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CADMIUM METAL AND CADMIUM OXIDE

CAS No: 7440-43-9 and CAS No: 1306-19-0

EINECS No: 231-152-8 and EINECS No: 215-146-2

Summary Risk Assessment Report

2008 **EUR 23424 EN**

The mission of the IHCP is to provide scientific support to the development and implementation of EU polices related to health and consumer protection. The IHCP carries out research to improve the understanding of potential health risks posed by chemical, physical and biological agents from various sources to which consumers are exposed.

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SUMMARY RISK ASSESSMENT REPORT

Final report, 2008

Belgium

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PREFACE

This report provides a summary, with conclusions, of the risk assessment report of the substances cadmium metal and cadmium oxide that has been prepared by Belgium in the context of Council Regulation (EEC) No. 793/93 on the evaluation and control of existing substances.

The present study essentially covers the production of cadmium metal and cadmium oxide, the use of these substances in the production of stabilisers, pigments, alloys and plated products. Further down-stream uses are not or partly included. However, major attention is attributed to the most important application, i.e. batteries with the whole life-cycle covered, thus including the main waste management options (recycling, incineration and landfill).

The risk assessments of metallic Cd and of CdO are combined in one study because both products transform into the environment to the same form and risk is associated with exposure to the most toxic form, mainly ionic Cd^{2+}.

For detailed information on the risk assessment principles and procedures followed, the underlying data and the literature references the reader is referred to the comprehensive Final Risk Assessment Report (Final RAR) that can be obtained from the European Chemicals Bureau[1]. The Final RAR should be used for citation purposes rather than this present Summary Report.

[1] European Chemicals Bureau – Existing Chemicals – http://ecb.jrc.it

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1 GENERAL SUBSTANCE INFORMATION

1.1 IDENTIFICATION OF THE SUBSTANCE

CAS Number:	7440-43-9	1306-19-0
EINECS Number:	231-152-8	215-146-2
IUPAC Name:	Cadmium metal	Cadmium oxide
Synonyms:	Not applicable	Not applicable
Molecular weight:	112.41 (several naturally-occurring isotopes ranging from 106-116 (Lexicon, 1972; WHO, 1992)	128.41
Molecular formula:	Cd	CdO
Colour:	blue-white (Sax and Lewis, in: ATSDR, 1998)	varies from greenish-yellow through brown to nearly black, depending on the thermal history (due to lattice defects) and on the particle size

1.2 PURITY/IMPURITIES, ADDITIVES

	Cadmium metal	Cadmium oxide
Purity (powder):	Min. 99.9%	Min. 99.9% (IUCLID, 1997)
Purity (massive):	Min. 99.9%	
Impurities (max.)	For 99.99% Cd metal: Fe: 10 ppm; Cu: 20 ppm; Ni: 10 ppm; Pb: 100 ppm; Zn: 30 ppm, Th: 35 ppm. Other levels are specified for other purity grades. (ASTM B440-00)	n.a. Powder reagent grade: max. chloride 0,002%; nitrate 0,01%; sulphate 0,20%; copper 0,005%; iron 0,002%; lead 0,01% (JT Baker chemical Co, 1984)
Additives:	none	none

Remark: It is stated that the purity levels and chemical analyses indicated here are purely arbitrary as many grades of both cadmium metal and cadmium oxide exist. It is recommended that the ranges or specifications should be listed using the appropriate ISO or EN standards (ICdA, com. 2003). However, only the ASTM standard was provided for Cd metal grades 99.95, 99.99 and 99.995%.

