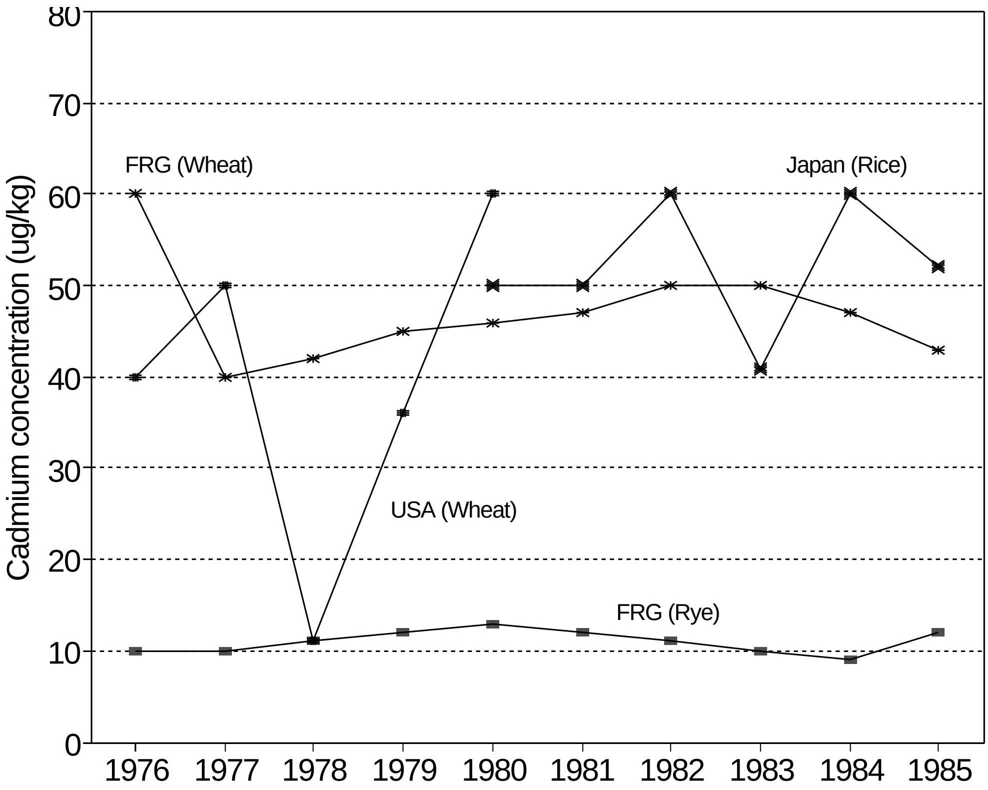


Figure 3.3 Levels of Cadmium in Potatoes

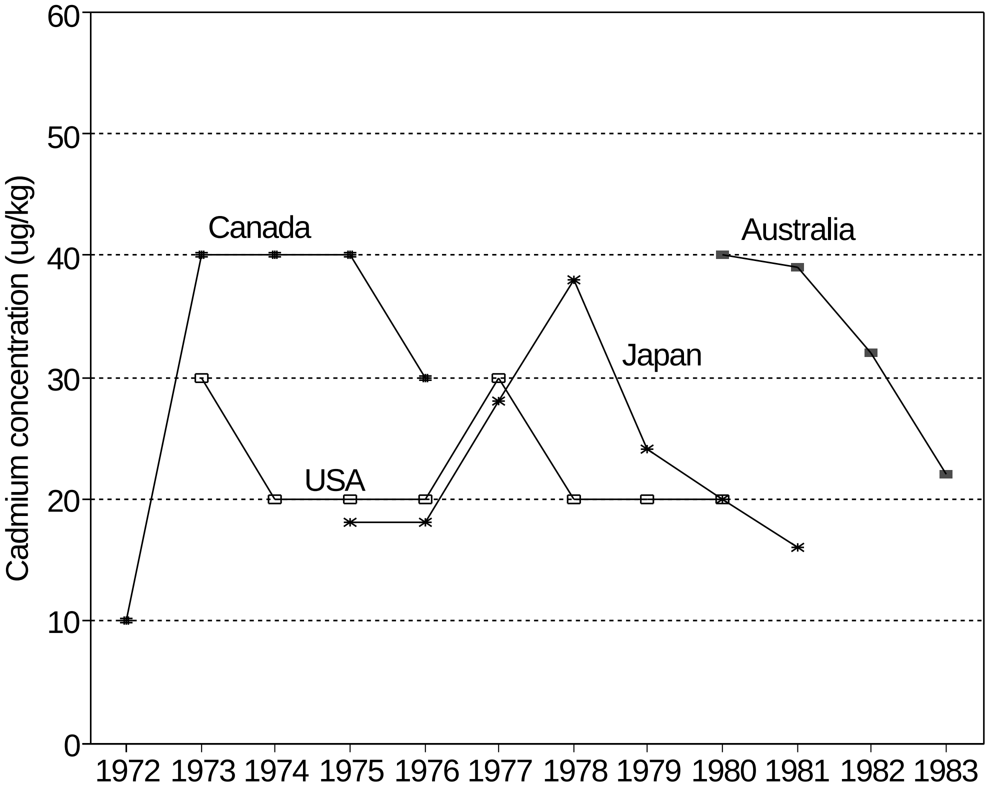


Figure 3.4 Cadmium Content of Certain Foodstuffs

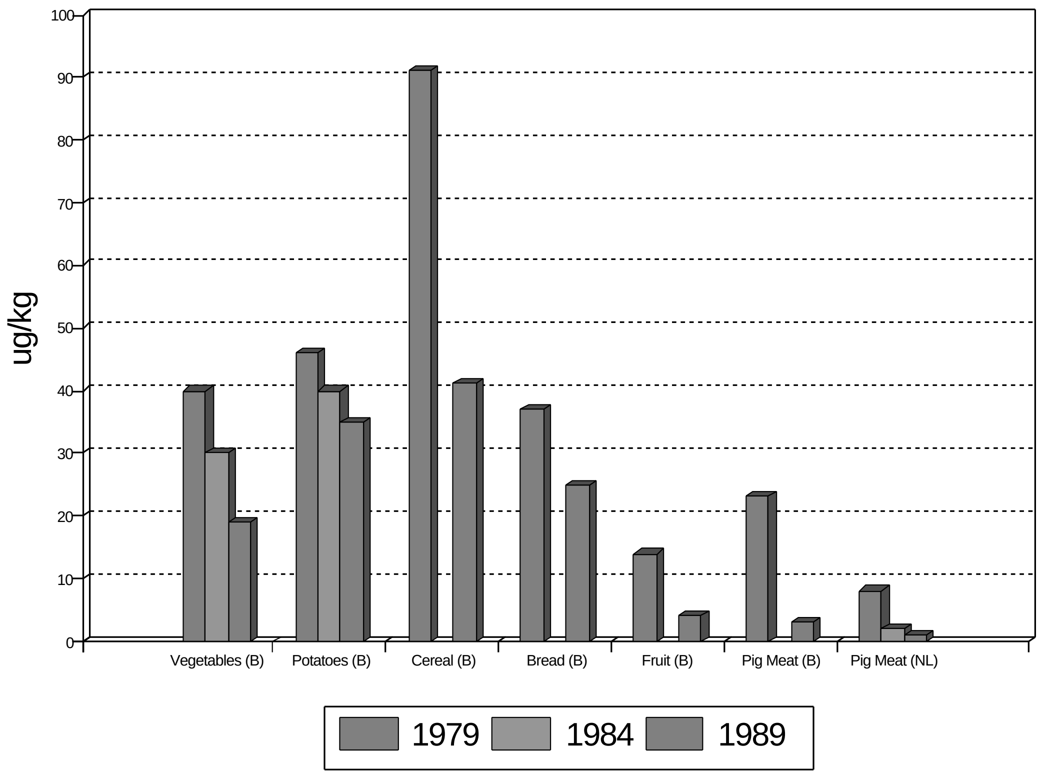
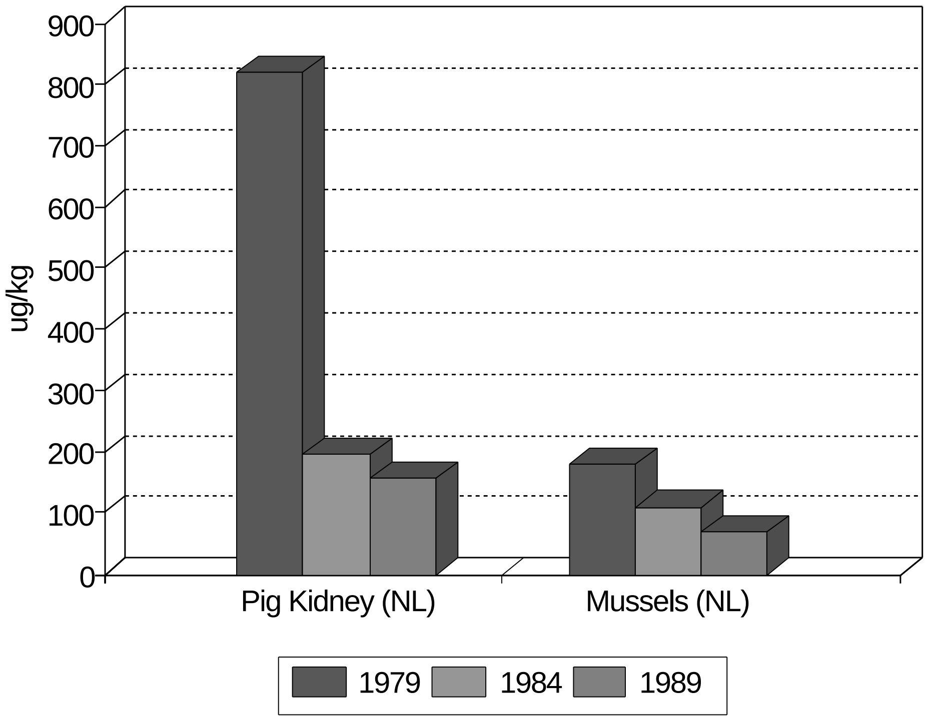


Figure 3.5   Cadmium Content of Pig Kidney and Mussels



3.2.3 Dietary intake of cadmium

At its 41st meeting in February 1993, the Joint FAO/WHO Expert Committee on Food Additives agreed to maintain the provisional tolerable weekly intake (PTWI) for cadmium at 7 µg per kg of body weight. The PTWI is derived from the estimated cadmium accumulation resulting from a daily uptake of 1 µg/kg body weight for adults over a period of 50 years. Excursions above this figure may be tolerated, provided they are not sustained for long periods of time and do not produce a significant increase in the integrated lifetime dose. The Committee noted that the recommended PTWI does, in fact, take into account the higher cadmium intake on a body weight basis by infants and children (WHO 1989). The Committee will revisit the PTWI when new data on the toxicological significance of excretion of low molecular weight proteins and bioavailability of cadmium from foods are available. At an absorption rate of 5 per cent, daily uptake from water and food would be 0.6-1.3 µg cadmium. In uncontaminated areas, heavy smokers may absorb more cadmium through the inhalation pathway than from dietary sources.

Table 3.4 presents post-1985 data regarding dietary intake in a variety of countries. The table also demonstrates that there can be variations in measured dietary intake levels within the same country and time periods. These variations are a reflection of the different approaches adopted in the estimation of total dietary cadmium intake (e.g. "market basket" or "duplicate meal" approaches). However, it is generally agreed that the duplicate meal approach provides the best estimate for dietary intake since a significant part of the cadmium present in foodstuffs is lost during preparation (cooking and peeling).

In Belgium, it was noted that once-a-week consumption of mussels or kidney would result in a mean intake that would approximate the PTWI (Fouassin and Fondu 1980). Similarly, in Denmark above average consumption of beef kidney, mussels from contaminated water or wild mushrooms would yield intakes exceeding the PTWI (National Food Agency of Denmark). In an area near a lead smelter (currently no longer in operation) in Denmark, consumption of home-grown vegetables and fruit increased cadmium intake from the nationwide average of 45 per cent of the PTWI to about 70 per cent of the PTWI (Anderssen 1981).

Although relatively low levels of cadmium are found in staple foods such as cereals and potatoes, the fact that they are consumed regularly in large amounts means that they make an important contribution to the overall intake. In the United States, concentrations of cadmium were approximately 40 µg/kg in leafy vegetables and 20 µg/kg in grain and cereal products. The contribution by each food/food group to the total intake of cadmium was highest for grain and cereal products (36 per cent), followed by potatoes (24 per cent) and dairy products (10 per cent), although average cadmium concentration in the dairy food group was only 3.5 µg/kg (Gartrell et al. 1986).

Of the countries which have reported their data to GEMS, only four (Australia, Hungary, Japan and the United Kingdom) have provided comparable data over the period 1980-1985 on the dietary intake, and no particular time trend was noticeable (**Figure 3.6**). The authors of the GEMS report caution that considerable judgement must be used in drawing conclusions concerning differences or trends in levels of contamination in foods (GEMS 1988).

Table 3.4 Post-1985 Daily Intake Data for Cadmium

Country	Period	Method	µg cadmium/ day	Ref.
United States	1985-1991	Total diet		
	16 year old F 14-16 y old M 25-30 y old F 25-30 y old N 60-65 y old F 60-65 y old M		9.2 13.3 9.5 12.9 8.8 11.2	(1)
Canada	1987 (P)	Duplicate meal	13.8	(2)
Germany (Bavaria)	1998	Total diet	12.7	(3)
Germany	1986-1987	Duplicate meal	10.3	(4)
Netherlands	1984-1985 1984-1986	Market basket Duplicate meal	23 9	(5)
United Kingdom	1986 1987 1988	Total diet Total diet Total diet	17 18 18 (maximum) 11 (maximum)	(6)
Sweden (Stockholm)	1991 (P)	Duplicate meal Fecal excretion	8.3 9.4	(7)
Finland	1986 1987 (P)	Total diet Market basket Duplicate meal Total diet	10.4 12 8.8 9.3	(8)
Yugoslavia (Zagreb)	1991 (P)	Duplicate meal Fecal excretion	8.3 15	(7)
Japan (Yokohama)	1991 (P)	Duplicate meal Fecal excretion	20 33	(7)
Japan	1985-1988	Market basket	38.7	(9)
China (Beijing)	1991 (P)	Duplicate meal Fecal excretion	7.1 7.3	(7)
China	1985-1988	Market basket	13.3	(9)
Denmark	1983-1987	Total diet	19.5	(10)
Australia	1992	Market basket	19.1	(11)
France	1983-1990	Duplicate portion	19	(12)

References (Table 3.4):

(1) FDA total diet study, unpublished results. (FDA anticipates that the cadmium data will be accepted for publication shortly, and that official citation of this data base will be possible in a not too distant future: E. Gunderson, pers. comm. to C. Boreiko, ILZR0.)

(2) Dabeka, R.W., et al., Food Additives and Contaminants 4, 89-102. 1987.

(3) Ribler, R. Publ. Bayerischen Staatsministeriums für Ernährung, Landwirtschaft und Porsten. 1989.

(4) Kampe, W. Erzmetall 40 (10), 531-540. 1987.

(5) CCRX. RIVM publ. Bilthoven, the Netherlands. 1991.

(6) Ministry of Agriculture, Fisheries and Food. The UK total diet study. N. Harrisson, pers. commun.

(7) Vahter, M., et al. Environmental Research 56, ˜8-89. 1991.

(8) Kumpulainen 3. In: ILSI Monographs: Monitoring dietary intakes. Chapter 6. Intake of heavy metals: comparison of methods. Springer Verlag publ. Berlin. 1991.

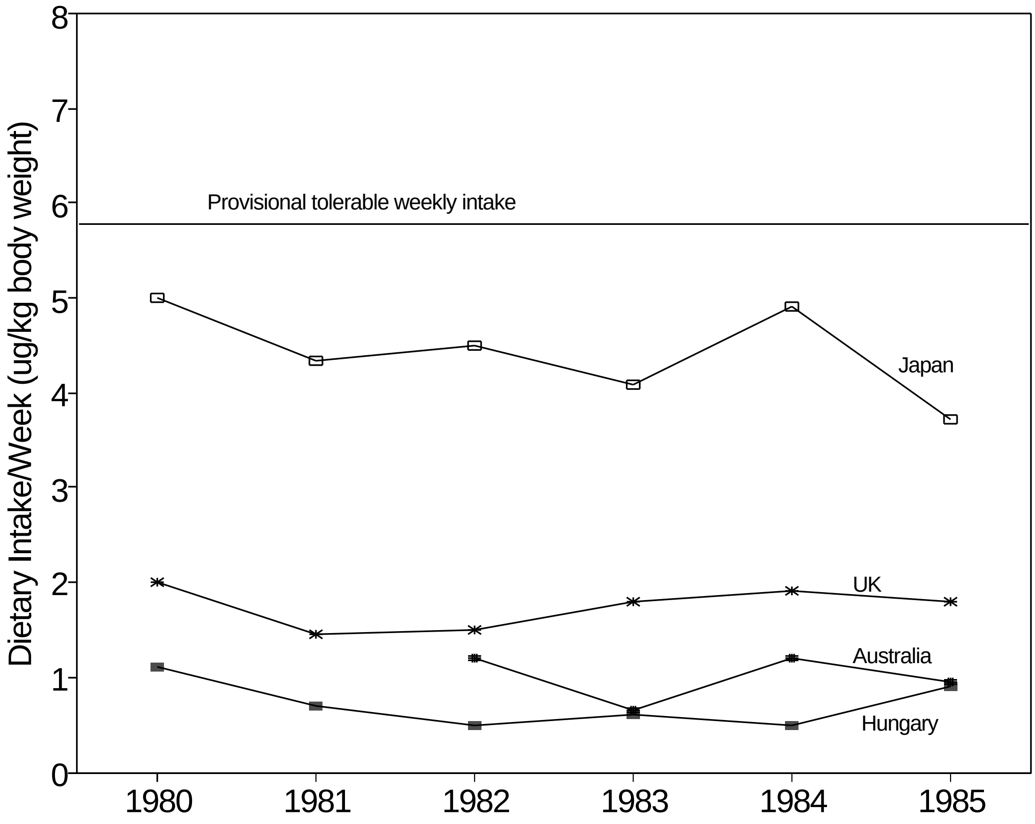
(9) Rivai, I., et al. Bull. Environ Contam. Toxicol, 44, 910-916. 1990.

(10) The National Food Agency of Denmark, Food Monitoring in Denmark, Nutrients and Contaminats 1983-1987.

(11) The 1992 Australian Market Basket Survey, National Food Authority.

(12) Boudene, C. (in press, reference made by Simonoff et al. in "Cadmium exposure from foods in France estimated by pixe analysis of duplicate portions," submitted by P.J. Quillon, APAO).

Figure 3.6 Dietary Intake of Cadmium in Four Countries, 1980-1985



There is some indication that concentration of cadmium in food might have increased over a long period of time, namely in Sweden. A doubling of the cadmium content of winter wheat (from 25 to 56 µg/kg) has been observed between 1918 and 1980. This may be attributed to acid precipitation increasing solubility and availability of the soil cadmium, continuous addition of cadmium through phosphate fertilizers, and atmospheric deposition leading to increased levels of cadmium in agricultural soil (Andersson and Bingefors 1985). Also in Australia, increase in soil cadmium content as well as elevated concentrations of cadmium in wheat (almost double as compared with control grown on phosphate fertilized soils) has been observed (Ashton and Laura 1992). In Finland, the use of high-cadmium phosphate fertilizers caused a 30 per cent increase in soil cadmium content in a relatively short time (from 1974 to 1987) (Sippola and Mäkelä-Kurtto 1986).

Conversely, a decreasing trend in cadmium intake has been reported for Belgium, Japan and the Netherlands (van Assche 1993). However, due to variations in analytical techniques over time and differences between the methodologies that were applied to make the evaluation, it is difficult to draw any firm conclusions in respect of trends of dietary intake. Studies of long-term trends of cadmium exposure, using comparable analytical techniques and consistent sampling protocols, are not available. The trend in accumulation of cadmium in agricultural land could be elucidated by making use of sample archives containing nationally representative plant samples.

There is evidence that in some industrial countries, Belgium for instance, the cadmium concentration in foods, and consequently also human exposure, has decreased. The decrease is probably due to diminished emissions from non-ferrous metal production. Risk reduction measures, especially in previously heavily polluted areas like Liège, have been successful (Ducoffre et al. 1992).

In a recent WHO/UNEP study, no significant change was seen in blood concentrations of cadmium. The study was carried out in 1981-82 and in 1988 and concerned the following sites: Beijing, Stockholm, Yokohama and Zagreb (Vahter and Slorach 1990). In Nordrhein-Westfalen, Germany, the blood cadmium level has shown a decrease from 1.2 µg/litre in 1979 to 0.4 µg/litre in 1986 (Ministerium für Umwelt 1989). Japanese measurements of blood cadmium levels have shown that the exposure of the general population decreased by 30 per cent between 1977/1981 and 1991 (Ikeda 1992). In Belgium, a 38 per cent decrease in blood cadmium levels was observed between 1980 and 1990 in a longitudinal study on the general population (Ducoffre et al. 1992).

In summary, no definitive conclusion with regard to trends of dietary intake can be drawn from the information presented above.

3.2.4 Factors affecting uptake

Airborne cadmium in contaminated areas may reach levels of 0.5 $\mu g/m^3$, which would lead to a daily inhalation of 7.5 µg and an absorption of about 2 µg. For smokers, the contribution from tobacco is 1-2 µg for every pack.

The total daily cadmium uptake will depend on the nature of cadmium contamination, i.e. whether food, water and air levels are elevated. It is unlikely to exceed 20 µg in uncontaminated areas (IPCS 1992). However, daily intakes from food and water of 150-200 µg have been reported for highly contaminated areas, where the majority of the staple food items were of local origin. At an absorption rate of 5 per cent, the daily uptake from diet in this particular situation would be 8-10 µg.

The uptake of cadmium from the gastrointestinal tract is modulated by a variety of factors. Increased uptake can be caused by deficiencies of calcium, protein or zinc. Conversely, the uptake of cadmium will be inhibited by excess zinc in the gastrointestinal tract (IPCS 1992, Hatchcock 1976).

Large individual variations occur due to variability in dietary habits and age-dependent changes in energy intake. The highest daily intake of cadmium is likely to occur among teenagers, since they have the highest calorific intake (Kjellstrom et al. 1978). Individuals from the general population who are extreme consumers of certain food items with elevated cadmium levels may have above average exposure. It has been estimated that 10 per cent of the population consumes twice the average quantity of a particular food class, and 2.5 per cent of the population consumes three times the average (IPCS 1992). In some other studies, the highest long-term dietary intakes of cadmium are estimated to be two-fold as compared with the average (Louekari et al. 1989, Vahter et al. 1990, Louekari et al. 1991).

A German study reveals a large variation in urinary excretion of cadmium, reflecting the body burden of cadmium. The average cadmium concentration in urine is about 0.1 µg/litre. However, in nine individuals in the sample (n = 2545), cadmium in urine exceeded 1 µg/litre and the maximum was 6.88 µg/litre. A skewed pattern of distribution was also observed in blood levels: the average was about 0.5 µg/litre and the maximum 11.5 µg/litre. Smokers' blood levels were about four-fold as compared with non-smokers (Krause et al. 1989). The conclusion from this skewed distribution of exposure is that, while the average daily intake of cadmium is below the PTWI value, there are groups in populations with significantly higher intake or uptake due to dietary and smoking habits, local contamination, and increased gastrointestinal absorption, etc. **(Table 3.5)**.

Cadmium intake in children via the ingestion of household dusts is unlikely to be important except in the most contaminated localities.

Table 3.5 Factors Affecting Exposure or Uptake of Cadmium

Factor	Remarks
High calorific intake	Teenagers have the highest intake of calories.
Food habits/preferences	Regular consumption of, for example, kidneys, liver, mushrooms, molluscs/ shellfish increases the intake.
Smoking	Smoking one to two packs of cigarettes daily increases the uptake of cadmium two- or three-fold.
Living in a contaminated area	Garden vegetables, ambient air and occasionally drinking water contain high concentrations of cadmium.
Nutrient deficiencies	Deficiency of calcium, iron and protein increases the gastrointestinal absorption and leads to a three-fold uptake of cadmium.
Low bioavailability of cadmium in certain foods	Cadmium in certain foodstuffs, such as shellfish, is less available for uptake.

3.3 Occupational exposure to cadmium

Inhalation of workplace air is the dominant occupational exposure pathway.

Elevated levels of airborne cadmium occur in the smelting of non-ferrous metals and in the production and processing of cadmium-containing articles. The thermal operations associated with some of these processes are mainly responsible for producing cadmium dusts and, if temperatures are sufficiently high, cadmium fume. Occupational exposure also occurs in many other industrial activities.

Airborne cadmium concentrations vary considerably according to the type of industry and the specific working conditions in each plant. Markedly elevated values, in the mg/m^3 range, were prevalent in the 1940s to 1960s. Considerable improvements in occupational hygiene have taken place in market economy countries since then, and these have led to progressive reductions in ambient levels in the workplace. Exposures now are in the tens of $\mu g/m^3$. Belgian industrial medical services reported that, in 1992, out of 2812 employees considered at risk from cadmium, 125 were exposed to a workroom atmosphere of 20 μg cadmium/m^3, 141 to 2-10 $\mu g/m^3$, and the remaining group to less than 2 $\mu g/m^3$. Data from modern electrolytic zinc production facilities show cadmium air concentrations in the range of 3-38 $\mu g/m^3$ with an average of 11 $\mu g/m^3$ (Van Sittert 1992). In modern NiCd battery manufacturing plants, work space cadmium air levels are currently below 50 $\mu g/m^3$ (IPCS 1992).

The daily cadmium intake, assuming air concentrations of 10-50 $\mu g/m^3$ and inhalation of 10 m^3 air during a work shift, would be 100-500 μg. An absorption rate of 25 per cent would thus lead to daily uptakes of 25-125 μg. Dust particles cleared from the lungs may be swallowed, and dust-contaminated food items can also make a significant contribution to the ingestion pathway. At an absorption rate of 5 per cent, this could lead to an additional uptake of 10-15 μg cadmium.

CHAPTER 4

INTERNATIONAL AND NATIONAL POSITIONS ON THE RISKS FROM CADMIUM

Section 4.1 of this chapter contains international assessments of the risks to human health and the environment from cadmium. Sections 4.1.1 and 4.1.2 are taken directly from Chapters 1, 9 and 10 of IPCS Environmental Health Criteria documents 134 (*Cadmium*) and 135 (*Cadmium – Environmental Aspects*), both of which were published in 1992.

Section 4.1.3 contains the International Association for Research on Cancer (IARC) evaluation of the carcinogenicity of cadmium and cadmium compounds, taken directly from Volume 58 of the IARC Monographs (1993). Section 4.1.4 contains the section on cadmium from the Forty-first Report of the Joint FAO/WHO Expert Committee on Food Additives (1993).

Section 4.2 presents Member country statements in regard to national positions on risks from cadmium. Essentially, these statements provide the rationale for any actions the countries have taken, or contemplate taking, to reduce risks associated with environmental or human exposure to cadmium. The risk assessments and risk characterizations that have led countries to take action have a national character. Countries develop positions on the need for risk reduction activities only after they have analysed the hazard and the significance of certain exposures and have factored in local social, economic and political considerations. These positions are usually arrived at after considerable debate on the numerous factors involved, and thus are not consistent across Member countries.

4.1 International positions

4.1.1 IPCS Environmental Health Criteria 134: Cadmium

The International Programme on Chemical Safety (IPCS) is a joint venture of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization. The main objective of the IPCS is to carry out and disseminate evaluations of the effects of chemicals on human health and the quality of the environment. The Environmental Health Criteria documents prepared by IPCS contain the collective views of an international group of experts and do not necessarily represent the decisions or the stated policy of the United Nations Environment Programme, the International Labour Organisation, or the World Health Organization.

The following assessments of the risks from cadmium are quoted directly from Chapters 1, 9 and 10 of IPCS Environmental Health Criteria document No. 134: Cadmium, published in 1992.

SUMMARY AND CONCLUSIONS

Identity, physical and chemical properties, and analytical methods

Several methods are available for the determination of cadmium in biological materials. Atomic absorption spectrometry is the most widely used, but careful treatment of samples and correction for interference is needed for the analysis of samples with low cadmium concentrations. It is strongly recommended that analysis be accompanied by a quality assurance programme. At present, it is possible under ideal circumstances to determine concentrations of about 0.1 µg/litre in urine and blood and 1-10 µg/kg in food and tissue samples.

Sources of human and environmental exposure

Cadmium is a relatively rare element and current analytical procedures indicate much lower concentrations of the metal in environmental media than did previous measurements. At present, it is not possible to determine whether human activities have caused a historic increase in cadmium levels in the polar ice caps.

Commercial cadmium production started at the beginning of this century. The pattern of cadmium consumption has changed in recent years with significant decreases in electroplating and increases in batteries and specialized electronic uses. Most of the major uses of cadmium employ cadmium in the form of compounds that are present at low concentration; these features constrain the recycling of cadmium. Restrictions on certain uses of cadmium imposed by a few countries may have widespread impact on these applications.

Cadmium is released to the air, land, and water by human activities. In general, the two major sources of contamination are the production and consumption of cadmium and other non-ferrous metals and the disposal of wastes containing cadmium. Areas in the vicinity of non-ferrous mines and smelters often show pronounced cadmium contamination.

Increases in soil cadmium content result in an increase in the uptake of cadmium by plants; the pathway of human exposure from agricultural crops is thus susceptible to increases in soil cadmium. The uptake by plants from soil is greater at low soil pH.

Processes that acidify soil (e.g. acid rain) may therefore increase the average cadmium concentrations in foodstuffs. The application of phosphate fertilizers and atmospheric deposition are significant sources of cadmium input to arable soil in some parts of the world; sewage sludge can also be an important source at the local level. These sources may, in the future, cause enhanced soil and hence crop cadmium levels, which in turn may lead to increases in dietary cadmium exposure. In certain areas, there is evidence of increasing cadmium content in food.

Edible free-living food organisms such as shellfish, crustaceans, and fungi are natural accumulators of cadmium. As in the case of humans, there are increased levels of cadmium in the liver and kidney of horses and some feral terrestrial animals. Regular consumption of these items can result in increased exposure. Certain marine vertebrates contain markedly elevated renal cadmium concentrations, which, although considered to be of natural origin, have been linked to signs of kidney damage in the organisms concerned.

Environmental levels and 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. In contaminated areas, cadmium exposure via food may be up to several µg/day. In exposed workers, lung absorption of cadmium following inhalation of workplace air is the major route of exposure. Increased uptake can also occur as a consequence of contamination of food and tobacco.

Kinetics and metabolism in laboratory animals and humans

Data from experimental animals and humans have shown that pulmonary absorption is higher than gastrointestinal absorption. Depending on chemical speciation, particle size, and solubility in biological fluids, up to 50% of the inhaled cadmium compound may be absorbed. The gastrointestinal absorption of cadmium is influenced by the type of diet and nutritional status. The nutritional iron status appears to be of particular importance. On average, 5% of the total oral intake of cadmium is absorbed, but individual values range from less than 1% to more than 20%. There is a maternal-fetal gradient of cadmium. Although cadmium accumulates in the placenta, transfer to the fetus is low.

Cadmium absorbed from the lungs or the gastrointestinal tract is mainly stored in the liver and kidneys, where more than half of the body burden will be deposited. With increasing exposure intensity, an increasing proportion of the absorbed cadmium is stored in the liver. Excretion is normally slow, and the biological half-life is very long (decades) in the muscles, kidneys, liver, and whole body of humans. The cadmium concentrations in most tissues increase with age. Highest concentrations are generally found in the renal cortex, but excessive exposure may lead to higher concentrations in the liver. In exposed people with renal damage, urinary excretion of cadmium increases and so the whole body half-life is shortened. The renal damage leads to losses of cadmium from the kidney, and the renal concentrations of cadmium will eventually be lower than in people with similar exposure but without renal damage.

Metallothionein is an important transport and storage protein for cadmium and other metals. Cadmium can induce metallothionein synthesis in many organs including the liver and kidney. The binding of intracellular cadmium to metallothionein in tissues protects against the toxicity of cadmium. Cadmium not bound to metallothionein may therefore play a role in the pathogenesis of cadmium-related tissue injury. The speciation of other cadmium complexes in tissues or biological fluids is unknown.

Urinary excretion of cadmium is related to body burden, recent exposure, and renal damage. In people with low exposure, the urine cadmium level is mainly related to the body burden. When cadmium-induced renal damage has occurred, or even without renal damage if exposure is excessive, urinary excretion increases. Cadmium-exposed people with proteinuria generally have higher cadmium excretion than such people without proteinuria. After high exposure ceases, the urine cadmium level will decrease even though renal damage persists. The interpretation of urinary cadmium is thus dependent on a number of factors. Gastrointestinal excretion is approximately equal to urinary excretion but cannot be easily measured. Other excretory routes such as lactation, sweating or placental transfer are insignificant.

The level of cadmium in faeces is a good indicator of recent daily intake from food in the absence of inhalation exposure. Cadmium in blood occurs mainly in the red blood cells, and the plasma concentrations are very low. There are at least two compartments in blood, one related to recent exposure with a half-life of about 2-3 months, and one which is probably related to body burden with a half-life of several years.

Effects on laboratory mammals

High inhalation exposures cause lethal pulmonary oedema. Single high-dose injection gives rise to testicular and non-ovulating ovarian necrosis, liver damage, and small vessel injury. Large oral doses damage the gastric and intestinal mucosa.

Long-term inhalation exposure and intratracheal administration give rise to chronic inflammatory changes in the lungs, fibrosis, and appearances suggestive of emphysema. Long-term parenteral or oral administration produces effects primarily on the kidneys, but also on the liver and the hematopoietic, immune, skeletal, and cardiovascular systems. Skeletal effects and hypertension have been induced in certain species under defined conditions. The occurrence of teratogenic effects and placental damage depends on the stage of gestation at which exposure occurs, and may involve interactive effects with zinc.

Of greatest relevance to human exposure are the acute inhalation effects on the lung and the chronic effects on the kidney. Following long-term exposure, the kidney is the critical organ. The effects on the kidney are characterized by tubular dysfunction and tubular cell damage, although glomerular dysfunction may also occur. A consequence of renal tubular dysfunction is a disturbance of calcium and vitamin D metabolism. According to some studies, this has led to osteomalacia and/or osteoporosis, but these effects have not been confirmed by other studies. A direct effect of cadmium on bone mineralization cannot be excluded. The toxic effects of cadmium in experimental animals are influenced by genetic and nutritional factors, interactions with other metals, particularly zinc, and pretreatment with cadmium, which may be related to the induction of metallothionein.

In 1976 and 1987, the International Agency for Research on Cancer accepted as sufficient the evidence that cadmium chloride, sulphate, sulphide, and oxide can give rise to injection site sarcomas in the rat and, for the first two compounds, induce interstitial cell tumours of the testis in rats and mice, but found oral studies inadequate for evaluation. Long-term inhalation studies in rats exposed to aerosols of cadmium sulphate, cadmium oxide fumes and cadmium sulphate dust demonstrated a high incidence of primary lung cancer with evidence of a dose-response relationship. However, this has not so far been demonstrated in other species. Studies on the genotoxic effects of cadmium have given discordant results.

Effects on humans

High inhalation exposure to cadmium oxide fume results in acute pneumonitis with pulmonary oedema, which may be lethal. High ingestion exposure of soluble cadmium salts causes acute gastroenteritis.

Long-term occupational exposure to cadmium has caused severe chronic effects, predominantly in the lungs and kidneys. Chronic renal effects have also been seen among the general population.

Following high occupational exposure, lung changes are primarily characterized by chronic obstructive airway disease. 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, as has occurred in the past.

The accumulation of cadmium in the renal cortex leads to renal tubular dysfunction with impaired reabsorption of, for instance, proteins, glucose, and amino acids. A characteristic sign of tubular dysfunction is an increased excretion of low molecular weight proteins in urine. In some cases, the glomerular filtration rate decreases. Increase in urine cadmium correlates with low molecular weight proteinuria and in the absence of acute exposure to cadmium may serve as an indicator of renal effect. In more severe cases there is a combination of tubular and glomerular effects, with an increase in blood creatinine in some cases. For most workers and people in the general environment, cadmium-induced proteinuria is irreversible.

Among other effects are disturbances in calcium metabolism, hypercalciuria, and formation of renal stones. High exposure to cadmium, most probably in combination with other factors such as nutritional deficiencies, may lead to the development of osteoporosis and/or osteomalacia.

There is evidence that long-term occupational exposure to cadmium may contribute to the development of cancer of the lung but observations from exposed workers have been difficult to interpret because of confounding factors. For prostatic cancer, evidence to date is inconclusive but does not support the suggestion from earlier studies of a causal relationship.

At present, there is no convincing evidence for cadmium being an etiological agent of essential hypertension. Most data speak against a blood pressure increase due to cadmium and there is no evidence of an increased mortality due to cardiovascular or cerebrovascular disease.

Data from studies on groups of occupationally exposed workers and on groups exposed in the general environment show that there is a relationship between exposure levels, exposure durations, and the prevalence of renal effects.

An increased prevalence of low molecular weight proteinuria in cadmium workers after 10-20 years of exposure to cadmium levels of about 20-50 μg/m^3 has been reported.

In polluted areas of the general environment, where the estimated cadmium intake has been 140-260 μg/day,[1] effects in the form of increased low molecular weight proteinuria have been seen in some individuals following long-term exposure. More precise dose-response estimates are given in section 8.[2]

Evaluation of human health risks

Conclusions

The kidney is considered the critical target organ for the general population as well as for occupationally exposed populations. Chronic obstructive airway disease is associated with long-term high-level occupational exposure by inhalation. There is some evidence that such exposure to cadmium may contribute to the development of cancer of the lung but observations from exposed workers have been difficult to interpret because of confounding factors.

General population

Food-borne cadmium is the major source of exposure for most people. Average daily intakes from food in most areas not polluted with cadmium are between 10-40 μg. In polluted areas it has been found to be several hundred μg per day. In non-polluted areas, uptake from heavy smoking may equal cadmium intake from food.

Based on a biological model, an association between cadmium exposure and increased urinary excretion of low molecular weight proteins has been estimated to occur in humans with a life-long daily intake of about 140-260 μg cadmium, or a cumulative intake of about 2000 mg or more.

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[1] The range "140-260 mg/day" found here and throughout the IPCS text will be replaced by "approximately 200 mg/day" by the IPCS in due course.

[2] Sections and tables referred to are in the Environmental Health Criteria document.

Occupationally exposed population

Occupational exposure to cadmium is mainly by inhalation but includes additional intakes through food and tobacco. The total cadmium level in air varies according to industrial hygiene practices and type of workplace. There is an exposure-response relationship between airborne cadmium levels and proteinuria. An increase in the prevalence of low molecular weight proteinuria may occur in workers after 10-20 years of exposure to cadmium levels of about 20-50 $\mu g/m^3$. *In vivo* measurement of cadmium in the liver and kidneys of people with different levels of cadmium exposure have shown that about 10% of workers with a kidney cortex level of 200 mg/kg and about 50% of people with a kidney cortex level of 300 mg/kg would have renal tubular proteinuria.

EVALUATION OF HUMAN HEALTH RISKS

Exposure assessment

General population exposure

In the ambient air, cadmium concentrations based on long-term sampling periods indicate, in most cases, a range of 0.001-0.015 $\mu g/m^3$ in rural areas, 0.005-0.05 $\mu g/m^3$ in urban areas, and up to 0.6 $\mu g/m^3$ near sources of pollution (section 5.1.1).

One cigarette usually contains 1-2 µg cadmium, of which about 10% may be inhaled (section 5.1.3).

Among staple foods, rice and wheat usually contain less than 0.1 mg/kg and other foods usually less than 0.05 mg/kg wet weight, but liver and kidney may contain 1-2 mg/kg wet weight and certain sea-foods as much as 10 mg/kg wet weight (section 5.2). Certain animals, e.g. the horse, may accumulate considerably higher concentrations in the liver and kidney. In polluted areas, these levels are further increased.

The content of natural waters is usually less than 1 µg/litre, but higher levels may be found near sources of pollution.

The total daily intake in non-polluted areas of most countries from food, water and air is estimated to be approximately 10-40 µg/day (food, 10-40 µg/day; water, <1 µg; and air, <0.5 µg/day for non-smokers).

Twenty cigarettes per day would contribute a further 2-4 µg. In polluted areas, the daily intake may be much higher, and intakes of several hundred µg/day have been reported (section 5.3.2).

Occupational exposure

Air is the main source of additional cadmium exposure for industrial workers. In many countries such exposures have now been reduced considerably. In the past, levels of several mg/m^3 were recorded in workplaces. Now, with proper industrial hygiene practices, levels of 0.02-0.05 mg/m^3 would be more typical (section 5.1.2).

Amounts absorbed from air, food and water

The proportion of cadmium from food and water that is absorbed will depend on the chemical nature of the cadmium compounds, but estimates based on the available data indicate that gastrointestinal absorption is approximately 5%, with considerable individual variation (section 6.1.2). Similarly, the amount absorbed from the air will depend on the chemical nature and the particle size of the inhaled material. The absorption varies between 25 and 50% depending on particle size and solubility (section 6.1.1). About 10% of the cadmium inhaled in cigarette smoke is absorbed.

Thus, the average amount absorbed from food and water in a person from a non-polluted area would be about 0.5-1.3 µg/day. The absorbed amount from smoking 20 cigarettes per day would be 1-2 µg/day and that from workroom air could be many times greater (section 5.3).

Dose-effect relationships

Renal effects

Long-term exposure to cadmium causes renal tubular dysfunction with proteinuria, glucosuria, and aminoaciduria, as well as histopathological changes, in both experimental animals and humans (sections 7.2.1.4 and 8.2.1, respectively). These are usually the first effects to occur after ingestion or inhalation exposure. As the renal dysfunction progresses in severity, the glomeruli may also be affected and, in a few cases, the cadmium-induced damage may lead to renal failure (section 8.2.1). Daily cadmium intakes in food of 140-260 mg/day for more than 50 years or workplace air exposures of 50 $\mu g/m^3$ for more than 10 years have produced an increase in renal tubular dysfunction in some exposed populations (section 8.3.3.2).

Bone effects

Cadmium may produce bone effects in both humans and animals. The most notable clinical entity in these cases is osteomalacia, but many subjects also show osteoporosis. Animal experiments show that both can be produced by long-term cadmium exposure (section 7.2.4). In animals and humans, osteomalacia has been seen in combination with cadmium-induced renal damage. The bone effects may be linked to cadmium effects on calcium and vitamin D metabolism in the kidney. The daily intakes via food and exposure levels in air at which the bone effects occur are uncertain, but they must be higher than those causing renal effects. Bone effects have been seen among both the general population and industrial workers in the past when exposure levels were very high. Host and nutritional factors influence the development and severity of cadmium-induced bone effects.

Pulmonary effects

Chronic obstructive airway disease has been reported in a number of studies of cadmium workers (section 8.2.3). This has, in severe cases, led to an increased mortality. The dose needed to produce these effects is uncertain, but it is higher than the dose needed to produce renal effects, as most workers reported to have lung effects also had renal effects. On the other hand, many workers with renal effects, who had been exposed to cadmium oxide dust and fume, had no lung effects.

Cardiovascular effects

Some animal studies have shown that, under certain exposure conditions, increased blood pressure and effects on the myocardium occur. Studies of cadmium-exposed workers and people in the general environment have been carried out, but most data do not support the animal findings.

Cancer

There is evidence that cadmium chloride, sulphate, sulphide and oxide give rise to injection site sarcomata in the rat and that the chloride and sulphate induce interstitial cell tumours of the testis in rats and mice.

Long-term inhalation studies in rats exposed to aerosols of cadmium chloride, sulphate, and oxide fume and dust at low concentrations demonstrated a high incidence of primary lung cancer with evidence of a dose-response relationship. This has not so far been shown in other animals.

There is evidence that long-term occupational exposure to cadmium may contribute to the development of cancer of the lung, but observations from exposed workers have been difficult to interpret because of inadequate exposure data and confounding factors. The evidence to date is inconclusive, but does not support the suggestion from earlier studies that cadmium can cause prostatic cancer.

IARC (1987a) considered that there was sufficient evidence for the carcinogenicity of specified cadmium compounds in experimental animals and limited evidence for carcinogenicity in humans exposed to cadmium. A combined evaluation of human and animal data by IARC (1987b) classified cadmium as a probable human carcinogen (IARC group 2A). The IPCS Task Group found no reason to deviate from this IARC evaluation.[3]

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[3] For the most recent IARC evaluation, see Section 4.1.3 of this OECD Risk Reduction Monograph.

Critical organ and critical effect

The kidney is the critical organ for chronic cadmium poisoning. Within the kidney, the cortex is the site where the first adverse effect occurs. Therefore, in assessing dose-response relationships, the cadmium concentration in the kidney cortex is of prime importance.

The critical effect is renal tubular dysfunction, which is most often manifested as low molecular weight proteinuria. Animal studies indicate that histological changes in the renal tubules occur at a dose level lower than that needed to produce low molecular weight proteinuria.

Critical concentration in the kidneys

In animals

Several studies with data on both cadmium concentrations in the renal cortex and the occurrence of tubular damage were discussed in section 7.2.1. The findings were summarized in Table 12. They showed that histological tubular lesions or proteinuria was usually seen at cadmium renal cortex levels of 200-300 mg/kg wet weight. In some studies on rats, monkeys, horses, and birds, certain effects were seen at lower levels.