1.3 PHYSICO-CHEMICAL PROPERTIES

Table 1.1 Summary of physico-chemical properties

Property	Cadmium metal	Cadmium oxide
Physical state	solid (massive or powder)	solid (powder)
Crystal structure	distorted hexagonal close-packed	cubic structure with each ion surrounded by six ions of opposite electric charge, octahedrally arranged. Also an amorphous form exists: stable at lower temperatures, forming crystals of the cubic type at red heat
Melting point	320,9°C (Lexicon, 1972, Sax and Lewis: in ATSDR, 1998;CRC: in IUCLID, 1997)	Decomposes at 900-1000°C (CRC, 1985; IUCLID, 1997)
Boiling point	765°C (idem); 767°C (Sax and Lewis: in ATSDR, 1998)	CdO is non-fusible but volatilises at high temperature. Sublimation at 1559°C
Relative density	8.64 g/cm^3 (Lexicon, 1972, Sax and Lewis: in ATSDR, 1998: analysis by WIAUX S.A., in LISEC, 1998e).	8.15 g/cm3 (cubic form); 6.95 g/cm^3 (amorphous) (EPA 1985).
Vapour pressure	1 mmHg at 394°C (Sax and Lewis: in ATSDR, 1998) 133 hPa at 394°C (CRC, in: IUCLID, 1997	1 mmHg at 1000°C (Sax, N.I., 1984)
Water solubility	quoted as 'insoluble' (The Merck index; in: ATSDR, 1998; CRC, in: IUCLID, 1997). However it was mentioned: 0,05 mg/1 at pH 10,5 a curve in function of pH and hardness: at pH 7: solubility is 10 to 100 times higher than at pH 8.5 dependent on the total carbonate concentration (M. Farnsworth, 1980). Measured dissolved cadmium concentrations after 7 days transformation/dissolution test with cadmium metal powder at loading 1 – 100 mg/l, were in the range 0.192 – 0.135 mg/l (at pH +/- 8) (LISEC, 1998e).	quoted as 'insoluble' However measured dissolved cadmium concentrations after 7 days transformation/dissolution test with cadmium oxide powder at loading 1 – 100 mg/l were in the range 0.095 – 0.227 mg/l (at pH +/- 8) (LISEC, 1998f). Soluble in acids and solutions of ammonium salts (Farnsworth, 1980).
Partition coefficient n-octanol/water (log value):	No data Not applicable	No data Not applicable

Table 1.1 continued overleaf

Table 1.1 continued Summary of physico-chemical properties

Property	Cadmium metal	Cadmium oxide
Physical state	solid (massive or powder)	solid (powder)
Granulometry	The average spherical diameter of cadmium powder prepared by distillation is about 18 µm +/- 13.3 µm (S.D.) (inhalable fraction) and the specific surface area : 580.4 cm2/g (analysis by WIAUX S.A., in: LISEC, 1998e). Particle size and surface area depend very much upon the specific process and specific application. For example, INMETCO produces a cadmium metal shot which is many times larger than the aforementioned cadmium metal powder (ICdA, com. 2003). See also remark related to flammability testing.	The average spherical diameter of CdO powder prepared by oxidation of Cd metal is about 0.55 µm (respirable fraction) (La Floridienne, 1997). Particle size and surface area depend very much upon the specific process and specific application (ICdA, com. 2003).
Self-ignitiony	Not applicable	Not applicable
Flammability	Slight fire hazard. The finely divided metal may be pyrophoric in air (MSDS, 1992; IUCLID, 1997)* GLP testing conform EC Testing methods A.10, A.12 and A.13 (BAM, 2002): Cadmium metal 'powder' [particle size distribution (in volume-%): d(0.1): 3.462µm; d(0.5): 7.154 µm; d(0.9): 14.117 µm; mean water content: 0.03] and cadmium 'fine billes' [particle size distribution (in volume-%): d(0.1): 2.485µm; d(0.5): 7.040µm; d(0.9): 15.753µm; mean water content: 0.05] are not flammable and do not have pyrophoric properties in sense of the EC-methods, Dir. 92/69/EEC.	Not flammable
Explosive properties	Dust/air mixture may be explosive. Even as fine powder, cadmium is hardly explosive (MSDS, 1992; INRS, 1987)	
Oxidizing properties	Not applicable	not applicable
Odour threshold:	No data	No data
Ionisation potential:	$E°Cd/Cd^{2+}$ = 0.4025 eV (= fairly reactive)	
Caloric value	0.16 Cal/g	

1.4 CLASSIFICATION

According to Annex I of Directive 67/548/EEC (29th ATP) of 16/06/2004.