As no dose-response data are given in most animal studies, it may be assumed that these renal cortex levels correspond to a 50% response rate (CC_{50}). Naturally, the cadmium levels at which lower response rates occur would be lower.

In studies on monkeys conducted in Japan, kidney cadmium levels were related to dose and duration of exposure. At the two highest dose levels, acute liver effects occurred.

If one wishes to establish a range of values for the critical concentration in individuals at which a small but significant part of an exposed population will show effects, animal studies indicate that a renal cortex level of about 100-200 mg/kg is likely to coincide with such a range. There is some evidence that the average critical concentration (CC_{50}) could be as high as 300 or 400 mg/kg for the more severe signs of renal tubular damage, but such high levels should not be used as a starting point for calculations of "acceptable daily exposures".

In humans

Section 8.2.1.5 reviewed all available data from cases in which both renal cortex cadmium levels and renal effects were measured. Data from autopsies or biopsies have mainly been cross-sectional, i.e. the renal cadmium concentrations and the effects were measured more or less simultaneously. This has made it difficult to interpret the data from a critical concentration point-of-view, as the cases with the most severe cadmium-induced kidney dysfunction had the lowest renal cadmium levels. Cadmium is lost from the kidney when the damage progresses (section 6.5.1.2).

In vivo neutron activation analysis has provided a new tool for establishing the human critical concentration of cadmium in the renal cortex. Longitudinal studies measuring the renal cortex cadmium concentrations several times during continued exposure can now be carried out. The cadmium level at which the first measurable signs of renal tubular dysfunction occurs can be estimated. However, only two studies using *in vivo* neutron activation have been published to date, and both of them are cross-sectional.

The renal cadmium concentrations are disproportionately low when the liver cadmium concentrations are high and renal effects have developed. Of the several methods available to estimate the average critical kidney concentration in these groups of exposed workers, the method of preference assumes that the peak for renal cortex cadmium level, plotted against liver cadmium, is equivalent to the point where renal tubular dysfunction occurs. This results in a value of 319 mg/kg tissue (based on a ratio of renal cortex cadmium to whole kidney cadmium of 1.5). There is considerable variance in the individual values, the 95% tolerance (which corresponds to a confidence interval) being in the range $\pm$ 90 mg/kg from the mean. Other studies, using similar assumptions, have reported a value of 332 mg/kg, 10% of the workers having a peak cadmium level of about 216 mg/kg tissue. A re-evaluation of the original study resulted in a calculated cadmium level of about 200 mg/kg. It was concluded that for the purposes of dose-response calculations, using a metabolic model, this concentration could be used as a starting point for renal effects occurring in an exposed population.

Dose-response relationships for renal effects

Two approaches can be used to estimate dose-response relationships. One employs epidemiological data from industry and the general environment studying associations between exposure and response. The other begins with a critical concentration in the kidney cortex and employs a metabolic model to calculate, on the basis of certain given assumptions, the exposure that is required to reach a critical concentration.

Evaluation based on data on industrial workers

Table 16 contains data from various group studies on cadmium workers. In most of these studies, the dose measurements were based on short sampling periods (hours or a few days). However, exposure may have lasted for decades, levels usually being higher in the past. The use of protective devices may also confound the picture.

As discussed in section 8.3.2., there are now several reports available that show a clear exposure-response relationship between cadmium in workplace air and the prevalence of proteinuria.

An increased prevalence of overt proteinuria, as measured by sulphosalicylic acid, trichloroacetic acid, or quantitative determination of total proteinuria, can occur after only 5-10 years of exposure to approximately 100 μg cadmium/m^3. If instead, the increased excretion of low molecular weight proteins (more than 97.5 percentile of control group) is used as the critical effect, 10-20% of workers would have this effect after a cumulative dose corresponding to 10-20 years of exposure to 50 μg cadmium/m^3. These evaluations are all based on levels of total cadmium in inhaled dust or air.

Evaluation based on data on the general population

As indicated in chapter 8, there exists a considerable amount of information from epidemiological studies carried out on the general population in Japan. It was shown that in some areas of high cadmium exposure the prevalence of low molecular weight proteinuria was significantly higher than in control areas. This may be considered in relation to the known cadmium concentrations in rice and the daily cadmium intakes in the affected areas (Tables 7 and 17). Contamination of drinking-water in some areas may be a complicating factor (section 8.3.3).

Taking all of the data in section 8.3.3 together, it seems that, when the most sensitive method for diagnosis of low molecular weight proteinuria is applied, there is an association between cadmium exposure and increased excretion of low molecular weight proteins among some people over 50 years of age at a daily intake of about 140-260 μg cadmium or a cumulative cadmium intake of about 2000 mg or more (for both men and women).

Evaluation based on a metabolic model and critical concentrations

Using the data on critical concentrations and kinetic models of cadmium metabolism, attempts have been made to calculate the dose-response relationship for cadmium. Assuming that cadmium in the kidney is accumulated in accordance with a one-compartment model and that a third or a quarter of the body burden of cadmium is in the kidney (and making certain other assumptions indicated in Tables 20 and 21), the daily cadmium intake via food and the occupational air concentrations needed to reach the critical concentration have been calculated (Tables 20 and 21).

As the values calculated in Tables 20 and 21 are for an average person, not all of those exposed to these levels would have reached the renal cortex cadmium concentration of 200 mg/kg tissue or their individual critical concentrations. Nevertheless, these calculations produce values that are similar to the levels at which effects have been observed, and the model approach may be a useful way to quantify the response rates at levels lower than those easily measurable.

Calculations have been reported of the relationship between intake and response rates using the observed frequency distributions of daily intake and renal cortex cadmium concentrations, and utilizing multi-compartment metabolic model values in the same range as those given in Tables 20 and 21. Further development of these modelling techniques would be of value.

Using a single-compartment model for the accumulation of cadmium in the kidney, the average daily intake that would give rise to an average concentration of 200 mg/kg wet weight in the kidney cortex at age 50 would be 260-480 μg/day, assuming 5% gastrointestinal absorption, various biological half-lifes, and different proportions of the body burden in the kidneys (Table 19). Assuming a 10% absorption rate, the intake needed would be 140-260 μg per day. These estimates will vary depending on the body weight estimates for different populations.

Table 20. Calculated daily cadmium intake via ingestion required by a non-smoker to reach a kidney cortex concentration of 200 mg/kg at age 50 (using a one-compartment model)[a]

Gastrointestinal absorption rate (per cent)	Proportion of body burden in kidney	Estimated half-life cortex[b]	
		17 years	30 years
5	one-third	365 µg (286 µg)	265 µg (208 µg)
10		182 µg (143 µg)	133 µg (104 µg)
5	one-quarter	486 µg (382 µg)	353 µg (277 µg)
10		243 µg (191 µg)	177 µg (139 µg)

[a] The data in the table are based on the following assumptions:

gastrointestinal absorption, either 5% or 10%;
half-life in kidney cortex, either 17 years or 30 years (as reported in section 6.6.2);
one-third or one-quarter of body burden in the kidneys;
cadmium concentration in renal cortex 25% higher than renal average:
average weight of both kidneys at age 50 of 300 g for a 70-kg person or 235 g for a 55-kg person;
average cadmium concentration in foodstuffs constant during the last 50 years;
variation of daily intake with age has been disregarded since such variation would influence the values by less than 10%.

[b] Data have been calculated for a 70-kg person; values in parentheses are for a 55-kg person.

Table 21. Calculated concentration of cadmium in industrial air required for a kidney cortex concentration of 200 mg/kg to be reached[a]

Proportion of body burden in kidney	Estimated half-life in kidney cortex[b]	
	17 years	30 years
one-third	16 μg/m^3 (13 μg/m^3)	14 μg/m^3 (11 μg/m^3)
one-quarter	21 μg/m^3 (17 μg/m^3)	19 μg/m^3 (15 μg/m^3)

[a] The data in the table are based on the following assumptions:

those assumptions given in Table 20;
exposure time of 25 years;
225 working days per year;
10 m^3 of air inhaled per day;
25% pulmonary absorption.

[b] Data have been calculated for a 70-kg worker;
values in parentheses are for an average 55-kg person.

CONCLUSIONS AND RECOMMENDATIONS FOR PROTECTION OF HUMAN HEALTH

Conclusions

The kidney is considered the critical target organ for the general population as well as for occupationally exposed populations. Chronic obstructive airway disease is associated with long-term high-level occupational exposure by inhalation. There is some evidence that such exposure to cadmium may contribute to the development of cancer of the lung but observations from exposed workers have been difficult to interpret because of confounding factors.

General population

Food-borne cadmium is the major source of exposure for most people. Average daily intakes from food in most areas not polluted with cadmium are 10-40 µg. 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.

An association between cadmium exposure and increased urinary excretion of low molecular weight proteins has been noted in humans with a life-long daily intake of about 140-260 µg cadmium or a cumulative intake of about 2000 mg or more.

Occupationally exposed population

Occupational exposure to cadmium is mainly by inhalation but includes additional intakes through food and tobacco. The total cadmium level in air varies according to industrial hygiene practices and type of workplace. There is an exposure-response relationship between airborne cadmium levels and proteinuria. An increase in the prevalence of low molecular weight proteinuria may occur in workers after 10-20 years of exposure to cadmium in levels of about 20-50 $\mu g/m^3$. *In vivo* measurement of cadmium in the liver and kidneys of people with different levels of cadmium exposure have shown that about 10% of workers with a kidney cortex level of 200 mg/kg and about 50% of people with a kidney cortex level of 300 mg/kg would have renal tubular proteinuria.

Recommendations of IPCS for protection of human health

a) Measures to increase recycling of cadmium should be systematically examined and promising ideas encouraged.

b) Information on the importance of minimizing waste discharge of cadmium, particularly into surface waters, should be supplied to countries.

c) Public health measures for protection from cadmium exposures would be improved by:

   i) collection of more data from countries on cadmium levels in foodstuffs and the environment;

   ii) determination of tissue cadmium levels and monitoring of health parameters in non-exposed populations and in those living near mines or smelters or exposed to elevated levels of the metal in foodstuffs;

   iii) technical assistance to developing countries for the training of staff, particularly for cadmium analysis;

   iv) development of means of reducing cadmium exposure by, for instance, improved working conditions and the dissemination of information on the proper use of fertilizers (which sometimes contain high levels of cadmium), techniques for the disposal of cadmium-containing wastes, etc.

4.1.2 IPCS Environmental Health Criteria 135: Cadmium – Environmental Aspects

The International Programme on Chemical Safety (IPCS) is a joint venture of the United Nations Environment Programme, the International Labour Organisation, and the World Health Organization. The main objective of the IPCS is to carry out and disseminate evaluations of the effects of chemicals on human health and the quality of the environment. The Environmental Health Criteria documents prepared by IPCS contain the collective views of an international group of experts and do not necessarily represent the decisions or the stated policy of the United Nations Environment Programme, the International Labour Organisation, or the World Health Organization.

The following assessments of the risks from cadmium are quoted directly from Chapters 1, 9 and 10 of IPCS Environmental Health Criteria document No. 135: Cadmium – Environmental Aspects, published in 1992.

SUMMARY

Cadmium (atomic number 48; relative atomic mass 112.40) is a metallic element belonging, together with zinc and mercury, to group IIb of the periodic table. Some cadmium salts, such as the sulphide, carbonate, and oxide, are practically insoluble in water; these can be converted to water-soluble salts in nature. The sulphate, nitrate, and halides are soluble in water. The speciation of cadmium in the environment is of importance in evaluating the potential hazard.

The average cadmium content of sea water is about 0.1µg/litre or less. River water contains dissolved cadmium at concentrations of between <1 and 13.5 ng/litre. In remote, uninhabited areas, cadmium concentrations in air are usually less than 1 ng/m^3. In areas not known to be polluted, the median cadmium concentration in soil has been reported to be in the range of 0.2 to 0.4 mg/kg. However, much higher values, up to 160 mg/kg soil, are occasionally found.

Environmental factors affect the uptake and, therefore, the toxic impact of cadmium on aquatic organisms. Increasing temperature increases the uptake and toxic impact, whereas increasing salinity or water hardness decreases them. Freshwater organisms are affected by cadmium at lower concentrations than marine organisms. The organic content of the water generally decreases the uptake and toxic effect by binding cadmium and reducing its availability to organisms. However, there is evidence that some organic matter may have the opposite effect.

Cadmium is readily accumulated by many organisms, particularly by microorganisms and molluscs where the bioconcentration factors are in the order of thousands. Soil vertebrates also concentrate cadmium markedly. Most organisms show low to moderate concentration factors of less than 100. Cadmium bound to proteins (metallothioneins) have been isolated from cadmium-exposed organisms. The concentration of cadmium is greatest

in the kidney, gills, and liver (or their equivalents). Elimination of the metal from organisms probably occurs principally via the kidney, although significant amounts can be eliminated via the shed exoskeleton in crustaceans. In plants, cadmium is concentrated primarily in the roots and to a lesser extent in the leaves.

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

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 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. 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, salmonids being particularly susceptible to cadmium. Sub-lethal 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. There is no consistent interaction between cadmium and zinc in fish. Cadmium is toxic to some amphibian larvae, although some protection is afforded by sediment in the test vessel.

Cadmium affects the growth of plants in experimental studies, although no field effects have been reported. The metal is taken up into plants more readily from nutrient solutions than from soil; effects have been mainly shown in studies involving culture in nutrient solutions. Stomatal opening, transpiration, and photosynthesis have been reported to be affected by cadmium in nutrient solutions.

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. Birds are not lethally affected by the metal even at high dosage, 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.

EVALUATION

General considerations

In evaluating the environmental hazard of cadmium, it is necessary to extrapolate from laboratory studies to ecosystems. This must be done with extreme caution for a number of reasons.

a) The availability of cadmium to organisms in the environment is limited by its strong adsorption to environment components such as soil, sediment, and organic matter. Organisms in contaminated areas accumulate high body burdens of cadmium.

b) Environmental variables such as temperature, pH, and the chemical composition of water or soil have been shown to affect both the uptake and the toxic impact of cadmium.

c) Available, rather than nominal or total, cadmium is the determinant in assessing uptake by, and effects on, organisms.

d) There are limited data from controlled experimental studies on the effects of mixtures of metals. Organisms in the environment are exposed to mixtures of pollutants. Acid deposition can release metals, including cadmium, into the environment.

e) Little experimental work has been carried out on species or communities that are either representative or key components of natural communities and ecosystems. Studies have not considered all of the interactions between populations and all of the environmental factors affecting these populations. As a result, the impact of cadmium on ecosystems may have been underestimated.

f) Results from laboratory studies based on very sensitive parameters may be indicative of physiological impacts on individuals rather than impacts on ecosystems.

The aquatic environment

Cadmium input to the aquatic environment is through discharge of industrial waste, surface run-off, and deposition. It is strongly adsorbed onto sediments and soils. The average cadmium content of sea water is about 0.1 μg/litre or less, while fresh waters contain <0.01 to 0.06 μg/litre in unpolluted areas. Cadmium levels of up to 5 mg/kg and 0.03 to 1 mg/kg have been reported for freshwater sediments and marine sediments respectively.

The rate of uptake and the toxic impact of cadmium on aquatic organisms is greatly affected by physicochemical factors such as temperature, ionic concentration, and organic matter content.

Cadmium is translocated by aquatic plants and concentrated in roots and leaves. It is also taken up and accumulated by various aquatic animals. The toxicity of cadmium to freshwater organisms varies considerably depending on the exposure duration, species, and life-stage. The early life-stages and the reproductive system are the most vulnerable. Cadmium is, by comparison, one of the most toxic heavy metals in the freshwater environment. Manifest responses of certain organisms to cadmium are observed at environmental concentrations lower than 1 μg/litre.

Cadmium-induced kidney damage has been reported in sea-birds sampled from the field. However, this damage is present in both cadmium-polluted areas and areas remote from industrial contamination. The effect is probably, therefore, due to natural cadmium in certain species and areas.

The terrestrial environment

Cadmium is introduced into the terrestrial environment from mining, non-ferrous metal production, landfill sites and from the application of sewage sludge, phosphate fertilizers, and manure. Background concentrations of cadmium are in the range of 0.1 to 0.4 mg/kg soil and can reach 4.5 mg/kg in volcanic soils. Levels up to 160 mg/kg soil have been found close to metal processing sources.

Reduced breakdown of leaf litter and recycling of nutrients has been attributed to metal pollution in the field. Cadmium appears to be the most potent metal at inhibiting litter degradation. The effect is thought to be due largely to reduced populations of microorganisms, which are responsible for the final stages of litter decomposition.

Plants take up cadmium and can translocate and accumulate it. However, uptake from soil is limited. Where there is high-level exposure to cadmium (in the range of hundreds of mg/kg), growth reduction is the major effect. Plants exposed to cadmium in the field for long periods can develop tolerances to the metal. There is no evidence of adverse effects of cadmium on plant populations in the field.

Terrestrial invertebrates vary considerably in their sensitivity to cadmium. Some species can take up and store cadmium to levels of up to 5000 mg/kg body weight without apparent ill effects, while others show population effects at levels of a few mg/kg soil. Populations of some terrestrial invertebrates could be adversely affected at levels of cadmium contamination seen in the field. Isopods and earthworms are useful biomonitors for cadmium contamination. Invertebrates with high body burdens may pose a threat to predators.

Kidney damage was found in experimental birds fed 20 mg cadmium/kg diet for 12 weeks, but not at lower doses. Reproductive effects have been observed at 200 mg/kg diet. A dose of 4 mg/kg affected the behaviour of ducklings. No effects of cadmium have been seen in terrestrial birds sampled from the field, although the cadmium level in the brain, kidney, and liver of pigeons has proved to be a good indicator of urban cadmium contamination.

Small mammals accumulate cadmium in the vicinity of mining spoil. The ionic balance was affected in voles exposed experimentally to a concentration of 10 mg/kg diet.

Populations of terrestrial organisms may also develop tolerance to cadmium after long-term exposure.

RECOMMENDATIONS FOR PROTECTING THE ENVIRONMENT

To eliminate environmental effects, emissions of cadmium from the following sources should be reduced as far as is practicable:

- smelters
- incinerators
- sewage sludge applied to the land
- phosphate fertilizers
- cadmium-containing manure

4.1.3 International Association for Research on Cancer (IARC) evaluation of the carcinogenicity of cadmium and cadmium compounds

In 1969, the International Agency for Research on Cancer (IARC) initiated a programme on the evaluation of the carcinogenic risk of chemicals to humans, involving the production of critically evaluated monographs on individual chemicals. In 1980 and 1986, the programme was expanded to include evaluations of carcinogenic risks associated with exposures to complex mixtures and other agents.

The objective of the programme is to elaborate and publish in the form of monographs critical reviews of data on carcinogenicity for agents to which humans are known to be exposed, and on specific exposure situations; to evaluate these data in terms of human risk with the help of international working groups of experts in chemical carcinogenesis and related fields; and to indicate where additional research efforts are needed.

The IARC evaluation of the carcinogenicity of cadmium and cadmium compounds, from Volume 58 of the IARC Monographs (1993), is quoted directly below:

Evaluation

There is sufficient evidence in humans for the carcinogenicity of cadmium and cadmium compounds.

There is sufficient evidence in experimental animals for the carcinogenicity of cadmium compounds.

There is limited evidence in experimental animals for the carcinogenicity of cadmium metal.

Overall evaluation

Cadmium and cadmium compounds are carcinogenic to humans (Group 1).

In making the overall evaluation, the Working Group took into consideration the evidence that ionic cadmium causes genotoxic effects in variety of types of eukaryotic cells, including human cells.

4.1.4 Forty-first Report of the Joint FAO/WHO Expert Committee on Food Additives

The Joint Food and Agriculture Organization (FAO)/World Health Organization (WHO) Expert Committee on Food Additives met for the forty-first time in Geneva, Switzerland, on 9-18 February 1993. The WHO Technical Report Series, in which this report appears, makes available the findings of various international groups of experts that provide WHO with the latest scientific and technical advice on a broad range of medical and public health subjects.

The section of this report on cadmium is quoted directly below:

Cadmium was evaluated at the sixteenth and thirty-third meetings of the Committee. At the sixteenth meeting, the Committee allocated a Provisional Tolerable Weekly Intake (PTWI) of 400-500 μg of cadmium per person. At the thirty-third meeting, the Committee retained this PTWI, but expressed it in terms of the intake per kg of body weight (7 μg per kg of body weight). In 1992, the International Programme on Chemical Safety (IPCS) produced a monograph on cadmium, which provides a detailed description of the models on which the PTWI is based and the various assumptions used in their construction.

At its present meeting, the Committee concluded that the models on which the PTWI was based have been conservative. However, the PTWI does not include a safety factor, and the Committee reiterated the statement made in the report of the thirty-third meeting that "there is only a relatively small safety margin between exposure in the normal diet and exposure that produces deleterious effects".

Cadmium has an extremely long biological half-life in humans and is accumulated in body tissues, particularly in the liver and kidney. There are no available chelating agents to enhance cadmium excretion. Cadmium is a nephrotoxin and produces renal tubular dysfunction characterized by increased excretion of low-molecular-weight proteins, particularly β_2-microglobulin, which, together with excreted cadmium, serve as biomarkers measurable in the urine as indicators of toxicity. With continuous exposure to high levels of cadmium, the effects on the kidney become increasingly severe.

Daily intake of cadmium varies in different countries and in different regions within countries. Cadmium is normally present in low concentrations in soil, but is increased from emissions from smelting and refining of ores, waste disposal of cadmium-containing metal products, and application of cadmium-containing fertilizers to agricultural land. It is readily taken up by plants, including foodstuffs, and for non-smokers the major source of human exposure is dietary.

The average dietary intake of cadmium is approximately 10-50 μg per day in areas of normal exposure. The level may be considerably higher in certain countries, however, according to the Joint UNEP/FAO/WHO Food Contamination Monitoring and Assessment Programme.

The Committee expressed concern about the use of retrospective information for estimating the cadmium intake from the dietary intake of rice and the lack of information regarding the impact of age on the excretion of β_2-microglobulin. It recognized the need to validate the significance of the concentration of cadmium in the renal cortex regarded as critical in the general population (the "population critical concentration"), which should be investigated in new epidemiological studies.

Additional studies should be performed on the relationship of renal glomerular dysfunction to cadmium exposure and on the validity of the mathematical models for estimating the biological half-life of cadmium. An assumption made in using these models is that urinary excretion of 1000 µg of β_2-microglobulin per 24 hours or 1000 µg per g of creatinine is indicative of renal tubular dysfunction. The low-molecular-weight proteinuria associated with long-term cadmium exposure is not likely to be reversible. Epidemiological studies have shown that for people who excrete more than 1000 µg of β_2-microglobulin in the urine per 24 hours, the renal tubular dysfunction either does not improve or worsens within 5 years of reduction of cadmium exposure. The Committee was informed of epidemiological studies in Belgium and the Netherlands that suggest that the current PTWI may not be adequately restrictive to prevent renal tubular dysfunction from cadmium.

A question was raised regarding the relative bioavailability of cadmium from different foods, particularly grains or seeds that are used as food, and foods where cadmium may be bound to metallothionein and other proteins that limit bioavailability. For example, in a study in New Zealand, the serum concentration and urinary excretion of cadmium were found to be surprisingly low in a population with a high dietary intake of New Zealand buff oysters, which contain high levels of cadmium.

The Committee maintained the current PTWI of 7 µg per kg of body weight, pending future research.

In acknowledging the need for research in areas recommended in WHO Environmental Health Criteria, No. 134, the Committee wished to highlight the following topics:

1. Further studies on the dose-response relationship between cadmium intake (daily or accumulative) and renal dysfunction (β_2-microglobulinuria) in the general population.

2. Re-examination of the existing epidemiological information correlating cadmium intake and β_2-microglobulinuria among inhabitants in a cadmium-polluted region.

3. Examination of data on cadmium intake and its health effects among the general population in various countries, including data on cadmium concentrations in foods.

4. Evaluation of the critical concentration of cadmium in the renal cortex in two groups exposed to high and low levels of cadmium.

5. Studies on the chemical identity and bioavailability of cadmium compounds in food.

6. Re-examination of mathematical models for estimating the biological half-life of cadmium.

7. Studies on the involvement of renal glomeruli in chronic cadmium intoxication.

A toxicological monograph was not prepared.

4.2 National positions

Denmark

Today, extensive documentation on cadmium's potential harmful effects on man and the environment is available. Since cadmium is non-degradable, it will sooner or later almost inevitably be released to the environment, once it enters man-made circulation.

The goal is to limit the exposure of man and the environment to cadmium to the extent possible. In practice this means that the concentration of cadmium in the environment and the human exposure to heavy metals should not be allowed to increase from its present level, but, if possible, be reduced.

To reach this goal it is still necessary to limit the release of cadmium to the environment, and the Danish strategy is primarily aimed at limiting the use of heavy metals through substitution, and secondly at promoting recycling and treatment.

Danish experience shows that only a general ban on the use of cadmium will secure the desired reduction in its consumption.

In 1990 the stock of cadmium in products being used in Danish society was still expanding. Other things being equal, it should be taken as a warning signal that the cadmium problem is in no way solved, as the amount of cadmium which will need to be disposed of in the future and that may potentially be released to the environment is actually expanding.

There also still remains a small net supply of cadmium to agricultural soils in Denmark. This results in a continued increase in the exposure of the population via food.

The preventive approach applied in Denmark may be characterized as a dynamic process, in that focus in initiatives may change between the different fields of application of cadmium and between the different parts of the environment.

Considerable transboundary transport of cadmium is taking place, primarily with industrial products and secondly with waste products, by air and water. Therefore, limiting the exposure of man and the environment to cadmium has to be the objective of international efforts.

Norway

Cadmium has no known essential role in biological processes, but is a poison that is harmful both to the environment and human health. The risk reduction measures regarding cadmium should therefore be based on concern both for health and for the environment.

The emissions of today – direct or indirect – will if continued in the long term lead to serious problems.

Risk reduction of cadmium is clearly an international issue. Cadmium compounds and products containing cadmium, as well as airborne or waterborne cadmium as pollutant, will cross borders. International actions are therefore the most realistic solution in the long term.

Cadmium ought to be substituted wherever possible according to the technology available. It is most important to reduce/substitute the use of cadmium in those applications that give rise to direct emissions/spreading and those which involve the greatest risk of hazardous effects. Research and development should be encouraged to find environmentally acceptable substitutes for areas of application where these alternatives do not exist today, so that the use of cadmium in the long term can be phased out.

Meanwhile the amount of cadmium discharged to the environment should be minimized, and highly effective re-collection and recovery systems for cadmium-containing products should be established.

Sweden

There are serious concerns both for health risks from cadmium and for risks for the environment. In spite of all the measures taken to decrease emissions of cadmium, they are still too high and add all the time to the present cadmium contamination of agricultural soils and the environment. If continued, this may lead to serious problems in time.

In human beings, cadmium has serious effects and a very long biological half-life of several decades. Chronic renal effects have been seen among the general population. The recent Cadmibel study indicates that such effects may occur at even lower cadmium levels than previously believed. For certain population groups dietary intakes of cadmium are close to or may even surpass internationally agreed maximum limits. In Sweden, accumulation in agricultural soils of cadmium from fertilizers and atmospheric deposition has led to raised cadmium content in crops. Concentrations above the limit of 0.1 ppm cadmium proposed by WHO occur, particularly in spring wheat from limited areas in the southernmost agricultural region.

In the environment, cadmium affects many organisms, often at extremely low concentrations, and may also be accumulated to a high degree in many organisms. The aquatic toxicity of cadmium is affected by water hardness, making soft water lakes most vulnerable. In central and southern Sweden, where the cadmium load from airborne deposition is highest, it has been calculated that already today about 6000 acidified lakes have cadmium concentrations at or above the lowest effect levels determined in laboratory experiments. Acid rain increases the leaching of cadmium from soil to surface waters.

In a longer time perspective, there is also a risk connected with those uses of cadmium that give rise to cadmium-containing products and waste. The amount of cadmium accumulated in society is so great that already the release of a small fraction will cause serious contamination, if and when it reaches the environment.

The contamination of agricultural soils and different environmental media depends to a great extent on transboundary effects from cadmium in airborne pollutants and in fertilizers (and raw materials) that are traded. Hence, an international approach is needed.

It is possible to substitute cadmium in an increasingly large number of application areas. Recycling of cadmium is minor, due to, for example, difficulties in succeeding with the collection of cadmium products.

The goal for risk reduction of cadmium and its compounds should be a stepwise cessation of uses. In those cases where alternatives are not yet available, this should be complemented with effective recycling. Not less important is to hinder the flow of cadmium impurities via fertilizers to the environment and into the food chains.

The Swedish Parliament stated in 1991 that the use of cadmium in Sweden shall be reduced considerably. Already in 1982, many uses of cadmium were prohibited.

United Kingdom

Introduction

Cadmium is widely distributed throughout the natural environment, occurring in low concentrations in soil, water and air. Mobilization occurs both naturally and as a result of man's activities. Large-scale consumption of cadmium dates only from the 1940s, and any resultant dispersion into the environment is therefore relatively recent. Nevertheless, since cadmium is present in coal and in zinc ores, incidental losses of cadmium to the environment following the use of these materials have occurred for a longer period.

Cadmium metal is produced by the refining of complex sulphide ores in which it appears at low concentrations (primarily ores of zinc and lead). Cadmium and its compounds are now used in a wide variety of industrial and domestic applications, notably as a constituent in nickel-cadmium batteries, as a colouring or stabilizing element in plastics, and as a coating on metals to prevent corrosion.

Cadmium serves no known useful biological function, and accumulation in man continues for decades and possibly throughout life. The Government therefore accepts the view that whilst present environmental concentrations are such that average intakes are within currently accepted tolerable limits, it would be prudent to keep man's total intake of cadmium as low as practicable. To this end it will be necessary to consider ways of reducing exposure, and to take every opportunity to do so when appropriate, whilst taking into account the technical advantages of cadmium and the merits and availability of alternatives.

Health effects

The kidney is the critical target organ. Cadmium accumulates in the kidney and is only very slowly excreted because of a long biological half-life. Tubular dysfunction can occur when a critical concentration of cadmium in the renal cortex is exceeded: this is thought to be about 200 µg/g wet weight. This damage is characterized by an increased excretion of low molecular weight proteins in urine.

Inhalation of high concentrations of cadmium fumes can cause severe respiratory symptoms. Long-term occupational exposure to cadmium fumes may contribute to the development of lung cancer, but interpretation of studies of different groups of workers is complicated by exposure to confounding factors. Earlier reports of an association between occupational cadmium exposure and prostatic cancer have not been replicated in more recent studies.

Exposure

Cadmium can be taken up by plants and animals in freshwater, marine and terrestrial environments. Food is the main pathway by which man takes up the metal, with water beverages and respiration being less important. Cigarette smoking significantly increases intake.

In the population as a whole, average intake of cadmium is well below the Joint FAO/WHO Expert Committee on Food Additives provisional tolerable weekly intake of 0.42 mg per person. A mean dietary intake of 0.13 mg/week of cadmium was estimated from the 1988 UK Total Diet Study. The largest contributions to the estimated intake were made by the "bread and cereals" (28 per cent) and "potato" (21 per cent) food groups. Higher than average intakes may occur through the consumption of certain vegetables grown in soils with elevated concentrations of cadmium, arising from past metal workings or long-term application of sewage sludge and other fertilizers.

A report entitled *Cadmium in the Environment and its Significance to Man*, produced by the Department of the Environment in 1980, provided the first comprehensive assessment of the exposure pathways to humans and provided the basis of a subsequent risk minimization programme.

References

Department of the Environment, UK (1980) *Cadmium in the Environment and its Significance to Man: An Inter-Departmental Report*. Pollution Paper No. 17. HMSO, London. 64pp.

Ministry of Agriculture, Fisheries and Food, UK (1983) *Survey of Cadmium in Food: First Supplementary Report*. Food Surveillance Paper No. 12. HMSO, London. 54pp.

United States

Provisional risk statement

Several United States agencies concerned with the health and environmental effects of cadmium exposure, including the US Environmental Protection Agency (US EPA), the Agency for Toxic Substances and Disease Registry (ATSDR), the Food and Drug Administration (FDA), and the Occupational Health and Safety Administration (OSHA), have drawn a number of conclusions regarding exposure to cadmium.

The uses of cadmium create the potential for occupational and general population exposure through several pathways. Cadmium is used in many industrial and consumer products including batteries, pigments, metal coatings, plastics, synthetics and alloys (HSDB 1990; NTP 1989; US Bureau of Mines 1990). Releases to the environment and exposure can occur during various production and use activities, including the manufacture of cadmium-containing products, fuel combustion, zinc and lead mining and refining processes, application of phosphate fertilizer and sewage sludge to land, disposal of metals, and waste incineration (EPA 1985b; Elinder 1985). NiCd batteries are the number one contributor of cadmium to municipal solid waste (EPA 1989d).

Each year almost 90,000 workers in the United States are occupationally exposed to cadmium. These workers are primarily metal product fabricators, special trade contractors, and construction labourers (NOES 1990). The highest levels of exposure are expected to occur in operations involving the heating of cadmium-containing products by smelting, soldering, welding, or electroplating, and in the production of cadmium powders (OSHA 1990). Inhalation of particulate cadmium and ingestion of dust from contaminated hands, cigarettes, or food represent the main routes of occupational exposure (OSHA 1990). Expected to be at highest risk from cadmium exposure are people who both smoke and are occupationally exposed to cadmium (Elinder 1985).

Food is usually the largest source of cadmium exposure in the general population. In the United States, the largest contribution to adult intake of cadmium is estimated to be from grain, cereal products and potatoes which take up and retain cadmium from soil. Cadmium is more readily taken up by plants than other metals such as lead. In addition, people who eat large amounts of cadmium-concentrating foods (liver, kidney and shellfish) may have increased exposure (WHO 1977; Gartrell et al. 1986; Elinder 1985). Cigarette smoke contains cadmium and may double a typical individual's exposure (Elinder 1985). Although intake from air or drinking water is generally low, individuals who live in the vicinity of cadmium-emitting industries or incinerators may absorb amounts through the lungs that are as high as amounts typically ingested from food (Elinder 1985). Exposure through inhalation is probably diminishing due to pollution controls at facilities, but exposure resulting from soil contamination by phosphate fertilizers and land spreading of sewage sludge may continue to be significant (Elinder 1985).

FDA monitors cadmium in US food materials. The change in FDA diet models and improved analytical detection limits during the 1980s, coupled with general lowering of cadmium in US foods, indicates that the lifetime average daily intake is about 12 μg/day or about 14 μg cadmium/day for teenaged males.

According to FDA, in information provided to the US Department of Agriculture (USDA) and US EPA in 1992 to assist in preparing the garden food cadmium diet risk assessment for the sewage sludge regulation (40 CFR 405), different age and sex groupings received the following exposures in μg/d (Note: Because cadmium exposure limits should be focused on at least 50-year average exposures rather than maximum daily intakes, USDA and EPA calculated a lifetime daily average intake):

6-11 mo.	2 yr.	14-16 yr F	14-16 yr M	25-30 F	25-30 M	60-65 F	60-65 M	Life
3.42	6.09	9.48	13.7	9.70	13.1	8.86	11.4	11.9

It may be inappropriate to repeat the claim of Elinder that application of sewage sludges and fertilizers will necessarily increase Cadmium in crops. Extensive research in the US has shown that application of normal phosphate fertilizers from Florida (contain 5-10 mg cadmium/kg) have caused no increase in crop cadmium. Some very high cadmium phosphate fertilizers have caused increased crop cadmium on acidic soils. Any discussion about phosphate fertilizers should reflect the lack of a demonstrated effect of lower cadmium products even though they add measurable amounts of cadmium to soils. Similarly, application of low cadmium sewage sludge does not necessarily increase cadmium in crops, depending on the cadmium adsorption properties of the sludge in question. Application of some sludges actually decreases cadmium uptake by crops while increasing soil cadmium concentration. These relationships are complex, and the European claims that all sludges are dangerous are not supported by extensive US research. European claims generally do not consider the low bioavailability of cadmium in sludge-grown crops for almost all sludges. Sludge normally contains 100-200 times more zinc than cadmium, which both reduces cadmium uptake by plants and inhibits cadmium retention in animals which ingest the crops. These issues are discussed fully in the Technical Support Document for the 40 CFR 405 Rule.

Because of accumulation in the kidney and the relatively low margins of safety for human exposure, there is concern for dietary uptake by the general population. Once absorbed, cadmium accumulates in the liver and kidney through ages 50 or 60, and is excreted only very slowly (Kjellström and Nordberg 1978). Thus, older members of the population may be at greatest risk of cadmium toxicity. Since cadmium bioaccumulates, increasing the cadmium content in the food chain by even a small amount results in increased potential for human and environmental exposure. The use of cadmium-contaminated phosphate fertilizers and spreading of cadmium-containing sewage sludge on agricultural land is a considerable public health concern. As noted below, frank toxic effects have been seen in humans as a result of diets high in cadmium (an average lifetime dose of 200 μg/day), and the health effects of cadmium are being discerned at lower and lower levels of exposure (EPA 1989a).

Application of high cadmium concentration phosphate fertilizers and sludges is a matter of concern in the long term, although no valid demonstration of long term increase in crop cadmium has been reported according to USDA scientists. Previous Swedish claims about a long term increasing pattern in wheat cadmium concentrations were found to be an artifact, more dependent on soil pH decline and change in cultivars of wheat, than due to increase in soil cadmium. British research at the Rothamsted Experiment Station showed that air pollution and manure application did increase soil cadmium over the last century; however, wheat cadmium actually declined over time on the manure-amended soils, probably due to changes in the cadmium binding strength of the amended soil.

Frank cadmium toxicity (proximal renal tabular dysfunction) has been observed to occur when cadmium intakes from rice or tobacco were in excess of 200 μg/day over decades. However, these crops have been shown to cause much higher cadmium exposure and absorption than other food cadmium. The failure of the IPCS report on cadmium to deal fully with the details of the "oyster eater" study in New Zealand, and two large epidemiological studies in the UK and Germany, points out the continuing controversy about toxicity effects in soil cadmium. These western populations were exposed to garden vegetables grown in highly cadmium + zinc contaminated soils which allow exposures in excess of 200 μg/day, but do not cause the malnutrition promoted by rice which in turn increased the retention of diet cadmium.

Errors in interpretation of the diagnostic endpoint for B2-macroglobulin in urine can have caused excessive fear about diet cadmium. Older citizens with no cadmium exposure have increased variability and normal range on urinary low molecular weight proteins as compared to the younger persons who were the basis of the traditional "normal" limit. This error in the endpoint has caused error in allowable kidney cadmium concentrations, and is causing error about diet cadmium in normal foods. USDA research has found no one in the US who suffers from adverse health effects due to cadmium in the diet, nor have any such conditions been reported in available European studies. For example, the large Cadmibel study in Belgium which concluded that emissions of cadmium which contaminated soils caused a kidney health effect in older women was evaluated by a new study (in 1993) which failed to confirm this when the general population was examined in the same region.

Several toxic effects are attributed to inhalation and ingestion of cadmium, many of which appear to be irreversible. Two major types of adverse health effects can be distinguished – acute and chronic. Acute cadmium toxicity usually results from inhalation of cadmium at high-dose levels encountered in occupational settings. Breathing very high levels of cadmium severely damages lungs and can cause death or chronic respiratory impairment (Barnhart and Rosenstock 1984; Townshend 1982; Beton et al. 1966; Patwardhan and Finckh 1976). Ingesting high levels of cadmium severely irritates the stomach, leading to vomiting and diarrhea (ATSDR 1991).

Chronic low-level exposures through inhalation or ingestion, which are more likely to occur than acute high-level exposures, primarily lead to cadmium concentration in the kidneys, which can lead to renal tubular dysfunction, as mentioned above. Disturbances in kidney function may exert their effects on bone and mineral metabolism, leading in extreme cases to osteoporosis and osteomalacia. Additional health effects identified in animal studies include liver damage and possible harm to offspring of females exposed to cadmium. Other health effects are specific to the route of exposure. Lung damage, an effect of high acute inhalation exposures, has also been demonstrated at lower inhalation exposure levels. Significant immune suppression effects have been observed with oral exposures of laboratory animals at levels below that required for renal toxicity (EPA 1981). Ingestion of cadmium by animals has resulted in iron-poor blood, increases in blood pressure, and nerve or brain damage (ATSDR 1991). Based on the health effects of ingesting cadmium, EPA has established an RfD, defined as an estimate of daily exposure to the human population (including sensitive subgroups) that will likely be without appreciable risk of deleterious effects during a lifetime. This value has been set at 5×10^{-4} mg/kg-day and 1×10^{-3} mg/kg-day for ingestion of drinking water and ingestion of food, respectively. An RfD for inhalation is under review (IRIS 1992). Dermal contact has not been shown to cause health effects in animals or humans (ATSDR 1991).

Inhalation of cadmium may cause lung cancer in humans. Animal studies have shown that prolonged exposure to cadmium dust and fumes causes lung cancer (Oldiges et al. 1989; Takenaka et al. 1983). In addition, increased rates of lung cancer have been found in one cohort of workers occupationally exposed to cadmium, although these workers were also exposed to other known carcinogens, suggesting that cadmium exposure may not have been the cause of the increased number of lung cancers (Thun et al. 1985., as cited in ATSDR 1993). This limited evidence in humans and lack of sufficient data in animals have led the EPA to classify cadmium as a probable human carcinogen (Group B1) (ATSDR 1991; IRIS 1992). In addition, the Department of Health and Human Services (DHHS) has determined that cadmium and certain cadmium compounds may be reasonably anticipated to be carcinogens, and the American Conference of Governmental and Industrial Hygienists

(ACGIH) has recommended that cadmium be classified as a suspected human carcinogen based on animal studies (ATSDR 1991; AIH 1990). Studies have not shown that ingesting cadmium causes cancer in either humans or animals.

ATSDR has developed a toxicological profile for cadmium because the metal is considered hazardous and is commonly found at facilities which are priorities for remediation under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 (ATSDR 1991). ATSDR has determined Minimum Risk Levels (MRLs) for inhalation and oral exposures. An MRL is an estimate of daily human dose levels of a chemical that are likely to be without appreciable risk of adverse non-cancerous health effects over a specified duration of exposure (ATSDR 1991).

Recognizing the need for better information, several organizations have sponsored research on cadmium. Sponsors of health effects research include the US Department of Energy (DoE), the USDA, the National Institutes of Health (NIH), and the National Institute of Environmental Health Sciences (NIEHS). USDA indirectly sponsors research on the potential for ecological and human exposure to cadmium by supporting research on uptake of cadmium into plants. USDA similarly conducts research on cadmium in soils and foods. For example, because of German demands for lower cadmium in food sunflower kernels and flax, the US has had to conduct extensive research on genetics of cadmium uptake by these crops and soils and agronomic management factors which affect cadmium in these crops. US companies are subsequently breeding lower cadmium genotypes of sunflower, and will do so for flax and durum wheat. However, these efforts represent huge costs compared to the benefits which might be obtained. Further, other plant breeding goals (yield and disease resistance) must be neglected if cadmium concentration is to be given priority because of market limitations.

The US Fish and Wildlife Service (FWS) sponsors analyses of cadmium content in fish and wildlife (ATSDR 1991). The Centers for Disease Control (CDC), in order to determine the frequency of occurrence and background levels of metals in the general population, will be analyzing human urine samples for cadmium and other metals as part of the Third National Health and Nutrition Evaluation Survey (NHANES III) (Paschal 1990).

Documents referenced

References for the United States entries in Chapters 4 and 5 of this Risk Reduction Monograph are listed together at the end of the United States entry in Chapter 5.

CHAPTER 5

MECHANISMS FOR RISK REDUCTION

Many OECD Member countries have taken steps to reduce unacceptable human and ecosystem risks from exposure to cadmium. Requests for information on cadmium risk reduction activities were made to all Member countries. The submissions received contain discussions of steps taken in the past to reduce cadmium exposure, as well as current activities and future measures contemplated.

The measures taken to reduce exposure to cadmium vary from country to country. The general base line consists of mostly comparable environmental quality criteria, and permissible levels, to limit emissions into air, water, soil and food. Many countries control the input of cadmium to the environment from contaminated products, e.g. fertilizer, sludge and manure. Measures to reduce or ban the use of cadmium in products show considerable variability between countries. In many countries regulations or voluntary programmes are aimed at the labelling, collection and recycling of NiCd batteries.

Some national risk reduction measures are shown in the tables in **Annex A** to this chapter. Absence of information on a particular Member country does not mean that risk reduction activities have not taken place in that country.

Australia

Risk reduction measures in Australia have been based on recognition of the known toxicological effect of accumulation of cadmium, together with the identification of the major sources of human exposure. There are currently standards for the maximum permissible levels of cadmium in air, water and food. Food is recognized as the major source of cadmium intake for the general population, while occupational exposure is largely the result of intake via inhalation.