Classification:	Carc. Cat. 2; R45	Category 2 Carcinogen; May cause cancer
	Muta. Cat. 3; R68	Category 3 Mutagen; Possible risks of irreversible effects.
	Repr. Cat. 3; R62-63	Category 3 Toxic to Reproduction; Possible risk of impaired fertility, and of harm to the unborn child
	T; R48/23/25	Toxic: danger of serious damage to health by prolonged exposure through inhalation and if swallowed
	T+; R26	Very toxic by inhalation
	N; R50-53	Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
Labelling:	T+; N R: 45-26-48/23/25-62-63-68-50/53 S: 53-45-60-61	

2 GENERAL INFORMATION ON EXPOSURE

Production

Metallic Cd is mainly produced in the EU as a by-product of zinc production via electrolytic processes. The rest is obtained in association with pyrometallurgical refining processes. Cadmium oxide is produced from Cd in a dry process. The Cd production in EU is 5,800 tonnes/year, its import 1,900 tonnes/year and its export 2,200 tonnes/year (data for 1996). The production of CdO in EU is 2,500 tonnes/year, there are no data on its import and about 1,400 tonnes/year is exported (data for 1996).

Uses

Cadmium and CdO are mainly used in the EU for the production of NiCd batteries. Less than 15% is used for the production of pigments and less than 15% is used in plating, alloys or stabilisers. The EU use pattern of Cd/CdO follows about the same distribution. The collection and recycling of NiCd batteries show increasing trend during the 8 years before 2001.

3 ENVIRONMENT

3.1 ENVIRONMENTAL EXPOSURE

Environmental releases

Cadmium is a naturally occurring element with a ubiquitous distribution in the environment. The ambient Cd in the EU environment exceeds by orders of magnitude the actual annual emissions. Reported trends of Cd concentrations in water and air indicate decreasing emission over the last two decades.

The exposure is assessed in this study for all sources of Cd, i.e. the ambient Cd in the environment and the actual industrial and diffuse emissions of Cd. The Predicted Environmental Concentrations (PECs) therefore include the ambient concentrations and which may directly be compared with measured concentrations. Information is available in this document to quantify the ambient and added Cd fractions in the PEC. Ambient Cd concentrations have a natural ('geogenic') component and a component related to historic emissions by man. The distinction between both components is considered as not critical for the current study and can, moreover, not unequivocally be made. The effects assessment, leading to the Predicted No Effects Concentrations (PNECs), is similarly based on total Cd concentrations, including the ambient concentrations. All toxicity tests with Cd are performed in environmental substrates that naturally contain some Cd, even when tests are performed in artificial substrates such as reconstituted water, artificial soil or synthetic diets.

Industry questionnaires in 1997 and 2001 provided updated Cd emission data from the Cd and CdO producing industry, NiCd battery producers and Cd recycling plants. Information on Cd losses associated with processing of Cd in pigments, stabilisers, plating and alloys were derived from other studies (WS Atkins, 1998, ERL, 1990 and ICdA, 1998). The total environmental emissions from the Cd/CdO industry and its downstream users (Cd/CdO processors) are given in **Table 3.1**. Emissions from other sources of Cd were derived from other studies with special attention for updated information on emissions from waste incineration or waste disposal and from P fertilisation. Natural processes (bush fires, runoff and leaching of natural Cd from soil, etc.) are not included in this list because the PECs are calculated from the sum of an assumed natural background concentration and the concentration related to anthropogenic emissions.

The emission from Cd/CdO producers and processors only form a minor part of the total emissions of Cd in Europe, illustrating the ubiquitous presence of Cd in the environment. The major sources of net Cd input at the continental scale are P fertiliser application, production of iron and steel and oil combustion. Various estimates have shown that Cd emissions in EU have reduced considerably compared with about 30 years ago. Local Cd emissions from Cd/CdO production sites vary considerably with clearly elevated atmospheric Cd emissions and emission factors at 3 Cd production sites that still use the pyrometallurgical refining.