The current maximum acceptable levels of cadmium in *food* are based on the provisional tolerable weekly intake of 7 µg/kg/day established by the joint FAO/WHO Expert Committee on Food Additives. The maximum levels (mg/kg) are as follows:

Beverages and other liquid foods	0.05
Bran	0.2
Crustaceans	0.2
Cocoa	0.5
Cocoa paste	0.35
Chocolate	0.25
Fish	0.2
Edible offal other than liver	2.5
Liver	1.25
Meat muscle	0.2
Molluscs	2.0
Seaweed (edible kelp)	0.2
Water	0.005
Wheat germ	0.2
All other food	0.05

While the contamination of food by cadmium may be the result of several factors, it is recognized that the contamination of soils through the use of phosphate fertilizers is a major source of cadmium for plants and animals and subsequently humans through the food chain. Consequently, the Fertiliser Industry Federation of Australia (FIFA) has agreed to new voluntary maximum concentrations for cadmium in fertilizers (mg cadmium/kg phosphorus) as follows:

1993 450

l995 350

2000 300

Table 5.1 Elements of Australian National Risk Reduction Strategies for Cadmium

Medium	Material	Type of standard	Value of standard	Legislation
Air	ambient		–	
	working place	quality for indoor air	50 µg/m^3	
		emission limits	3 mg/m^3	in most states of Australia
Water	drinking water	quality	5 µg/litre	
	potable water	quality	5-10 µg/litre	in different states of Australia
	irrigation water		10 µg/litre	
	mining drainage	effluent		
	effluent	emission	0.01-0.2 mg/litre	in different states of Australia
	fresh water	quality	0.2-5 µg/litre (based on chronic toxicity levels to aquaculture)	in different states of Australia
	sea water	saline water quality	2-40 µg/litre (based on chronic toxicity levels to aquaculture)	in different states of Australia
Soil	assessment criteria for contaminated sites	quality	env. investigation level 5 mg/kg health investigation level 20 mg/kg	recommendation

Source: N. H. Clark, personal communication to Environment Protection Agency

The voluntary maximum concentration for cadmium in fertilizer used for horticulture is 250 mg per kg of phosphorous. It is proposed that non-phosphate fertilizers and soil amendments containing less than 2 per cent phosphorus be limited to 10 mg cadmium per kg and trace element supplement be limited to 80 mg cadmium per kg.

The National Occupational Health and Safety Commission (NOHSC) exposure standard for cadmium is currently 0.05 mg/m^3 time weighted average (TWA) over an eight-hour working day, for a five-day working week. The occupational health surveillance requirements for cadmium are under review and a new standard of 0.01 mg/m^3 has been proposed. NOHSC lists cadmium as a category 2 carcinogen (carcinogen proven in animals, evidence insufficient in humans).

The Australian Water Quality Guidelines set a maximum of 0.2-2.0 µg/litre cadmium (depending on water hardness) for the protection of aquatic ecosystems. The limit for drinking water is currently 5 µg/litre, but a new draft guideline of 2 µg/litre has been proposed. For other uses, such as irrigation of livestock, the guideline is 10 µg/litre.

The Australian and New Zealand Guidelines for the Assessment and Management of Contaminated Sites propose a health investigation level for cadmium of 20 mg/kg. Disposal of wastes at sea requires a permit to be issued under the Environment Protection (Sea Dumping) Act 1981. One permit issued under this Act specifies that the waste should not contain more than 0.035 per cent total cadmium (dry weight) and not more than 0.016 per cent soluble cadmium (dry weight).

Australian Standard 1647 specifies the maximum permissible concentration of leachable cadmium in coating, plastics, graphic and printed materials for children's toys of 100 mg/kg using a hydrochloric acid leaching test. AS 1647 also sets the maximum permissible concentration of cadmium in modelling materials as 0.05 mg/kg.

Austria

According to the Austrian Chemicals Law, the Government prepared a prohibition to place on the market or use cadmium and cadmium compounds as pigments, stabilizers and for plating of metal surfaces (cadmium ordinance 855/1993) which entered into force on 1.1.1994. Pigments and lacquers may not contain more than 0.01 per cent of cadmium as an impurity. If the zinc content of the pigments is high they may contain 0.1 per cent of cadmium at most. Zinc platings on metal surfaces may not contain more than 0.025 per cent of cadmium. There are several exemptions to this ban, covering for example artist's colours, colours for glass, ceramics and enamel, products containing recycled plastics and products where cadmium plating is needed for safety reasons (Ministry of the Environment, Youth and Family, 1993).

Ordinance 97/1992 (Ban of Certain Dangerous Substances in Plant Protection Products) prohibits the use of cadmium compounds as additives in plant protection products. Ordinance 647/1990, concerning the ban of specific lubricant additives and the use of chain-saw oils, prohibits the use of cadmium and its compounds as additives.

Waste containing cadmium is considered as hazardous waste. The following groups are important: non-ferrous metal dusts, rechargeable NiCd batteries, electroplating sludge, heavy-metal sulphides.

There are regulations concerning the labelling of NiCd accumulators with a recycling symbol.

The limit value of cadmium in drinking water is 5 µg/litre and in groundwater 3 µg/litre.

The quality standard of food is between 0.002 mg/kg and 1.0 mg/kg cadmium.

The limit value for sewage water is 0.1 mg/litre.

Belgium

Belgium has signed the Ministerial Declaration of the Third International Conference on the Protection of the North Sea, which is aimed at a 70 per cent reduction of the total cadmium input between 1985 and 1995.

Use trend and replacement of cadmium

No pigments containing cadmium are being produced in Belgium. Following the substitution of cadmium pigments, especially in PVC, a strong reduction in the import of cadmium pigments has been noticed. The use of cadmium pigments in paints ended some years ago.

The use of stabilizers in plastics has decreased strongly, following the introduction of EEC standards regulating the use of cadmium stabilizers in PVC packaging for food (84/500/EEC) and for PVC toys (88/500/EEC). In Belgium, only imports from the EU are significant.

The main reduction in the use of cadmium plating occurred in Belgium when the car industry substituted cadmium by NiZn alloys, especially in brake systems. This accounted for an 80 per cent reduction between 1984 and 1988. No NiCd batteries are being produced in Belgium.

Restrictions of use

The use of cadmium has been regulated by the EU Directive 91/338/CCE.

Labelling, collection and recycling of NiCd batteries

NiCd batteries in Belgium are labelled on a voluntary basis with the information that the batteries contain cadmium.

Collection of NiCd batteries as small dangerous waste is organized by each municipality. Consumers are informed (information leaflets, press, media) about the nature of small dangerous wastes, and how to recognize, store (e.g. in special "milieboxes") and dispose of them (possibilities of mobile or fixed collecting points). Whereas collection is still the responsibility of the municipalities, legislation is in progress giving responsibilities to the retailer or importer. The choice may differ, according to regions.

Quality standards and emission and immission limits

- quality of drinking water: 5 µg cadmium/litre
- fertilizers: 2.5 mg cadmium/kg d.w.
- animal food: 0.75-2 mg cadmium/kg (12 per cent humidity)
- air emission from non-ferrous metal industry: 22 µg cadmium/m^3
- immission (ambient air): 40 ng cadmium/m^3
- incineration of waste: 0.5 mg cadmium/ m^3
- dust precipitation: 5 µg cadmium/m^2/day
- sewage sludge for agricultural use: 12 mg cadmium/kg d.w.
- soil: 1-3 mg cadmium/kg d.w.
- soil supply: 150 g cadmium/ha/year

Generally, mean values for cadmium concentrations are lower than the accepted standards. However, near point sources concentrations may be extremely high.

Canada

Risk reduction measures in Canada have been taken based on the known, inherent toxicological properties of cadmium. A number of programs have specific safety standards. These include: (1) controls on cadmium in foods and ceramic glazes on food containers; (2) a prohibition of cadmium use in toys; (3) safety labelling, handling and packaging for transportation; (4) controls in the workplace; (5) national guidelines for drinking water quality, compost, and municipal solid waste incinerator emissions and guidelines for the protection of freshwater aquatic life.

A comprehensive assessment of the risks posed by cadmium to health and the environment was recently completed as part of the *Priority Substance Program* mandated under the *Canadian Environmental Protection Act* (CEPA). This program is designed to ascertain whether Priority Substances in the environment pose a risk to the environment or to the health of the Canadian general population (i.e., whether they are "toxic" as defined under CEPA), and then to take appropriate measures to control substances deemed "CEPA toxic". In this assessment, it was concluded that dissolved and soluble forms of inorganic cadmium are "CEPA toxic", inasmuch as they are entering the environment under conditions that are having or may have a harmful effect on the environment, and that may constitute a danger to human life or health. Options to further control risks from exposure to cadmium in the general environment are currently being considered, in consultation with stakeholders.

Occupational exposure is primarily a provincial responsibility; however, there is a national program called the *Workplace Hazardous Materials Information System* (WHMIS). This system ensures that standardized *Material Safety Data Sheets* (MSDS) are available in the workplace, and that the associated hazards of controlled products are communicated by the MSDS. The presence of cadmium and its compounds in controlled products must be disclosed. Worker training and safe labelling practices are also mandated under WHMIS.

There have also been voluntary industry initiatives with regard to cadmium. At least one Canadian small appliance manufacturer is taking a life-cycle approach to its cordless appliances. Appliances are designed to enable easy removal of NiCd batteries for recovery. The company has set up a return system for its products that is easy for its customers to use. In addition, one Canadian automobile manufacturer has eliminated all cadmium fasteners in its new vehicles, as of 1992. Other manufacturers are expected to follow this voluntary action.

Canada does not have regulations for management or recycling of NiCd batteries; however, a voluntary program is being initiated for the collection and recycling of batteries across Canada. At present, some industries operating in Canada have already established their own voluntary program for recycling NiCd batteries.

Quality guidelines, emission and emission limits

Soil contamination is being addressed by the Canadian Council of Ministers of the Environment (CCME), under the joint federal/provincial initiative known as the *National Contaminated Sites Remediation Program*. Interim criteria have been established for the assessment and remediation of water and soil in the context of agricultural, residential/park land, and commercial/industrial land uses. These criteria are currently undergoing a validation and review process. The new criteria should be available shortly (1994/1995). The CCME has made a commitment to limit cadmium concentration in waste effluent streams from hazardous waste treatment plants to 0.1 mg/litre (CCME 1989).

Control of point sources of emissions or discharges is principally instituted at the provincial level. Under the CCME, guidelines for operating and emission levels have been set for municipal solid waste, where 100 μg Cd/m^3 is the recommended stack discharge limit for incinerators. Leaching of cadmium from landfill sites, and cadmium levels in sewage or wastes, are controlled through provincial legislation and local, municipal regulations.

Canadians ingest trace amounts of cadmium in foods, mostly from cereal products, shellfish, baked goods, pasta, potatoes, and some leafy vegetables. The provisional tolerable weekly intake for cadmium is 7 μg/kg body weight/week. The recommended provisional tolerable daily intake should not exceed 1 μg/kg body weight/day. These recommendations are based on technical reports of the Joint FAO/WHO Expert Committee on Food Additives.

The Canadian water quality guideline for cadmium in drinking water is 5 μg/litre. The Canadian environmental quality guideline for the protection of freshwater aquatic life is related to water hardness and ranges from 0.2 μg/litre for soft water (0-60 mg/litre $CaCO_3$) to 1.8 μg/litre for very hard water (>180 mg/litre $CaCO_3$). The environmental quality guideline for water used for livestock watering is 20 μg/litre, and for irrigation is 10 μg/litre.

Table 5.2 Canadian Environmental Regulations, Guidelines and Recommendations for Cadmium

Medium	Material	Type of standard	Value of standard	Regulations/guidelines/ recommendations	Year published/ in effect
Air	ambient		–	regulated at provincial level	
	working place	quality for indoor air	0.05 mg/m^3	regulated at provincial and federal levels (Canada Labour Code and Regulations; Hazardous Products Act and Control Products Regulations)	
Water*	drinking water	quality	5 µg/litre	Drinking Water Guideline - Federal/Provincial Committee on Drinking Water	1978
	fresh water	quality	0.2 µg/litre-1.8 µg/litre depending on water hardness	Canadian Water Quality Guideline - Canadian Council of Ministers of the Environment (CCME)	1987
	irrigation water	quality	10 µg/litre	Canadian Water Quality Guideline - Canadian Council of Ministers of the Environment (CCME)	1987
	industrial effluent	effluent	1.5 mg/litre	Metal Finishing Liquid Effluent Guidelines	1977
	industrial effluent	discharge to publicly owned sewage treatment plants		Provincial Guidelines	
Soil	remediation criteria for contaminated sites	solution analysis	3 mg/kg dry weight for agricultural soil 5 mg/kg for residential soil 20 mg/kg for commercial/industrial use	Interim Canadian Environmental Quality Criteria for Contaminated Sites - CCME	1991
Wastes	waste considered for ocean dumping	quality for sea dumping	0.6 mg/kg in solid phase 3.0 mg/kg in liquid phase	Ocean Dumping Regulations - under CEPA Part VI	1988
	criteria for contaminated waste and labelling	safety	0.5 mg/litre	Transportation of Dangerous Goods Act/ Transportation of Dangerous Goods Regulations	1992/ 1985
	sewage sludge	safety	20 mg/kg dry weight	Metal concentration of processed sewage and by-product Guidelines under Federal Fertilizer Regulations	
	hazardous waste treatment plants	effluent	0.1 mg/litre	National Guidelines on Physical-Chemical-Biological treatment of Hazardous Wastes	1989
Food			7 µg/kg-bw/week 1µg/kg-bw/day	Recommended Provisional Tolerable Weekly Intake and Provisional Tolerable Daily Intake - FAO/WHO Joint Expert Meeting	
Consumer goods	toys, equipment, etc.	quality	0.5 ppm into 4 per cent acetic acid 68°F for 18 hours	Hazardous Products Act (Chapters 925 and 928)	

** Although no guidelines or regulations are in existence for controlling cadmium from mining effluent, regulations and guidelines do exist to reduce other metals in mining effluent and have resulted in the reduction of cadmium in the effluent.*

The Canadian tolerance for cadmium in sludge-based products is 20 ppm. The maximum acceptable cumulative long-term (over 45 years) metal addition to soil is 4 kg Cd/ha. This limit is currently under review. The guideline for acceptable levels of cadmium in phosphate fertilizers is based on the sludge standard. Cadmium present in phosphate fertilizers is largely dependent on the cadmium content of phosphate rocks used to make the fertilizer. Most provinces also have guidelines limiting the cadmium content of sludge applied to agricultural soils.

Centralized composting sites are becoming increasingly widespread as a result of recycling activities. The number of centralized private and municipal composting facilities throughout Canada has more than tripled, from 30 sites in 1989 to over 120 sites in 1994. The amount of cadmium that is allowed in compost is regulated under Agriculture Canada's Fertilizers Act with a maximum concentration of 20 mg/kg. The Canadian Council of Ministers of the Environment (CCME) is presently working on a national set of guidelines for compost which recommends a maximum cadmium concentration set also at 20 mg/kg.

In Canada, disposal at sea is only permitted for non-hazardous substances and where it is the environmentally preferable and practical alternative. Permits are not granted if practical opportunities are available to recycle, reuse or treat the waste. Canada controls disposal at sea and meets its international obligations under the London Convention 1972 by means of a permit system since 1975. The Canadian Environmental Protection Act (CEPA) Part VI is the enabling legislation for the permit system and includes provisions for making regulations. Under the Ocean Dumping Regulations (1988), materials containing cadmium can be authorized for ocean disposal only if cadmium occurs at or below the regulated levels (i.e. in the solid phase of waste 0.6 mg/kg, and in the liquid phase of a waste, 3.0 mg/kg).

Applications for disposal of dredged or excavation material must include concentrations of cadmium in the material proposed for sea disposal. In keeping with recent decisions made at the London Convention 1972, Canada is in the process of amending the Ocean Dumping regulations (1988) to prohibit sea disposal of industrial wastes.

A summary of quality standards, emission and emission limits is given in **Table 5.2** as well as in the summary tables annexed to Chapter 5.

Consumer information

There is continuing concern about potential adverse effects of cadmium resulting from its use in certain hobbies and crafts, particularly metalworking, pigments used in fine art, dyeing, printing and pottery. Public information booklets and posters have been distributed to targeted groups.

Cadmium levels are high in organ meats of some game animals in Canada, particularly in liver and kidneys of musk oxen, caribou, deer, and moose. Provinces, the territories, and the federal government have issued health advisories to ensure that consumption of these organs does not lead to health problems. The high levels in the game animals (and perhaps elsewhere) are considered to be due, in large part, to elevated soil and plant levels.

Cigarette smoking is another source of cadmium exposure. Data indicate that, while cadmium levels have decreased, smokers inhale approximately 200 ng/cigarette. Consideration is being given to requiring disclosure of cadmium levels in tobacco products. The Canadian strategy for addressing risks from smoking is a program of strict controls on tobacco advertising.

Denmark

The accumulation of cadmium in the environment can only be halted by preventive efforts based on the concept of cleaner technology in the total consumption of cadmium.

Surface treatment, pigment and stabilizer

The first major initiative in Denmark was taken in the beginning of the 1980s, when time limits for use of cadmium in the then dominant applications (surface treatment, pigment or stabilizer in plastics) were established. After ten years it can be documented that the time limits have been respected. Today the consumption of cadmium, for the uses concerned, in reality has stopped. During the same period, however, the consumption of rechargeable batteries containing cadmium has grown exponentially. This has counteracted the obtained gain. This example illustrates that only a general ban on the use of cadmium will secure the desired reduction in its consumption.

Measures

Measures aimed at reducing the use and consumption of cadmium and promoting recycling and treatment include:

- Bans, i.e. legal regulation
- Agreements between the Minister for the Environment and trade associations
- Economic incentives, such as subsidies for research/development work
- Development and dissemination of knowledge

In Denmark the maximum concentration of cadmium allowed in drinking water is 5 µg/litre, and the maximum dissolved amount of cadmium in the surface area of ceramics may not exceed 0.1 mg/dm^2 of the surface area when cooked for 3 ½ hours in 4 per cent acetic acid.

In **Table 5.3** important Danish regulations affecting consumption or recycling of products containing cadmium are listed, together with regulations affecting application of cadmium containing residual products and emissions to air and water.

Table 5.3 Danish Cadmium Regulations

Medium	Regulation	Legal basis
Products	Ban on sale, import and manufacturing of products in which cadmium is used as surface treatment, pigment or stabilizer.	Statutory order No. 396 1983, and No. 1199, 1992
Phosphate fertilizers	Threshold values concerning the content of cadmium in phosphate fertilizers. Present limit value 150 mg Cd/kg P. From July 1995, the limit value will be 110 Cd/kg P.	Statutory order No. 223
Rechargeable batteries	Agreement concerning the establishment of a voluntary collection arrangement for rechargeable batteries containing cadmium (information campaign and fee arrangement).	Agreement between the Minister for the Environment and the Association for collection of rechargeable batteries, 1991, and statutory orders No. 10 and 15, 1992
Waste	Threshold value concerning the content of cadmium in clinker and fly ash originating from combustion of solid waste used for construction purposes. Limit value 10 mg/kg dm.	Statutory order No. 568, 1983
Waste	Threshold values concerning the content of cadmium in sewage sludge, waste water, compost, etc. to be used for agricultural purposes. Present limit value 12 mg Cd/kg dm or 320 mg/kg P. From the year 1995, the limit value will be 0.8 mg Cd/kg dm or 200 mg Cd/kg P.	Statutory order No. 736, 1989, and No. 227, 1991
Water	Threshold value concerning the discharge of cadmium by waste water from certain industrial activities. Limit value 0.2 mg/litre.	Statutory order No. 10, 1991
Air	Threshold values concerning the emissions from solid waste incineration plants. Limit value 0.2 mg Cd + Hg/Nm^3.	Statutory order No. 10, 1991
Air	Demands utilization of the best air cleaning techniques available. Threshold values concerning emissions to air from industrial manufacturing activities.	Guideline No. 6, 1990

Future action

Development and testing of heavy metal-free products is included in the Danish Cleaner Technology Action Plan 1993-97 and comprise, among other things, alternatives for NiCd batteries.

Rapid progress is taking place worldwide within the field of rechargeable batteries, and it is likely that a wide selection of alternatives to NiCd batteries will be available in a few years.

Denmark has the intention of reaching a rate of re-collection of 75 per cent of the NiCd batteries, and has imposed a fee on NiCd batteries. This is based on an agreement between the Minister for the Environment and the Danish Association for Rechargeable Batteries. This goal has not been reached yet, and other instruments to reduce the amount of NiCd batteries in general and in the waste stream (i.e. increasing the fee deposit systems, tax on NiCd batteries) will be examined.

Furthermore the use of heavy metal free products will be promoted by information to the public and the implementation of a "green" procurement policy for government agencies in Denmark along with the eco-label award scheme.

The future regulations and guidelines from the Danish EPA concerning reduction of emissions will to the extent possible be based on the principle that environmental requirements should be based on what can be obtained by using the least polluting technology. A number of specific initiatives directed towards different industrial branches (galvanization industry, companies recycling metals) are taking place.

(Also see the section on Nordic countries below.)

Finland

Regulations on direct emissions of cadmium

According to the provisions of the Water Act (264/61) the emitting industry shall apply for permission to discharge wastewater. The Water Courts will issue permission for a certain period. The maximum total load and, in some cases, the maximum concentrations are established in the permission. The limit value of 0.2 mg/litre for cadmium discharges has been set for some industries by Council of State Decision 363/94 (implementation of Directive 83/513/EEC).

According to the Air Protection Act (67/82), the emitting industry has to apply for a licence from the County Council or the municipal authorities. These issue permits which include regulations on maximum emissions and emission monitoring.

Wastes containing cadmium are generally hazardous wastes and are subject to special requirements for hazardous wastes under the Waste Act (1072/93). In individual cases the handling of waste containing cadmium is supervised through waste permit procedures.

Fertilizers and sludge

The maximum permitted content of cadmium in agricultural and garden fertilizers is 50 mg cadmium/kg of phosphorous.

Concentration of cadmium in sludge (dry weight) may not exceed 3 mg/kg. Sludge may only be used on soils which have a cadmium concentration below 0.5 mg/kg d.w. The concentration of cadmium in sludge has been decreased by restricting cadmium discharge from industrial enterprises to public sewers.

NiCd batteries

Regulations concerning the use, delivery, labelling and collection of cadmium-containing batteries are under preparation. Directives 91/157/EEC and 93/86/EEC are implemented by administrative decision.

Restrictions of use

A provision containing similar restrictions to those of EEC Directive 76/769, 10th amendment, has been enforced in Finland. Consequently, the use of cadmium compounds in certain plastics such as pigments and stabilizers, and the use of cadmium in certain metal plating applications, is prohibited

Food and drinking water

According to a decision by the Ministry of Trade and Industry (169/93) the maximum allowable concentration of cadmium in food is as follows (mg/kg):

Fish and fish products	0.1
Molluscs and mollusc products	0.5
Potato	0.05
Other vegetables	0.1
Crustaceans and crustacean products	0.3
Raw cereals and products thereof, excluding bran, germs, durum wheat	0.1
Bran, germs, durum wheat	0.15
Cereals	0.1

According to a Decision by the Ministry of Social Affairs and Health (74/94) the maximum allowable concentration of cadmium in drinking water is 5 μg/litre.

According to a Decision by the Ministry of Trade and Industry (267/92) the limit values for leakage from ceramic objects are as follows: non-fillable objects 0.07 mg/dm^2, fillable objects 0.3 mg/litre, cooking appliances and others 0.1 mg/litre (implementation of EEC Directive 84/500). The limit value for the migration of cadmium from toys is 75 mg/kg toy material, except for finger paints and modelling clay where the limit value is 50 mg/kg.