Table 3.1 Total anthropogenic Cd emissions in the EU-16 (T y-1) from Cd/CdO industry and its downstream users and diffuse Cd emissions from other sources. Source: RAR Cd/CdO (2002) and TRAR on Cd/CdO in batteries (2002)

	to air (T y^{-1})	to water (T y^{-1})	to soil (T y^{-1})
Cd/CdO production	3.9	1.2	-
Cd/CdO processing (batteries, alloys, plating, pigments, recycling)	0.8	0.3	-
other non-ferrous metals production	9.7	9.7	-
production of iron and steel	31	> 15.6	-
oil/coal combustion	54	0.1	-
processing phosphates	0.7	9.1	-
municipal incineration	3.2	0.4	-
wood/peat combustion	1.7	_	-
other (cement, glass prod., traffic, municipal wastewater)	> 19	> 1.2	-
landfilling	-	0.55	-
mining	-	1.1	-
phosphate fertilisers			231
sludge application on soil			> 13.6
Totals	> 124	> 39.25	> 244.6

The emissions of Cd from waste disposal have been estimated with measured and modelled Cd emissions for municipal waste incineration and landfilling. The contribution of NiCd batteries in the waste stream is currently about 10%. Future Cd concentrations in municipal solid waste are predicted to reach steady state concentrations in about 10 years. The steady state Cd concentrations in the waste can be 2.4 fold larger than current concentration assuming a worst case scenario of only 10% collection efficiency of batteries. The predicted emission to surface waters from waste incineration will increase in that scenario from currently 0.4 tonnes y^{-1} to 3.5 tonnes y^{-1} if also 100% of the waste in EU becomes incinerated (now 26.9%). The atmospheric emissions from that waste incineration scenario may increase from currently 3.2 tonnes y^{-1} to 14 tonnes y^{-1}. The 10% collection efficiency of the Ni-Cd batteries represents the situation in countries with a collection system with low efficiency whereas 75% collection is representative for a country with a collection system with a high efficiency. The 75% collection efficiency is considered by industry as representing an EU-wide realistic target (Wiaux, pers. com.). In this target scenario and with constant fractions of waste allocated to incinerators and landfills, atmospheric emissions from waste incineration are predicted not to increase whereas annual emissions to surface waters will increase by a factor 1.3 from current emissions.

The Cd present in incineration residues is currently equivalent to about 270 tonnes Cd y^{-1} and may increase significantly in the future if more waste becomes incinerated and more Cd containing products ends up in the waste-stream, even at increasing battery collection schemes. The re-use and/or landfilling of incineration residues may result in a long-term diffuse emission potentially contaminating groundwater, surface water and soil. The delayed cadmium emissions of the re-use of incineration residues have, however, not been quantified

in this study since the use of incineration residues is only allowed if the results of leaching tests are favourable.

Environmental fate

One of the difficulties in a risk assessment of 'total' Cd is the differences in bioavailability and effect of Cd among all forms considered, i.e. metallic Cd, CdO powder, the Cd emissions products from Cd/CdO production and use and the ambient (background) Cd. The metallic Cd and the CdO powder are less available in the environment than soluble Cd^{2+}, suggesting that effects assessment should be based on the products and not on Cd^{2+} salts. However, metallic Cd and the CdO powder can slowly transform in the environment to the more toxic Cd^{2+}.

Transformation tests in soil (99 days) showed that the solubility of metallic Cd powder and CdO powder was less than a factor 2 different from that of Cd^{2+} salts. Toxicity of CdO for plant growth was less than a factor 3 smaller than that of Cd^{2+} salts at equivalent Cd concentrations in three different tests. Plant uptake studies using Cd isotopes revealed that recently added Cd^{2+} is less than twofold more available than the ambient Cd in the soil. This experimental evidence was used to conclude that the differences in bioavailability between, on the one hand, recently added Cd^{2+} salts and, on the other hand, ambient Cd or Cd added to soil as metallic Cd powder or CdO powder are too small to take the source of Cd into account in the risk assessment of the soil compartment.

Transformation test in water unequivocally showed that CdO and metallic Cd have a limited solubility. However, releases to the aquatic compartment by the producers and processors are generally based on measurements in effluents after the sewage treatment plant (STP). Most Cd/CdO particles are retained in the STP and the Cd in the effluent is mainly present as dissolved Cd. It is furthermore assumed that soluble Cd, either from the background or added by man, is equally available as soluble Cd^{2+} salts in water, i.e. a risk assessment based on tests with Cd^{2+} salts is assumed to be valid for this study.