Occupational environment

The maximum permitted concentrations of cadmium compounds and cadmium oxide fume in an occupational environment are 0.02 mg/m^3 and 0.01 mg/m^3, respectively. This regulation has been issued by the Ministry of Labour.

According to the decision of the Ministry of Labour, cadmium and its compounds should be considered carcinogenic. Information regarding workers exposed to these compounds is to be recorded in a special data base. The employer maintains a list of the compounds and exposed workers, and the Institute of Occupational Health maintains the data base.

(Also see the section on Nordic countries below.)

Germany

A summary of quality standards, and emission and immission limits, is given in **Table 5.4**.

Regulations on direct emissions of cadmium

The stringent requirements of the Ordinance on Large Combustion Plants and Waste Incineration Plants (13th and 17th Ordinance for the implementation of the Federal Immission Control Act), as well as the TA Luft, result in a drastic reduction of heavy metals emitted to the atmosphere. The classic thermal power plants are responsible for about 1 tonne/year; the emissions from waste incinerators are about 0.5 tonnes/year.

Fugitive emissions are an important source of cadmium emissions into the atmosphere. In Germany, the TA Air has therefore established requirements for the treatment, production, transport and handling of dusty materials, in keeping with the principle that precautions must be taken to protect the environment against adverse effects caused by air pollutants.

Table 5.4 Elements of German National Risk Reduction Strategies for Cadmium

Medium	Material	Type of standard	Value of standard	Legislation	Year of enforcement
Air	ambient	immission limits	0.04 µg/m³	TA Luft	1986
	facilities subject to license (4.BImSchV)	emission limit	0.1 mg/m³	TA Luft in connection with the decision of the Länderausschuß für Immissionsschutz	1991
	ambient, dust deposition	immission limit	5 µg/(m²d)	TA Luft	1986
	waste incinerators	emission limit for cadmium and thallium	0.05 mg/m³	17th ordinance for the implementation of the federal immission control law	1990
Water	drinking water	quality	5 µg/litre	Trinkwasserverordnung	1986
	manufacture of coating materials and resins for lacquers and varnishes	emission limit	0.1 mg/litre	Anhang 9 der Rahmen-Abwasser-VwVzu § 7a des WHG	1989
	production of ceramics	emission limit	0.07 mg/litre	Anhang 17 der Rahmen-Abwasser-VwVzu § 7a des WHG	1992
	mixed effluent	emission limit	0.2 mg/litre[2] 5 µg/litre[5]	Anhang 22 der Rahmen-Abwasser-VwVzu § 7a des WHG	1991
	soda production	emission limit	0.8 g/t[c]	Anhang 30 der Rahmen-Abwasser-VwVzu § 7a des WHG	1989
	production of anorganic pigments: - cadmium pigments - Lithopone, $ZnSO_3$, $BaSO_4$ - titanium dioxide	emission limit	0.15 kg/t[c] 0.002 kg/t[c] 0.01 mg/litre	Anhang 37 der Rahmen-Abwasser-VwVzu § 7a des WHG	1991
	Non-ferrous metal industry	emission limit	3 g/t[c]	Anhang 39 der Rahmen-Abwasser-VwVzu § 7a des WHG	1989
	Metal treatment - sewage water from rinsing - galvanics - hot galvanizing - battery production - enamelling plants - mechanical workshops - paint shops	emission limit	0.2 mg/litre 0.2 mg/litre 0.3 kg/t used cadmium 0.1 mg/litre 0.2 (0.1 primary cells) 1.5 kg/t used cadmium 0.2 mg/litre 0.1 mg/litre 0.2 mg/litre	Anhang 40 der Rahmen-Abwasser-VwVzu § 7a des WHG	1989

Medium	Material	Type of standard	Value of standard	Legislation	Year of enforcement
	glass manufacturing, production of mineral fibres	emission limit	0.1 mg/litre	Anhang 41 der Rahmen-Abwasser-VwVzu § 7a des WHG	1989
	effluent from municipal waste incinerators and coal powder plants or other furnaces	emission limit	0.05 mg/litre	Anhang 47 der Rahmen-Abwasser-VwVzu § 7a des WHG	1989
	effluent from sanitary landfill	emission limit	0.1 mg/litre	Anhang 51 der Rahmen-Abwasser-VwVzu § 7a des WHG	1989
Soil	farmland	guide value	1 mg/kg	Kloke listing	
	farmland	quality	10 mg/kg[d]	Kläschlammverordnung	1992
Consumer goods	colourisation of utility articles as far as not covered by the EEC Directive 76/796	quality	0.01 into 0.1n hydrochloric acid DIN 53770	recommendation of the Federal Health Office	
	cosmetics	quality	application prohibited		
	ceramics	limit values in 4% acetic acid	- 0.07 mg/dm^2 (applies only to non-fillable objects) - 0.3 mg/litre (filling depth > 25mm) - 0.1 mg/litre (filling volume > 3 l)	Keramik-Bedarfsgegenstände-Verordnung	1988
Plant protection agent		quality	application prohibited	Verordnung über Anwendungsverbote für Pflanzenschutzmittel	1989

a. 0.2 mg/litre for wastewater from production and use of cadmium
b. 5 µg/litre for wastewater from other processes
c. production-specific emission value
d. allowed only if the concentration in the soil is lower than 1.5 mg cadmium/kg soil

Particular account is taken of the harmful components of dusts. For cadmium-containing dusty materials, the most effective measures must be taken. This means in general that complete coverage is necessary and that heavy metal-containing dust in waste gases has to be collected and fed to a de-dusting device.

Fertilizers and sludge

There is a voluntary agreement between the authorities and the fertilizer industry. The industry pledged not to exceed a concentration of 90 g cadmium/tonne P_2O_5. At least 89 per cent of their products should not exceed 70 g cadmium/tonne P_2O_5 and 63 per cent should not exceed 40 g cadmium/tonne P_2O_5.

A highly specialized pilot plant for the production of phosphoric acid using sulphuric acid, of semi-industrial size producing about 200 tonnes P_2O_5 per day, has been in operation in Budenheim. The process was based on the extraction of cadmium in the form of cadmium-chloro complexes by amine-kerosene solvents. The pilot plant was shut down because of serious technical and cost problems. Before the start of operations, cost estimates were an additional 10 to 11 DM per tonne P_20_5. Real experience indicated an additional cost of 43 to 45 DM per tonne, not including the cost of disposal of the waste solution. The technology cannot be applied to the nitrophosphate process because of heavy corrosion stemming from the formation of nitrosyl chloride. It has therefore to be concluded that, for nitrophosphate fertilizer plants, no technical process for cadmium separation is available.

The present limit for sewage sludge is 10 mg cadmium/kg sludge. For that, the concentration of cadmium in the soil must be lower than 1.5 mg cadmium/kg soil. In soils with a pH 5-6 the limit for sewage sludge is 5 mg cadmium/kg sludge and the concentration in the soil must be lower than 1 mg cadmium/kg soil.

Use trend and replacement of cadmium

According to a study performed by Bätcher (1992), window frame producers stated that long-term guarantees for cadmium/zinc-stabilized window frames can be given. Tests over several years have shown no difference in long-term quality protection as compared with cadmium stabilizers. The costs will increase by about 10 per cent for the stabilizers and by less than this for the ultimate product.

Occupational environment

There is no occupational standard value in Germany for cadmium because cadmium and its compounds are considered to be carcinogenic. For such substances the "Ausschuß für Gefahrstoffe (AGS)" establishes Technische Richtkonzentrationswerte (TRK-Wert). The AGS has not yet established a TRK value for cadmium.

In Germany, the "non-migration" principle applies to materials in contact with food (e.g. packaging, utensils, dinnerware), consumer items (e.g. sanitary ware) and toys; i.e. when used as intended, no colourant (including cadmium pigments) may transfer from the consumer item to food or to saliva. The EEC Directive 76/769 (10th amendment) has been enforced. It will have no discernible effect on consumption pattern since the requirement of the Directive falls behind technical facilities and progress in actual substitution in Germany (Bätcher et al. 1992).

NiCd batteries

The EEC Directive on batteries will be enforced in the near future. A future ordinance regulating batteries should provide for mandatory labelling, return, acceptance of returned batteries, separate collection and recycling. Closing the cycle will hardly be possible unless an appreciable deposit is levied on NiCd accumulators. This instrument is a matter for debate in Germany.

Japan

Use trend and voluntary replacement of cadmium

1) Industry has voluntarily restricted the use of cadmium in food packaging, containers, toys, etc. In accordance with such voluntary restriction, and subsequently in other applications, the use of cadmium pigments has become restricted.

2) It is extremely difficult to comply with the regulation of the working environment in the case where cadmium pigments are used.

The domestic demand has therefore decreased, especially in the field of paints and plastics colouring, through progressive replacement with organic pigments or with other inorganic pigments. Production volume has decreased accordingly.

Pigments

1) Colouring of plastics

- Approximately 90 per cent of the use of cadmium pigments is in plastics. The concentration is normally less than 1 per cent.
- Voluntary restrictions of use are agreed by companies concerning food packaging materials, containers, toys, etc. For example:
    - the Standard Positive List for Polyolefin Application
    - the Standard Positive List for PVC Food Packaging Application
- The replacement of cadmium in plastics colouring has already progressed well and the demand is decreasing gradually. It is, however, rather difficult to replace cadmium in some specialty resins such as engineering plastics (for example, fluoroplastics) which require high temperature in the moulding process. It will therefore be necessary to continue using cadmium pigments in the future.

2) Paint applications

The replacement of paint applications has been mostly completed. Use is limited to applications in which high heat resistance is required, such as in heatproof paints. The pigment content in paints is normally less than 30 per cent.

3) Colouring of ceramic products

- Ceramic tiles: Cadmium pigments are used in the glaze of ceramic tiles. The pigment content of the glaze is normally less than 5 per cent.

- Enamel wares: Cadmium pigments are used in the glaze for enamel wares. The pigment content of the glaze is normally less than 5 per cent.

- Glass products: Cadmium pigments are used in the glaze called glass colour, and the pigment content in such a glaze is normally less than 5 per cent. Where the glass itself is coloured by formulating the pigments in the recipe of glass materials, the pigment concentration is normally less than 1 per cent.

- Since ceramic products require an extremely high temperature for colouring, normally up to 800°C or more, there is no other pigment to replace cadmium. For this reason, cadmium pigments remain indispensable, also for the future. The demand tends to be diminished, minimizing the area requiring cadmium pigments.

4) Collection and recycling of products

- Since cadmium pigment is used in products as described above, collection of the used products is practically impossible.

5) Provision of information to consumers

- Users of cadmium pigments have come to avoid their use as far as possible. They limit the use to applications where there is no substitute, or where the study on their replacement is delayed. Therefore, users of intermediary semi-products containing cadmium pigments are informed that the product contains cadmium, while the final consumer product does not specify that cadmium is used in the product nor how the product can be disposed of.

Metal coating

The electroplating industry voluntarily decided not to use cadmium in 1970. Total volume of cadmium for electroplating amounted to 1006 kg in fiscal 1991; 749.1 kg in fiscal 1992; and 729 kg (estimated) in fiscal 1993.

Table 5.5 Japanese Legal Environmental Standards for Cadmium

Medium	Material	Type of standard	Value of standard	Legislation	*
Air	ambient	emission	≤1 mg/m^3	Air Pollution Control Law	1971
	mining smoke	emission	≤1 mg/m^3	Mining Safety Law	1972
	working place	quality for indoor air	≤0.05 mg/m^3	Industrial Safety and Health Law	1975
Water	drinking water	quality	≤0.01 mg/litre	(administrative guidance) Water Supply Law	(1969) 1979
	public water	quality	≤0.01 mg/litre	Basic Law for Environmental Pollution Control	1970
	drainage	effluent	≤0.1 mg/litre	Water Pollution Control Law	1971
	mining drainage	effluent	≤0.1 mg/litre	Mining Safety Law	1972
	public sewage	effluent	≤0.1 mg/litre	Sewerage Law	1976
Soil	paddy field	quality for rice	≤1.0 ppm	Agricultural Land Soil Pollution Prevention, etc., Law	1970
	soil	solution of analysis	≤0.01 mg/litre	Basic Environment Law	1991
	agricultural land	quality for rice	<1.0 ppm	Basic Environment Law	1991
Food	unpolished rice	quality	<1.0 ppm	Food Sanitation Law	1970
	polished rice	quality	<0.9 ppm	Food Sanitation Law	1970
Industrial wastes	sludge, slag, cinder, fly ash	quality for landfilling	≤0.3 mg/litre	Waste Disposal and Public Cleansing Law	1973
	organic sludge, water-soluble inorganic sludge	quality for ocean dumping	≤5 mg/kg	Law for Prevention of Marine Pollution and Maritime Disasters	1973
	slightly water-soluble inorganic sludge, slag, cinder, fly ash	quality for ocean dumping	≤0.1 mg/litre	Law for Prevention of Marine Pollution and Maritime Disasters	1973
	acid-waste fluid, alkaline-waste fluid	quality for ocean dumping	≤1 mg/litre	Law for Prevention of Marine Pollution and Maritime Disasters	1973

**Year of enforcement*

NiCd batteries

1) Labelling

- NiCd batteries were designated in the Law for Promotion of Recyclable Resources (June 1993). The label "NiCd battery, recyclable" is obligatory after June 1995.

2) Easy removal

- The products powered by NiCd batteries are also designated in the same law. Manufactures have to redesign such products for easy removal of the battery after July 1993.

3) Collection of spent batteries

- Targets of 30 per cent by the end of 1995 and 35 per cent by the end of 1997 are set out in the Guideline of Industrial Structure Council, MITI, September 1993.

- Present main routes of collection are OEM service routes. In order to achieve the target, more systematic routes will be established by the Japan Storage Battery Association.

Emission limits

The emission of cadmium and its compounds has been controlled below 0.1 mg/litre under the Water Pollution Control Law.

The Netherlands

Voluntary actions by industry

After several years of discussions, in 1990 the Dutch Government issued a decree to reduce the amount of cadmium emitted into the environment. Probably because the users of cadmium knew that this decree was coming, they have already started to replace cadmium in their products.

Restriction of cadmium in products

In general, it is not permitted to use cadmium as a stabilizer, pigment or plating. Products containing plastics or paint should not have a cadmium content of more than 50 mg/kg.

In the cadmium decree, a list of exceptions is given for those products for which there was no alternative at the end of the 1980s (see copy of the decree for more details). There are exceptions for the use of cadmium stabilizers in window and door panels, and construction panels used for building purposes.

We are now working on an amendment to the decree, in which we want more stringent restrictions on cadmium uses for which there are no alternatives.

Other products:

- animal feed: implementation of Directive 87/238/EEC.

- gypsum: see cadmium decree (<10 mg cadmium/kg). After 01-01-96: <2 mg Cd/kg.

- in case of fertilizer use in agriculture:

    - sewage sludge: till 31-12-94 <3.5 mg/kg, after 01-01-95 <1.25 mg/kg
    - "clean" sludge: <1.5 mg/kg till 31-12-94
    - compost: till 31-12-94 <2 mg/kg, after 01-01-95 <1 mg/kg
    - "clean" compost: till 31-12-94 <1 mg/kg
    - "very clean" compost: <0.7 mg/kg

- cadmium-containing bottle crates for repeated use in the beer and soft drink industry, due to an agreement between industry and government:

    - no restriction on cadmium content (> 50 mg/kg);
    - no introduction of newly designed crates after 01-01-90;
    - no introduction of newly designed crates at all after 01-01-2006;
    - no further use of crates after 01-01-2010.

Other cadmium-containing products are not separately collected and recycled, except crates in the beer/soft drink industry.

The amendment of the decree concerning emissions from power plants will result in a reduction of cadmium emissions as well.

The Dutch Emission Guidelines, which have been in use since 1992, prescribe the best practicable means for licensing.

NiCd batteries

Directive 91/157/EEC on 01.01.94 has been implemented. NiCd batteries heavier than 500 g are treated according to the Dutch cadmium decree: this means prohibition of sale, import and stocking, unless an exception is made for specific purposes.

On 01-01-94, due to Directive 91/157/EEC, cadmium information will be given by labelling, possibly including the cadmium content.

NiCd batteries are recycled in so far as they are separately offered to the recycling industry.

Responsibility of retailer/importer: At this time, collection is on a voluntary basis. An agreement has been prepared for implementation. If unsuccessful, a deposit system will be introduced by the government.

Collection and recycling of batteries:

After implementation of Directive 91/157/EEC by a national decree on batteries on 15-09-92, a battery implementation plan was created simultaneously covering the collection and recycling of (NiCd) batteries. During the period 1993-1997 the main objectives are:

- stimulation of the use of batteries containing less cadmium;
- reduction of cadmium content in batteries;
- stimulation of research on replacement of cadmium in batteries;
- stimulation of introduction of NiH rechargeable battery;
- decrease of battery content in household waste;
- research on a recycling plant for NiCd batteries in the Netherlands;
- separate collection of batteries according to annex 1 of Directive 91/157/EC, including:
    - agreement with the battery branch on a percentage of separate collection in 1997 (in 1992 this was 55 per cent)
    - unilateral introduction by the government of a deposit regulation if no agreement is reached or if the collection goal is not reached by 1997;
- introducing a label on batteries and equipment containing batteries, and a manual for easy removal of batteries from the equipment by the consumer;
- special attention to those aspects above concerning equipment already in use before implementation of the regulation (for instance, facilitating collection of whole equipment).

Waste disposal

1985 figures from the Dutch criteria document on cadmium:

- Household waste: 33,100 kg cadmium out of 40,000 kg cadmium
- Industrial solid waste: 22,000 kg cadmium out of 48,500 kg cadmium

In addition to the Dutch restrictions on use mentioned in the annexes to this chapter, "It is prohibited to import, to stock and to handle......"

A separate agreement on bottle crates for repeated use in the beer and soft drink industry was signed in 1988. For details see "Restriction of cadmium in products", above.

In 1994 an updated Annex 3 of the decree with exceptions to the Dutch cadmium decree will come into force. As far as can be foreseen, a lot of applications in polymers/plastics will be additionally banned in comparison with the existing Annex 3.

Collection and recycling of cadmium containing polymers/plastics: In production and recycling, research is being carried out on:

- removal of cadmium from the matrix;

- introduction of cadmium-containing polymers/plastics after recycling into a controlled circuit (this means an available collection system).

On a national basis, the environmental and economic cadmium mass balances are being studied.

Norway

Industry has replaced cadmium in some applications, i.e. as stabilizers in PVC and in pigments for some areas of use. The amount of cadmium used in sacrificial anodes is decreasing, partly because of the increasing use of anodes which are not alloyed with cadmium.

Fertilizers and sludge

The limit for the cadmium content in fertilizers is 100 mg cadmium/kgP. The average cadmium content in the fertilizers on the Norwegian market is, however, much lower.

The present limit value for cadmium in sludge used on agricultural land in Norway is 10 mg cadmium/kg dry weight. This limit will be decreased to 4 mg cadmium/kg dry weight.

Occupational health standards

The threshold limit values are:

Cadmium and inorganic cadmium compounds (except cadmium oxide): 50 µg cadmium/m^3

Cadmium oxide: 20 µg cadmium/m^3 (ceiling value)

Alkaline batteries

The present limit on cadmium for non-rechargeable alkaline manganese dioxide batteries is 0.001 per cent cadmium by weight.

NiCd batteries

The Norwegian regulations concerning environmentally harmful batteries and accumulators were amended in July 1994, and now include a requirement for the batteries to be labelled indicating which heavy metal they contain, according to the EU Directive 93/86/EEC. All NiCd batteries placed on the Norwegian market after 1 January 1995 should then be labelled with the chemical symbol of cadmium, as required in the EU. There is an organized collection of used NiCd batteries in Norway. There is, however, no domestic recycling of NiCd batteries yet.

The Norwegian battery regulation states that retailers who sell batteries and accumulators required to be labelled (for example, NiCd batteries) are under obligation to accept comparable types of batteries in return from the consumer, free of charge.

Consumers have been informed through an information campaign that rechargeable batteries and products with rechargeable batteries contain cadmium, and that they should deliver the batteries to the retailer.

Other products

No other cadmium-containing products are separately collected and recycled.

Restrictions on use

Norway has a regulation concerning the use of cadmium compounds in certain plastics as pigments and stabilizers, and the use of cadmium in certain metal plating applications. This regulation is a direct implementation of an EU Directive (10th amendment to 76/769/EEC).

(See also the section on the Nordic countries below.)

Sweden

By means of regulations, a systematic phase-out of many uses of cadmium has been carried through. There are regulations concerning NiCd batteries and cadmium in fertilizers. Also, various voluntary measures have been carried through. Sweden has had many positive experiences of cadmium risk reduction, comprising the successful substitution of the use of cadmium within several application areas, and a reduction of the cadmium content in fertilizers. The Swedish Parliament in 1991 stated that the present use shall be reduced considerably. This implies an on-going phase-out of the use of cadmium.

Pigments, stabilizers and plating

The use of cadmium in pigments, stabilizers and plating was prohibited in Sweden already in 1982. There are exemptions made only for some specified areas of application. During the first years after 1982, there were many problems, as cadmium was found to be present in considerably more products than what had been assumed when the ban was under preparation. Today the situation is quite different. The Swedish net input of cadmium within these three fields of application is estimated to be only 5-10 tonnes/year presently, imported products included. Before the ban this figure was about 100 tonnes/year.

In Sweden cadmium pigments are now used mainly in artist's paints, in the production of certain glass and ceramic materials, and a very small amount in special plastics. In the high volume plastics such as polyethylene (LDPE, MDPE and HDPE), polypropylene, polystyrene, ABS and PVC it is possible in most cases to replace cadmium without any deterioration. There are also available substitutes for cadmium pigment in high temperature plastics if there is no demand for a very specific colour.

Cadmium stabilizers for PVC have been used in rigid PVC for outdoor use, and in the manufacture of window frames and roofing tiles. They have also been used in plastic insulation material used for coating building board in the construction industry. Long-term tests of cadmium-free PVC for outdoor uses have been going on in Sweden since the beginning of the 1980s and the results have been encouraging. Swedish producers now consider it possible to replace cadmium and to produce such products with the quality guarantee for long-life external use. As a consequence, cadmium stabilizers are today no longer used in Swedish industry for these applications.

Cadmium plating is today only used in the aerospace and defence industries and for certain instruments.

NiCd batteries

Since the end of the 1980s there are regulations comprising the labelling of NiCd batteries with a recycling symbol, and separate collection of used NiCd batteries and products containing such batteries for recovery and controlled disposal. Today the symbol on the label should conform to the European Commission Directive 93/86/EEC. Producers and importers have to pay a fee to cover the costs for the final disposal of the batteries and for the information which needs to be distributed about the measures. Notwithstanding these regulations, the collection rate presently is estimated to be only about 30 per cent. According to a recent voluntary agreement, the collection rate is to be raised to 90 per cent. Concerning alternatives to NiCd batteries, nickel-hydride (Ni-HM) batteries and rechargeable lithium batteries are now introduced for some fields of application.