The Cd mobility in anaerobic sediments is controlled by the concentration of acid-volatile sulphides (AVS) by the particulate organic carbon (POC) and by the dissolved organic carbon (DOC). In aerobic conditions, in which the AVS are virtually absent, Cd mobility depends on the content of the POC and of Fe and Mn-hydroxides. The toxicity of Cd most likely depends on its mobility in the sediment. A relationship was found between cadmium toxicity and the AVS normalised Cd content. In general, toxicity was expected to be absent when the ratio of the simultaneously extractable metals (SEM) to the AVS < 1 (molar ratio) and could increase drastically from SEM/AVS ≥1. Metal toxicity above this value furthermore depends on water hardness, pH and solid phase properties. However, the molar ratio did not seem to be a good predictor of potential effects, because the ratio gives no indication about the absolute amount of SEM present in excess of AVS. Therefore, the molar difference was introduced as a better predictor. At a molar SEM-AVS difference < 0 no toxic effects are expected while at molar SEM-AVS difference > 0 toxic effects may occur.

No data were found to make a risk assessment of Cd or CdO in the atmospheric compartment.

Environmental concentrations

Environmental Cd concentrations have been calculated from the actual emissions with the EUSES 1.0 programme and default parameter values to represent the EU continent and region. These predicted concentrations refer to 'anthropogenic' (added) Cd since they are calculated from anthropogenic emissions. The background Cd concentrations were finally

added to these theoretical added concentrations, yielding the predicted total Cd concentrations (PECs). The parameter values that critically affect the PECs are the background concentrations, the solid:liquid distribution coefficient in soil and the fraction dissolved Cd in the water columns. These parameter values have been chosen by expert judgment to reflect 'typical average conditions' in EU, thereby realising that these parameter values can vary more than one order of magnitude. The PECs calculated by EUSES 1.0 refer to the 'steady state' concentrations in the environment. Cadmium has a very long residence time in soil (elimination half-life is about 380 years with default parameters) and, therefore, steady state may not be achieved within the next centuries. The PECs in water and sediment may also not reflect immanent conditions since they are indirectly affected by the soil Cd via runoff and erosion of Cd from soil. The regional and continental PECs should therefore be used as indicative generic values and more attention should be paid to measured concentrations. Typical values for measured concentrations in water and air correspond reasonably well with predicted values (see **Table 3.2**), whereas sediment and soil concentrations were clearly overestimated. The overestimation is ascribed to the steady state assumption in the model and which is a situation that may not even be reached within the next centuries.

An alternative model has been used to calculate the PECs of agricultural because this compartment is critical in the Cd risk assessment. Retrospective analyses of archived soil samples revealed increasing trends in soil Cd concentrations and potential increasing trends in soil Cd concentrations deserve special attention because biotransfer of Cd from Cd to crops and to food determined for more the 90% the Cd exposure to the general non-smoking population. The alternative model does not require steady state and 7 different scenarios have been selected to reflect typical conditions in the EU. This modelling exercise showed that the current Cd input in European agricultural soils is reduced from historical input and that the soil Cd concentration is predicted to change by between a 19% decrease to a 37% increase (EU mean: 6%) in 60 years. However, there is always uncertainty in the input-output data and it now appears that estimating Cd leaching losses is critical for drawing firm conclusions. An average steady state at EU level obviously does not preclude that a strong increase in soil Cd is found in local areas. This drawback is not considered as a major shortcoming in the risk assessment since risk is driven by foodchain contamination in which food groups such as cereals and potatoes have a large impact. These food groups are unlikely to be consumed by individuals from one location throughout a lifetime. Cumulative lifetime exposure to Cd results in the most critical pathway in the Cd risk assessment.

3.2 EFFECTS ASSESSMENT

Aquatic compartment (incl. sediment)

The Cd concentrations in large European rivers vary between < 0.02-0.35 μg L^{-1}, with most values found < 0.1 μg L^{-1} (see **Table 3.2**). Adverse effects in reliable chronic single and multi-species studies are found between 0.3 and 100 μg Cd L^{-1} with a tendency to find lowest toxic thresholds for invertebrates in soft waters. Single species chronic studies were selected in which a requirement of measured rather than nominal concentration for NOECs near background was a critical screening factor. The $PNEC_{water}$ of Cd was derived with statistical extrapolation (HC_5, Aldenberg and Slob, 1993) from 44 chronic NOEC values, some of which are geometric species means. An assessment factor of 2 was applied to the HC_5 after considering the species richness in the data (28), the number of full chronic studies, the comparison with mesocosm studies and the occurrence of some unbounded LOEC values in the data below the HC_5. The $PNEC_{water}$ derived this way is **$PNEC_{water}$ = 0.19 μg Cd L^{-1}** (dissolved fraction). No adverse effect of Cd below this PNEC was found in 168 reliable tests