Alloys

The use of cadmium alloys has decreased substantially as the result of voluntary measures. At present, for example, the use of cadmium copper alloys in the sheets for car radiators is being substituted with copper-tellurium alloys.

Fertilizers

In December 1992, the Swedish parliament decided to limit the cadmium content of fertilizers to 100 g cadmium per tonne of phosphorus. Recently, the parliament has decided on a fee for cadmium contents of 50-100g per tonne of phosphorus.

However, already in the 1970s there was a focus on cadmium in fertilizers and a demand for measures to be taken. This has through the years resulted in voluntary undertakings e.g. by Lantmännen, the Swedish farmers supply and crop marketing organization, and by the Swedish manufacturer. The import into Sweden of fertilizers (and raw materials) has been directed to supplies where the cadmium content has been low. In this way it has been possible to gradually lower the medium cadmium content in the fertilizers used in Sweden to the present medium content of about 35-50 g cadmium/tonne P. The cadmium content has been measured and reported voluntarily. Also, support has been given for a pilot plant for the purification of phosphoric acid which has demonstrated technical possibilities to decrease the cadmium content to 5 g cadmium/tonne P.

Besides this, efforts have been made, for example analyzing cadmium content in soils and in various crops, and relating cadmium content of crops (cereals) to the cadmium content of the soil. This is to make it possible to avoid the cultivation of certain varieties on fields with a high cadmium content in the soil, and to choose varieties with low cadmium uptakes. It should also be noticed that several Swedish mills presently do not buy cereals where the cadmium content exceeds 0.1 ppm. Concentrations above 0.1 ppm cadmium occur, particularly in spring wheat from limited areas in the southernmost agricultural region.

Sludge

The present limit value for cadmium in sludge used on agricultural land in Sweden is 4.0 mg/kg dry weight. From 1995, the limit value will be 2.0 mg/kg dry weight.

Point sources

Systematic work has been carried out to decrease emissions from point sources through demands for BAT in connection with the environmental licensing of factories, etc. This has resulted in substantial decreases of the emissions, from about an annual 50 tonnes totally to air and water in the early 1970s to less than five tonnes at present.

Occupational standards

The ceiling limit value for cadmium and inorganic cadmium compounds (as cadmium) is 0.05 mg/m3 for total dust and 0.01 mg/m3 for respirable dust. There are also regulations comprising exposure (cadmium in air) and medical (cadmium in blood) monitoring.

Switzerland

Legal, Environmental and Other Standards for Cadmium in Switzerland

Medium:	**Air**
Material	ambient
Type of standard	maximum permissible cadmium concentration (annual averages)
Value of standard	10 ng/m^3 suspended dust; 2 µg/m^2/day redeposition
Legislation	Clean Air Ordinance (1985)
Material	installations
Type of standards	emission limit
Value of standard	0.2 mg/m^3 if the mass flow is 1 g/h or more (total concentration of Cd, Hg and Tl)
Legislation	Clean Air Ordinance (1985)
Material	waste incineration
Type of standard	emission limit
Value of standard	0.1 mg/m^3
Legislation	Clean Air Ordinance (1985)
Material	working place
Type of standard	maximum allowable air concentration
Value of standard	0.05 mg/m^3 (time-weighted average over 8 hours)
Legislation	Occupational Hygiene Limits (1992)

Medium:	**Water**
Material	surface water flows and impounded river water
Type of standard	limit value
Value of standard	0.005 mg cadmium/litre
Legislation	Ordinance for Waste Water Discharge (1975)
Material	effluents discharged into surface waters
Type of standard	limit value
Value of standard	0.1 mg cadmium/litre
Legislation	Ordinance for Waste Water Discharge (1975)

Material	effluents discharged into public sewers
Type of standard	limit value
Value of standard	0.1 mg cadmium/litre
Legislation	Ordinance for Waste Water Discharge (1975)
Material	effluents from industrial sectors
Type of standard	limit value (load or concentration)
Value of standard	0.3-1.5 g/tonne sector specific, or 0.2 mg/litre for all sectors
Legislation	in force since 1988, based on the Recommendation of the International Commission for the Protection of the Rhine against Pollution

Medium: Soil

Material	soil content
Type of standard	guide value
Value of standard	0.8 mg/kg (total); 0.03 mg/kg (soluble)
Legislation	Ordinance on Contaminants in Soil (1986)

Medium: Food

Regulation	• maximum permitted amounts of cadmium in food and drinking containers are prescribed • the use of cadmium in cosmetics is prohibited • there are maximum concentrations for certain specific foodstuffs
Legislation	Ordinance on Foodstuffs

Fertilizers and sewage sludge

Commercial fertilizers containing more than 1 per cent phosphorus shall not contain more than 50 g cadmium per tonne of phosphorus. The cadmium content of compost and sewage sludge is limited to 1 and 5 ppm respectively of dry substance. Special restrictions exist in regard to maximum output amounts.

Restrictions of use

In Switzerland, the Ordinance relating to Environmentally Hazardous Substances prohibits the import and supply by a manufacturer of plastics containing cadmium, mainly cadmium compounds used as stabilizers and pigments. Exemptions for a limited time may be granted by the Federal Office of Environment, Forests and Landscape. A plastic is considered to contain cadmium if the content is 100 ppm or more.

The import or supply by a manufacturer of articles protected against corrosion by means of cadmium is prohibited. Several exemptions exist if no non-cadmium plated replacement is available, and provided that no more cadmium is used than is necessary for the article's intended use. Upon reasoned request, further exemptions may be granted by the Federal Office. The cadmium content of zinc-plated articles has been limited to a maximum of 250 ppm since 1st January 1991.

NiCd batteries

In Switzerland, batteries are deemed to be pollutant if the total amount of cadmium and mercury they contain exceeds 250 mg/kg of battery. Concerning separate collection, pollutant batteries must be labelled with the pictogramme "Hazardous Waste", or there must be an internationally agreed pictogramme and the instructions "to be returned to the place of sale after use". The same labelling is required for their packaging. Manufacturers and traders who supply pollutant batteries must take back free of charge all types of used batteries.

Carbon-zinc batteries may not exceed a total amount of cadmium and mercury of 250 mg/kg of battery.

Cadmium is mainly used in small, sealed nickel-cadmium accumulators today. The total cadmium content of these accumulators sold in Switzerland increased from 2000 kg in 1981 to approximately 66,000 kg in 1991. Therefore it is intended to take measures to increase the return rate of small, sealed nickel-cadmium accumulators. They are already labelled as NiCd batteries.

United Kingdom

Environmental media

Drinking Water: Maximum allowable concentration of cadmium in drinking water is 5 µg/litre.

Surface Waters: Environmental Quality Standards establish limits for cadmium in inland waters and coastal/territorial waters of 5 µg/litre (total cadmium) and 2.5 µg/litre (dissolved cadmium) respectively based on the mean annual concentrations.

Ambient Air: No UK guidelines at present.

Soil: Guidance for redevelopment of contaminated land; Guideline levels of 3 mg/kg for domestic gardens and allotments and 15 mg/kg for recreational land. Maximum permissible concentration of 3 mg/kg for agricultural soil (pH 5.0 and above) treated with sewage sludge.

Environmental sources

Air Point Sources: The best practical means (BPM) must be used to treat/control industrial emissions; the limit for municipal waste incinerators is set at 0.1 mg/m^3; HMIP suggests a guideline limit of 0.1 mg/m^3 for other industrial plants.

Water Point Sources: Permissible cadmium concentrations vary according to location of the plant and environmental quality objective of receiving waters; as a prescribed substance HMIP has established a guideline limit of 0.05 mg/litre based on a monthly average.

Sewage Sludge: Controls on the application rate of sewage sludge give maximum permissible average annual rate of addition over a ten year period of 0.15 kg per hectare.

Cadmium-containing Wastes: Subject to duty of care.

Dust: No established limit.

Foodstuffs or Feed: No established limits for foodstuffs for human consumption. Limits in the range of 0.5-10 mg/kg for various feed stuffs recognizing the variability in cadmium content of some natural constituents of feeding stuffs.

Paint: Limit of 0.01 per cent by mass except for paints with a high zinc content where cadmium arises by association and the limit is therefore 0.1 per cent by mass.

NiCd batteries

Programs and measures for the reduction of NiCd batteries containing more than 0.025 per cent cadmium by weight in household waste and for their separate collection and disposal are to be established in the UK following the adoption of Directive 91/157/EEC.

Restrictions of use

Plastics: Limit of 0.01 per cent cadmium when used as a pigment or stabilizer in certain plastics established under the conditions set out in Directive 91/338/EEC.

Plating: Restrictions on the use of cadmium for certain metal finishing applications as specified under Directive 91/338/EEC.

Food Containers: No established limits for plastics other than those specified in Directive 91/338/EEC. Restrictions on the sale of articles of ceramic ware or vitreous enamel ware likely to be used in contact with food based on limits of leachability of cadmium linked to degree of contact.

Fertilizers: No established limits.

Occupational Exposures: Cadmium and cadmium compounds except cadmium oxide fume and cadmium sulphide pigments, 0.05 mg/m^3 (long term exposure limit, measured as cadmium, over an 8 hour reference period); cadmium oxide fume, 0.05 mg/m^3 (long term exposure limit, measured as cadmium, over an 8 hour reference period) and 0.05 mg/m^3 (short term exposure limit, measured as cadmium, over a 10 minute reference period); cadmium sulphide pigments respirable dust, 0.04 mg/m^3 (long term exposure limit, measured as cadmium, over an 8 hour reference period).

United States

Because of cadmium's potential to cause adverse health effects, many United States Federal and state agencies have issued regulations and guidelines to reduce human and ecological risks associated with cadmium and compounds containing cadmium. These activities include limits on cadmium in the environment, in food and drinking water, and in the workplace. For certain products where limits are not feasible, activities have been initiated to recycle cadmium and educate users as to the cadmium content in products. In some cases, cadmium use has been cancelled. Finally, monitoring programmes have been established to track existing levels of cadmium in the environment and in humans exposed to the metal. This chapter describes the federal and state activities regarding cadmium. The information is summarized in the table "Regulations and Guidelines Applicable to Cadmium" (ATSDR 1993).

Cadmium in drinking water

Effective September 1992, the US Environmental Protection Agency (EPA) lowered the maximum contaminant level (MCL) for cadmium in drinking water from 0.01 mg/litre to 0.005 mg/litre (EPA 1991b). This standard is required under the Safe Drinking Water Act of 1986, and is part of the Agency's National Primary Drinking Water Standards. Groundwater systems are required to be monitored every three years while surface water systems require monitoring every year (IRIS 1992). In addition to these levels, EPA has established Health Advisories, or acceptable drinking water levels for cadmium for one day, ten days, and longer-term (referring to an exposure period of up to seven years) for children and for longer-term and lifetime for adults. These Health Advisories are not regulatory but are designed to guide officials in determining safe levels in drinking water (EPA 1989a).

Standards for environmental media

Under the Clean Water Act, EPA has set an Ambient Water Quality Criterion of 0.01 mg/litre as the maximum concentration of cadmium allowed in surface water to protect humans who ingest contaminated water and organisms (EPA 1980). Additional standards for surface water are intended to protect aquatic organisms against acute and chronic effects; at a water hardness of 100 mg/litre $CaCO_3$, the freshwater acute and chronic guidelines are 0.0039 mg/litre (one-hour average) and 0.0011 mg/litre (4 day average), respectively. Saltwater criteria designed to protect aquatic organisms are 0.043 mg/litre and 0.0093 mg/litre for acute and chronic effects, respectively (EPA 1985a).

Standards for point source controls

EPA regulates the releases of cadmium to water. Release of cadmium in wastewater from industrial facilities and municipal wastewater treatment facilities are regulated by effluent guidelines and pretreatment standards for existing and new sources (40 CFR 401 and 403). These limits are implemented through facility-specific permits under the National Pollution Discharge Elimination System (NPDES) and may be more stringent than federal requirements (40 CFR 122).

EPA has issued National Emissions Standards for cadmium and cadmium compounds released to air from sources that have the potential to emit ten tonnes or more cadmium per year (EPA 1992a; CAAA 1990). These limits are technology-based standards set for different industries; existing sources of cadmium must reduce their emissions to match the emissions obtainable by the best-performing twelve per cent of existing sources, while new sources must reduce emissions to match the reductions achieved by the best controlled similar source. States may either adopt EPA's standards or more stringent numbers (CAAA 1990). Sixteen industries that emit cadmium have been identified for regulation by technology standards on the initial list of sources (EPA 1992a). Early environmental benefits of reducing cadmium emissions to air are encouraged under the Clean Air Act. According to the early reductions programme, owners or operators of existing sources are encouraged to voluntarily reduce particulate emissions by ninety-five per cent; if an industry reduces its emissions by this amount, it may receive an extension on complying with technology standards and would need to meet an alternative emissions limitation established by permit (EPA 1991a).

EPA's Office of Emergency and Remedial Response has established reportable quantities for cadmium compounds emitted to the environment. Releases of at least ten pounds of cadmium, cadmium acetate, cadmium bromide, or cadmium chloride must be reported (EPA 1989c; 40 CFR 302.4). For the compounds cadmium oxide and cadmium stearate, industry must report releases of one pound or more; however, a reportable quantity of ten pounds has been proposed for both of these compounds (EPA 1989b).

EPA also regulates cadmium in wastes. A new rule, due for publication in 1994 and effective thirty days after publication, sets the total loading of cadmium in municipal sludge that may be applied to land producing food chain crops at a maximum of 39 kg/ha. The concentration of cadmium in sludge applied to land is limited to 39 mg/kg (Southworth 1993). This rule replaces the interim final rule that required no more than a total of 20 kg/ha cadmium be applied to this type of land and that the annual amount must be limited to 0.5 kg/ha (40 CFR 257.3-5). (Note: According to USDA, sludges which contain up to 39 mg cadmium/kg may be marketed for general use if pasteurized and stabilized. USDA comments during a post publications federal review indicated that this limit should have been no higher than 21 kg cadmium/ha and 21 mg cadmium/kg dry sludge. USDA and EPA reached agreement to develop a guidance for application of sludges on land which may grow crops for export, and the 21 kg cadmium/ha limit will be imposed at that time.)

In addition, wastes containing cadmium and compounds are considered hazardous wastes if the cadmium concentration in the leachate used to test the waste exceeds 1 mg/litre (EPA 1990; 40 CRF 261.24). Other cadmium-containing wastes may be regulated as hazardous wastes by virtue of the process by which they are generated ("a listed waste"), regardless of the leachate concentration (EPA 1990).

Source reduction activities

EPA initiated a pollution prevention programme in 1991, designed to help reduce releases of cadmium, its compounds and 16 other toxic substances to the environment. This programme, the "33/50 Project", encourages industry to commit to voluntarily reducing releases of some or all of these toxics by 33 per cent by 1992, and 50 per cent by 1995. The programme uses EPA's database on industrial releases of toxics (the Toxics Release Inventory) in helping to persuade companies to reduce their releases of these toxics. Although the project does not directly act to reduce sources of cadmium emissions, many of the participants meet their goals by reducing consumption of the toxics. Of the total number of cadmium and cadmium compounds released in 1988, 49 per cent were associated with companies that have made commitments to the 33/50 project (EPA 1992b).

Cadmium in food

The largest source of exposure to cadmium in the general population is from foods. To control this exposure, the Food and Drug Administration has set limits on the amount of cadmium to 15 ppm in the following food colours: bronze powder, copper powder and zinc oxide (21 CFR 73.1646, 1647; 1991) and has established a permissible level in bottled water of 0.01 mg/litre (21 CFR 103.35). The level of cadmium allowed in zinc methionine sulphate tablets, a direct food additive, is 0.05 ppm (21 CFR 172.399). In addition to these standards, FDA sponsors on-going analyses of the amount of cadmium in foods (ATSDR 1991).

Cadmium in pesticides

Within the last few years, concern over the health effects of cadmium, including oncogenicity, mutagenicity, teratogenicity, and fetotoxicity, has led to cancellation of all pesticide uses of cadmium compounds (ATSDR, 1991; IRIS 1992).

Labelling and education

Several states including Connecticut, Iowa, Maine, Minnesota, New Hampshire, New Jersey, New York, Oregon, Rhode Island and Vermont, have passed legislation, effective in 1993 or 1994, requiring the chemical contents of nickel-cadmium batteries to be labelled. In addition, in most states that require labels, manufacturers must also instruct users to properly dispose of, or recycle, the batteries (PRBA 1992a).

Recycling

Two states, Minnesota and Vermont, have initiated pilot programmes for collection of nickel-cadmium batteries for recycling or disposal (PRBA 1991; 1992b). Several other states are requiring manufacturers to develop and submit battery management plans (PRBA 1992c). In addition to these recycling efforts, ten states require that batteries be easily removable from products (PRBA 1992a).

EPA recently proposed regulations to facilitate the recycling of NiCd batteries from major users; households are not covered (EPA 1993).

Occupational standards and monitoring

The Occupational Safety and Health Administration (OSHA) regulates exposure to cadmium in the workplace by establishing standards for acceptable exposures. In September 1992, OSHA lowered the permissible exposure limit (PEL) for cadmium to 0.005 mg/m^3 (averaged over eight hours), after determining that workers faced significant risks of lung cancer and serious kidney damage from exposure at previously regulated levels of 0.2 mg/m^3

for dust and 0.3 mg/m^3 for fumes (OSHA 1990; 29 CFR 1926.63 as referenced in OSHA 1992). For a few industries, separate engineering control air limits (SECALs) have been set as the lowest feasible level above the PEL that can be achieved by the workplace and engineering controls. The administration has also issued separate standards for the construction industry (OSHA 1992; 29 CFR 1926.63 as referenced in OSHA 1992).

Groups in addition to OSHA also make recommendations about acceptable exposures to humans in the workplace. The American Conference of Governmental and Industrial Hygienists (ACGIH), an independent association of professionals working closely with the US government, has published a Threshold Limit Value (TLV), comparable to OSHA's PEL, of 0.05 mg/m^3 for cadmium and compounds. In 1990, however, ACGIH proposed to lower its recommended TLV to 0.01 mg/m^3 for total cadmium dust, to prevent the development of preclinical kidney dysfunction. In addition, ACGIH has proposed an additional TLV of 0.002 mg/m^3 for the respirable fraction of cadmium , to protect the lower respiratory tract from accumulation of cadmium that could cause lung cancer (AIH 1990; ILZRO 1992). The National Institute for Occupational Safety and Health (NIOSH), a branch of the Department of Health and Human Services, recommended in 1984 that cadmium and cadmium compounds be considered potential occupational carcinogens, and has recommended that the concentration of cadmium be limited to the lowest feasible level (OSHA 1992). In addition, NIOSH recommends a limit of 40 mg/m^3, called the IDLH (Immediately Dangerous to Life and Health) limit, defined as the maximum concentration that an individual could withstand for thirty minutes without irreversible health effects (NIOSH 1985; ATSDR 1991).

Several states monitor individuals' body concentrations of cadmium. In New York, health facilities, clinical laboratories, and physicians must report state residents with elevated levels of cadmium in blood or urine to the Heavy Metals Registry. Twenty-six individuals occupationally exposed to cadmium were located by this registry over a five year period. Similar registries have been established in New Jersey, California, Texas, and Maryland (ATSDR 1991).

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Nordic countries

The Nordic countries have undertaken a number of joint initiatives towards protecting the environment.

Denmark, Finland, Sweden and Norway have signed the Ministerial Declaration of the Third International Conference on the Protection of the North Sea. This declaration states that the total inputs of cadmium (via all pathways) are to be reduced between 1985 and 1995 by 70 per cent or more, provided that the use of Best Available Technology or other low waste technology measures enables such a reduction.

Denmark, Finland and Sweden have through the Helsinki Commission (HELCOM), and their Declaration on the Protection of the Marine Environment of the Baltic Sea Area, adopted the goal of reducing emissions of cadmium to water and air by 50 per cent not later than 1995, using 1987 as a reference year.

The Nordic Countries also participate in the risk reduction work within the Paris Commission (PARCOM).

Commissioned by the Nordic Chemicals Group under the Nordic Council of Ministers, a consultant report describing Nordic experiences regarding the technological possibilities for reducing the use of cadmium (NMR 1992:597 *Assessment of Possibilities for Reducing the Use of Cadmium*) has been elaborated. The report concludes that there are technologically acceptable substitutes for most areas of application. For some applications, problems are still to be solved.

European Union

Directive 91/157/EEC concerns batteries containing more than 0.025 per cent cadmium. The Directive, which will enter into force 1.1.1994, contains the following:

- Identification of batteries and details for specific aspects;
- Installation of batteries and appliances only under provision that the batteries can be removed easily (without special tools);
- Organization of separate collection, possibly including a deposit system;
- Consumer information;
- The requirement for Member States to draw up programmes for the removal, separate collection and transportation for re-use;
- Prohibition of obstruction into circulation of batteries conforming to the guidelines.

Tests of deposit systems have shown collection rates of 60-80 per cent depending on the deposit. Even low deposits result in higher collection rates than voluntary systems.

EEC Directive 83/513 sets the limit value of 0.2 mg/litre (had to be complied with as of 1.1.1989) for cadmium discharges from the following industrial processes: zinc mining, lead and zinc refining, cadmium metal and non-ferrous metal industry, manufacture of cadmium compounds, pigments, stabilizers, batteries, phosphoric acid, and phosphatic fertilizers and electroplating.

EEC Directive 86/278 sets limit values for cadmium content in soil and in sludge used in agriculture. The limit value for soil is 1-3 mg/kg (dry matter) and EEC Member States should prohibit the use of sludge where the concentration of cadmium in soil exceeds this limit. The maximum concentration of cadmium in sludge to be used in agricultural land is 20-40 mg/kg (dry matter).

EEC Directive 84/500 sets limits for leakage from ceramic objects intended to come into contact with food: non-fillable objects 0.07 mg/dm^2, fillable objects 0.3 mg/litre, cooking appliances and others 0.1 mg/litre.

EEC Directive (10th amendment to 76/769/EEC) prohibits use of cadmium compounds in certain plastics as pigments and stabilizers, and the use of cadmium in certain metal plating applications. The approach of EEC is different from that of Sweden and Denmark in the respect that in the Directive the prohibited uses are listed, whereas the exemptions are listed in the annexes of Swedish and Danish statutes/resolutions.

ANNEX A (TO CHAPTER 5)

CADMIUM RISK REDUCTION ACTIVITIES: SUMMARY TABLES

Maximum concentration in drinking water: legal standards and guideline values	
Country	**Actions**
Australia	5 µg/litre
Austria	5 µg/litre
Belgium	5 µg/litre
Canada	5 µg/litre
Denmark	5 µg/litre
Finland	5 µg/litre
France	
Germany	5 µg/litre
Greece	
Iceland	
Ireland	
Italy	
Japan	10 µg/litre administrative guidance value
Luxembourg	
Mexico	
Netherlands	5 µg/litre
New Zealand	
Norway	
Portugal	5 µg/litre
Spain	
Sweden	5 µg/litre
Switzerland	5 µg/litre
Turkey	
United Kingdom	5 µg/litre
United States	5 µg/litre

Maximum concentration in effluent/discharges from industrial processes and landfills	
Country	**Actions**
Australia	0.01-0.2 mg/litre (in different states of Australia)
Austria	0.1 mg/litre
Belgium	
Canada	0.1 mg/litre dissolved cadmium from hazardous waste treatment plants; 1.5 mg/litre for metal finishing effluent
Denmark	0.2 mg/litre for certain industrial branches
Finland	0.2 mg/litre for certain processes, in accordance with Directive 83/513/EEC
France	
Germany	0.1 mg/litre effluent from municipal waste landfill
Greece	
Iceland	
Ireland	
Italy	
Japan	0.1 mg/litre (mining and other drainage)
Luxembourg	
Mexico	
Netherlands	0.2 mg/litre
New Zealand	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	0.1 mg/litre effluents discharged into surface waters
Turkey	
United Kingdom	0.05 mg/litre monthly average (guideline)
United States	

Air quality standards for the workplace			
Country	**Cadmium measured as:**	**Maximum exposure limit (µg/m³)**	**Short term exposure limit (STEL) (µg/m³)**
Australia	Total cadmium; cadmium fume	50; 50	
Austria	Classified "probable carcinogen", hence no limit value		
Belgium	Total cadmium; cadmium fume	50*; 50*	
Canada	Cadmium total	50	
Denmark	Total cadmium; cadmium fume	10; 10	
Finland	Total cadmium; cadmium oxide fume	20; 10	
France	Cadmium oxide; cadmium fume	50*; --	50*
Germany			
Greece			
Iceland			
Ireland			
Italy			
Japan	Total cadmium	50	
Luxembourg			
Mexico			
Netherlands	Cadmium total	20	
New Zealand			
Norway			
Portugal			
Spain			
Sweden	Cadmium total; cadmium respirable	50; 20	
Switzerland	Cadmium total Cadmium chloride (respirable) Cadmium sulphide Cadmium stearate	50 50 50 50	
Turkey			

Air quality standards for the workplace			
Country	**Cadmium measured as:**	**Maximum exposure limit ($\mu g/m^3$)**	**Short term exposure limit (STEL) ($\mu g/m^3$)**
United Kingdom**	Cadmium oxide fume Cadmium (pigment) respirable Cadmium and other than the above cadmium compounds	50 40 50	50
United States	Cadmium dust Cadmium fume Cadmium total (Provisional)	200 100 50	

* Voluntary government-industry agreements
** Under review

Maximum concentration in phosphate fertilizers	
Country	**Limit (mg cadmium/kg phosphorous)**
Australia	
Austria	275 mg
Belgium	
Canada	
Denmark	150 mg (from July 1992) 110 mg (from July 1995)
Finland	50 mg
France	
Germany	200 mg (voluntary)
Greece	
Iceland	
Ireland	
Italy	
Japan	340 mg
Luxembourg	
Mexico	
Netherlands	40 mg
New Zealand	
Norway	100 mg (from 1993)
Portugal	
Spain	
Sweden	100 mg (there is a fee for concentrations between 50 and 100 mg)
Switzerland	50 mg (from 1992)
Turkey	
United Kingdom	
United States	

Maximum concentration on agricultural land	
Country	**Actions**
Australia	
Austria	1 mg/kg dry weight
Belgium	1-3 mg/kg dry weight
Canada	
Denmark	0.5 mg/kg for soils treated with sewage sludge
Finland	0.5 mg/kg dry weight
France	
Germany	0.5-10 mg/kg soil (depending on type and use of the soil)
Greece	
Iceland	
Ireland	
Italy	
Japan	
Luxembourg	
Mexico	
Netherlands	0.5 (sand) and 1.0 (clay) in mg/kg d.w.
New Zealand	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	0.8 mg/kg (total); 0.03 mg/kg (soluble guide value)
Turkey	
United Kingdom	3 mg/kg for soils treated with sewage sludge (pH 5.0 and above)
United States	

Maximum ambient air concentration (emission limit)	
Country	**Actions**
Australia	
Austria	
Belgium	0.04 µg/m^3
Canada	
Denmark	
Finland	
France	
Germany	0.04 µg/m^3
Greece	
Iceland	
Ireland	
Italy	
Japan	
Luxembourg	
Mexico	
Netherlands	0.05 µg/m^3
New Zealand	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	0.01 µg/m^3 in suspended dust
Turkey	
United Kingdom	
United States	

Remediation criteria for soil concentration at contaminated sites	
Country	**Actions**
Australia	See Table 5.1.
Austria	
Belgium	
Canada	Interim remediation criteria in µg/g dry weight are: agricultural soil 3, residential/parkland 5, commercial/industrial soil 20
Denmark	
Finland	
France	
Germany	0.8-40 mg/kg
Greece	
Iceland	
Ireland	
Italy	
Japan	
Luxembourg	
Mexico	
Netherlands	Target value: 0.8; intervention value: 12 (in mg/kg d.w.)
New Zealand	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	
Turkey	
United Kingdom	Guidance for redevelopment of contaminated land; Guideline levels of 3 mg/kg for domestic gardens and allotments and 15 mg/kg for recreational land. Maximum permissible concentration of 3 mg/kg for agricultural soil (pH 5.0 and above) treated with sewage sludge.
United States	

Limit of input to agricultural land (with sludge and other materials)	
Country	**Actions**
Australia	
Austria	fields: 25 g/hectare/year; grassland: 12.5 g/hectare/year
Belgium	150 g cadmium/hectare/year
Canada	4 kg cadmium/hectare (over 45 years)
Denmark	
Finland	3 g cadmium/hectare/year
France	
Germany	50 g cadmium/hectare with sewage sludge over three years
Greece	
Iceland	
Ireland	
Italy	
Japan	
Luxembourg	
Mexico	
Netherlands	
New Zealand	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	
Turkey	
United Kingdom	0.15 kg/hectare with sewage sludge in ten years
United States	500 g/hectare allowed in municipal sludge applied to land

Maximum dissolvable amount in consumer goods (toys, ceramics, equipment, etc.)	
Country	**Actions**
Australia	The maximum permissible concentration of leachable cadmium in coating, plastics, graphic and printed materials for children's toys is 100 mg/kg in a test specimen. The leach test is performed using hydrochloric acid. Another class of toys for which a standard exists is modelling materials. These are to have a maximum concentration of cadmium of 0.05 mg/kg.
Austria	in accordance with EC Directive 76/769/EEC
Belgium	
Canada	glazed ceramics: 0.5 ppm; cribs and cradles: 0.1% of the total cadmium applied to the decorative portions or coatings following extraction in 5% HCl for 5 min at 20°C; toys and equipment for learning: 0.1% of the total cadmium applied to the decorative portions or coatings following extraction in 5% HCl for 10 min at 20°C
Denmark	Ceramics: maximum dissolved amount may not exceed 0.1 mg/dm^2 of the surface area of ceramics or when cooked for 3 1/2 hours in 4 per centacetic acid.
Finland	Limit values for leakage from ceramic articles: non-fillable objects 0.07 mg/dm^2, fillable objects 0.3 mg/litre, cooking appliances and others 0.1 mg/litre (EC Directive 84/500/EEC. Toys: limit value for migration 75 mg/kg toy material; 50 mg/kg for finger prints and modelling clay.
France	
Germany	Colouring of utility articles (as far as not covered by EC Directive 76/769/EEC): 0.01% cadmium into 0.1 N HCl (DIN 53770); limit value for ceramics: 0.07 mg/dm^2, and 0.1-0.3 mg/litre (in 4% acetic acid).
Greece	
Iceland	
Ireland	
Italy	
Japan	
Luxembourg	
Mexico	
Netherlands	products containing plastics or paint: <50 mg/kg toys: biological availability <0.6 µg/day

Maximum dissolvable amount in consumer goods (toys, ceramics, equipment, etc.)	
Country	**Actions**
New Zealand	
Norway	
Portugal	
Spain	
Sweden	The amount dissolved from household ceramics in contact with 4 per cent acetic acid for 24 hours should not exceed 0.1 mg cadmium per litre of the volume of the ceramic ware. From 1st January 1995, the European Commission Directive 84/500/EEC will apply, allowing for higher dissolved amounts than at present.
Switzerland	
Turkey	
United Kingdom	
United States	

Guidelines and standards for emissions to air from industrial sources	
Country	**Actions**
Australia	
Austria	0.2 mg/m^3 for foundries
Belgium	22 μg cadmium/m^3 from non-ferrous metal industry
Canada	
Denmark	
Finland	No emission standards; maximum annual emissions are regulated
France	
Germany	100 $\mu g/m^3$ facilities subject to a licence; 50 $\mu g/m^3$ waste incinerators
Greece	
Iceland	
Ireland	
Italy	
Japan	1000 $\mu g/m^3$ (mining smoke and other emissions)
Luxembourg	
Mexico	
Netherlands	20 mg/m^3
New Zealand	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	200 $\mu g/m^3$ if mass flow is ≥ 1 g/h (total of cadmium, mercury and titanium); 100 $\mu g/m^3$ from waste incinerators
Turkey	
United Kingdom	100 $\mu g/m^3$ from waste incinerators; 100 $\mu g/m^3$ has been suggested for other plants
United States	

Maximum concentration in sewage sludge	
Country	**Actions**
Australia	
Austria	5 mg/kg dry weight
Belgium	20-40 mg cadmium/kg dry weight
Canada	20 mg/kg for sludge based products
Denmark	
Finland	3 mg/kg dry weight
France	
Germany	5-10 mg/kg sludge (depending on pH and cadmium content of the soil)
Greece	
Iceland	
Ireland	
Italy	
Japan	
Luxembourg	
Mexico	
Netherlands	1.25 mg/kg
New Zealand	
Norway	10 mg/kg dry weight; will be decreased to 4 mg/kg dry weight
Portugal	
Spain	
Sweden	4 mg/kg; as of 1995: 2 mg/kg
Switzerland	5 mg/kg dry weight
Turkey	
United Kingdom	
United States	

Labelling and recycling of NiCd batteries	
Country	**Actions**
Australia	
Austria	Since 1991, there are legal regulations for collection of spent batteries.
Belgium	NiCd batteries in Belgium are labelled with the information that batteries contain cadmium, on a voluntary basis.
Canada	Canada does not have regulations for management or recycling of NiCd batteries; however, a voluntary programme is being initiated for the collection and recycling of batteries across Canada. At present, some industries operating in Canada have already established their own voluntary programme for recycling NiCd batteries.
Denmark	Denmark intends to reach a re-collection rate of 75 per cent and has imposed a fee on NiCd batteries (Nordic Council of Ministers 1992). This was based on the 1991 arrangement by the Danish Minister of Environment with the Danish Association for Rechargeable Batteries that at least 75 per cent of the NiCd batteries should be re-collected. In 1992, 1/3 to 1/2 of small NiCd batteries were collected after a recycling campaign had taken place. Denmark has a legal regulation for the collection of waste batteries. According to Directive 91/157/EEC on batteries, a separate collection system should exist for these batteries. The Directive entered into force 1 January 1994.
Finland	Organization of labelling and recycling of batteries containing cadmium has been planned in co-operation with the other Nordic countries. The general provisions concerning batteries are being prepared.
France	
Germany	There are regulations concerning labelling of NiCd batteries with a recycling symbol in Germany (Bätcher 1992). Germany has voluntary regulations for the collection of waste batteries. According to the EEC Directive on batteries, a separate collection system should exist for these batteries.
Greece	
Iceland	
Ireland	
Italy	
Japan	The label "NiCd battery, recyclable" will be obligatory after June 1995. A more systematic collection of spent batteries will be established.

Labelling and recycling of NiCd batteries	
Country	**Actions**
Luxembourg	
Mexico	
Netherlands	Information is given by labelling. NiCd batteries are recycled in so far as they are separately offered to the recycling industry. Collection is on a voluntary basis. If unsuccessful, a deposit system will be introduced by the government.
New Zealand	
Norway	Organized collection of NiCd batteries exists in Norway. There is, however, no recycling of NiCd batteries yet.
Portugal	
Spain	
Sweden	There are regulations concerning labelling of NiCd batteries with a recycling symbol. Today the symbol conforms to Directive 93/86/EEC. Sweden has regulations for the collection of waste batteries. A separate collection system should exist.
Switzerland	In Switzerland, batteries are deemed to be pollutant if the total amount of cadmium and mercury they contain exceeds 250 mg per kg of battery. Concerning separate collection, pollutant batteries must be labelled with the pictogramme "Hazardous Waste" or an internationally agreed pictogramme and the instructions "to be returned to the place of sale after use". The same labelling is required for their packaging. Manufacturers and traders who supply pollutant batteries must take back free of charge all types of used batteries. Carbon-zinc batteries may not exceed a total amount of cadmium and mercury of 250 mg per kg of battery. Measures are intended to be taken to increase the return rate of small, sealed nickel-cadmium accumulators. They are already labelled as NiCd batteries.
Turkey	
United Kingdom	Programmes and measures for the reduction of NiCd batteries containing more than 0.025 per cent cadmium by weight in household waste, and for their separate collection and disposal, to be established in the UK following the adoption of Directive 91/157/EEC.

Labelling and recycling of NiCd batteries	
Country	**Actions**
United States	Several states, including Connecticut, Iowa, Maine, Minnesota, New Hampshire, New Jersey, New York, Oregon, Rhode Island and Vermont, have passed laws on labelling and recycling of batteries (PRBA 1992a). Two states have initiated pilot programmes on collection and recycling of batteries (PRBA 1991, 1002b). Such programmes generally require rechargeable battery and battery powered product manufacturers to develop and adopt battery collection and management plans, participation in the respective state's battery recycling programme often being a prerequisite for the sale of batteries or battery powered products. Furthermore, battery powered products should be designed and marked so that the rechargeable battery is easily identifiable and removable.

Restrictions on use	
Country	**Actions**
Australia	
Austria	Since 1st February 1994, a prohibition to place on the market or use cadmium and cadmium-compounds as pigments, stabilizers and in plating is enforced. According to the ordinance, pigments and lacquers may not contain more than 10 mg/kg of cadmium as an impurity. If the zinc content of pigment is high they may contain 100 mg/kg of cadmium at most. Zinc-plated metal may not contain more than 20 mg/kg of cadmium. Several exemptions from this prohibition exist, covering for example the glass in signal devices, ceramics, enamel, artist's colours, products containing recycled cadmium derived from goods sold before 1st January 1994, plating metal containing no more than 5 per cent of cadmium, parts of aircraft, products where cadmium is used for safety reasons, etc. (Bundesministerium für Umwelt, Jugend und Familie, 1993).
Belgium	The use of cadmium has been regulated by the EC Directive 91/388/CCE.
Canada	
Denmark	In Denmark, the use of cadmium in pigments, stabilizers and plating is prohibited. Exemptions are made for some specified areas of application. In Denmark, further exemptions for the cadmium prohibitions can be granted by the responsible authority.
Finland	A provision containing similar restrictions as in Directive 76/769/EEC, 10th amendment has been enforced in Finland. Consequently use of cadmium compounds in certain plastics as pigments and stabilizers, and use of cadmium in certain metal plating applications, is prohibited.
France	
Germany	The use of cadmium is regulated by EC Directive 76/769/EEC
Greece	
Iceland	
Ireland	
Italy	
Japan	
Luxembourg	
Mexico	
Netherlands	The Dutch Cadmium Decree bans the use of cadmium in stabilizers, pigments and coatings. A list of exceptions is given.

Restrictions on use	
Country	**Actions**
New Zealand	
Norway	Norway has limits for the cadmium content in non-rechargeable batteries. Norway is going to implement the EEC Directive (10th amendment to 76/769 EEC) concerning the use of cadmium compounds in certain plastics as pigments and stabilizers, and the use of cadmium in certain metal plating applications.
Portugal	
Spain	
Sweden	In Sweden, the use of cadmium in pigments, stabilizers and plating is prohibited. Exemptions are made for some specified areas of application. In Sweden, further exemptions from the cadmium prohibitions can be granted by the responsible authority. Between 1977 and 1985 Swedish industry reduced cadmium consumption in the application sectors affected by the prohibition from about 100 tonnes/year to 10-11 tonnes/year.
Switzerland	In Switzerland, the Ordinance relating to Environmentally Hazardous Substances prohibits the import and supply by a manufacturer of plastics containing cadmium, mainly cadmium compounds used as stabilizers and pigments. Exemptions for a limited time may be granted by the Federal Office of Environment, Forests and Landscape. A plastic is considered to contain cadmium if the content is 100 ppm cadmium or more. The import or supply by a manufacturer of articles protected against corrosion by means of cadmium is prohibited. Several exemptions exist if no non-cadmium plated replacement is available and provided that no more cadmium is used than is necessary for the article's intended use. Upon reasoned request further exemptions may be granted by the Federal Office. The cadmium content of zinc-plated articles is limited to a maximum of 250 ppm since 1st January 1991.
Turkey	
United Kingdom	Plastics: Limit of 0.01 per cent cadmium when used as a pigment or stabilizer in certain plastics established under the conditions set out in Directive 91/338/EEC. Plating: Restrictions on the use of cadmium for certain metal finishing applications as specified under Directive 91/338/EEC. Food Containers: No established limits for plastics other than those specified in Directive 91/338/EEC. Restrictions on the sale of articles of ceramic ware or vitreous enamel ware likely to be used in contact with food based on limits of leachability of cadmium linked to degree of contact.
United States	

Surface water and river water quality	
Country	**Actions**
Australia	0.2-5µg/litre, in different States of Australia
Austria	
Belgium	
Canada	0.2-1.8 µg/litre, depending on hardness of water
Denmark	
Finland	5 µg/litre for surface water used as drinking water supply
France	
Germany	
Greece	
Iceland	
Ireland	
Italy	
Japan	
Luxembourg	
Mexico	
Netherlands	
New Zealand	
Norway	
Portugal	
Spain	
Sweden	
Switzerland	5 µg/litre
Turkey	
United Kingdom	5 µg/litre (total cadmium) and 2.5 µg/litre (dissolved cadmium) in inland waters and coastal/territorial waters, mean annual concentrations
United States	10 µg/litre as ambient water quality criterion; 1.1 µg/litre (four-day average) to protect aquatic organisms

APPENDIX 1

CADMIUM BALANCE IN AGRICULTURAL SOILS: SOME NATIONAL EXAMPLES

Detailed mass balance studies have been established for agricultural soils in Denmark and the Netherlands representing, respectively, elevated and moderate levels of contamination. These studies suggest that an insignificant or possibly zero accumulation can only be achieved by a combination of measures which reduce the inputs of cadmium from all sources, e.g. atmospheric deposition, fertilizers and sewage sludge. Jensen and Bro-Rasmussen (1992) have suggested that to achieve a zero accumulation, the percentage of reduction should be, respectively, 50-70 per cent for fertilizers, 65-75 per cent for sewage sludge, and 50-65 per cent for atmospheric deposition.

One must take into consideration the fact that significant differences may exist between countries regarding the quantification necessary to achieve a significant reduction. It is therefore difficult to extrapolate the above percentages to all countries. In some countries, for example Australia, the normal application rate of fertilizers is much lower than in the Netherlands and Denmark. Consequently, cadmium input to soil is lower.

In Germany, a survey conducted by the Sachverständigenrat für Umweltfragen (Umwelt und Landwirtschaft) provided the following figures for 1985 for cadmium in the agricultural soil:

Input:

- average content in soil (28 cm, weight 1.5 kg), 840 g/hectare;
- average atmospheric deposition (low and heavily polluted areas), 4-15 g/hectare/year;
- average application due to fertilizers, 3 g/hectare/year;
- average application due to sewage sludge, 5.8 g/hectare/year (only for soil to which sewage sludge is applied frequently).

Output:

- average uptake by plants, 1.5-3 g/hectare/year;[4]
- average output due to leaching, 0.5 g/hectare/year.

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[4] Due to high uptake, cadmium concentration in plants (e.g. in grain) is considerable. Concentrations of 0.5 up to 1 mg/kg have been observed in Germany (Sauerbveck et al. 1988, Agrarsoziale Gesellschaft 1992).

More recent data on cadmium balance in soils in Germany are available (Iserman 1992 and 1993).

The recent cadmium balances published in Sweden (**Table A.1**) and Finland (Louekari et al. 1991) are rather similar to those of the Netherlands and Denmark, although the input to agricultural land is slightly smaller.

Table A.1 Total Cadmium Balance for Swedish Cultivated Soil

	Tonnes/year	**Per cent**
Sources of cadmium added to soil		
Atmospheric deposition	2.26	57
Fertilizers	1.56 *	39
Feed	0.05	1
Lime	0.10	2
Sludge	0.02	1
Total	3.99	100
Loss of cadmium from soil		
Leakage	0.17	49
Grain export	0.05	14
Sludge deposit	0.13	37
Total	0.35	100

** At present, the Swedish manufacturer estimates the contribution of cadmium from fertilizers at 1.0 to 1.2 tonnes per year.*

Source: "Less cadmium in fertilizers", SOU 1992:14, a report to the Swedish Government

In **Tables A.2 and A.3**, the cadmium balance for Danish and Dutch agricultural land is presented. The amount of cadmium input from sewage sludge is calculated here by dividing the total cadmium content of sludge by the total agricultural area. However, in practice sludge is applied on only a small percentage of farmland (about 1 per cent) and usually replaces the use of phosphate fertilizer. Thus in certain areas the amount of cadmium input from sewage sludge is much higher than indicated in the tables, while the input is zero for most farmland.

In the studies presented on cadmium in soil, it is unclear whether leaching includes loss of material via runoff and wind erosion. These factors are important to consider in interpreting total accumulation. There is evidence that the "disappearance" of cadmium from experimental land areas is due to horizontal and not to vertical movement. This would imply that the amount of cadmium in leachate is overestimated here.

Table A.2 Cadmium Balance for Farmland in Denmark, Sandy Soil (grams of cadmium/hectare/year)

Commercial fertilizers	0.93
Sewage sludge	0.04
Atmospheric deposition	1.1
Total input	**2.07**
Leaching	2.47
Crops	0
Total output	**2.47**
Accumulation in top soil	1.47
Annual per cent increase in top soil	0.3

Top soil content of cadmium is 510 g and concentration is 0.17 ppm.

Table A.3 Cadmium Balance for Farmland in the Southern Netherlands

Commercial fertilizers Sewage sludge Atmospheric deposition	3.8 1.6 4.0
Total Input	**9.4**
Leaching Crops	0.5-2.5 about 0.2
Total Output	**0.7-2.7**
Accumulation in top soil	6.7-8.7
Annual per cent increase in top soil	0.57-0.73

In grams of cadmium/ha/year. Top soil content of cadmium is 1200 g and concentration is 0.40 ppm.

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