that have been reviewed. A correction of the PNEC for water hardness has been proposed based on relationships between hardness and chronic values in univariate tests. Multi-species NOECs have been reported between 0.08 and 4.2 µg Cd L^{-1}. The lowest NOEC was found at very low water hardness. The hardness corrected $PNEC_{water}$ was within the range of multi-species NOEC values and below all multi-species LOEC's. The PNEC in very soft water is the previously agreed regional **$PNEC_{very\ soft\ water}$ of 0.08 µg/L** which is proposed for water with hardness 2.7-40 mg $CaCO_3$/L and DOC concentrations above 2 mg C/L with the additional warning that for the most sensitive species there is no information that there would be no adverse effects below that PNEC below hardness 5 mg $CaCO_3$/L and DOC 4 mg/L.

Table 3.2 The environmental Cd concentrations in Europe (observed and predicted for the regional scale) and the environmental thresholds derived in the RAR of Cd/CdO

Compartment	Environmental concentrations away from point sources					PNEC
	Units	Observed		Predicted (regional)		
		Typical range	Typical value	Natural background	Background +added (=PEC)	
freshwater	µg $L^{-1\$}$	0.02-0.35	< 0.1	< 0.05	0.11	0.19
sediment	mg kg^{-1}_{dw}	1.0-10	2.0	0.1-0.8	10	2.3
soil	mg kg^{-1}_{dw}	0.1-1.8	0.3	unknown	0.41	0.9-2.3†
air	ng m^{-3}	0.1-0.5	~ 0.5	~0	0.6	-

$ Dissolved fraction;
† Including protection of mammalian wildlife

The Cd concentrations in sediments range 1-10 mg kg^{-1}_{dw} with most values around 1 mg Cd kg^{-1}_{dw}. The **$PNEC_{sediment}$ =2.3 mg Cd kg^{-1}_{dw}** and is derived from a chronic study and an assessment factor.

Terrestrial compartment

The total Cd concentrations in European soils generally vary between 0.1-1.6 mg kg^{-1} with most values around 0.3 mg kg^{-1} (see **Table 3.2**). Adverse effect concentrations in laboratory and field tests are found at total Cd concentrations between 2.5 and >1,000 mg kg^{-1} with a tendency to find lowest thresholds for plants grown in potted soil applied with Cd^{2+} salts. Fifty-four single species studies were selected in which requirements of absence of mixed metal pollution and information that the dose has been mixed in the soil were critical screening factors. The $PNEC_{soil}$ of Cd was derived with statistical extrapolation (HC_5, Aldenberg and Slob, 1993). It was considered appropriate not to mix NOECs from tests with microbial processes (multi-species) with these from single species tests (plants and invertebrates) in the statistical extrapolations. The HC_5 was lowest when applied to 21 selected NOEC values of microbial processes, even though plant data overall showed lowest LOEC values. An assessment factor of 1-2 was applied to the HC_5 after considering the species richness in the data (20+ 5 microbial processes), evidence indicating equal or smaller toxicity in field studies and the lack of LOEC values below the HC_5 in the database containing >160 tests. The $PNEC_{soil}$ derived this way is **$PNEC_{soil}$ = 1.15-2.3 mg Cd kg^{-1}**. The overall database did not reveal significant trends between soil properties (pH, % clay) and Cd toxicity and similar information from studies using multiple soil types was inconsistent. Therefore, no model was considered appropriate to define PNEC values as a function of soil properties.

Atmosphere

No data were found to make a risk assessment of Cd or CdO in the atmospheric compartment.

Secondary poisoning

The median Cd Bioconcentration Factors (BCF, L kg^{-1}_{ww}) decrease in the order algae > invertebrates > vertebrates and the water-fish Cd Bioaccumulation Factors (BAF's) are about 40 L kg^{-1}_{ww} with maximal values around 600 Lkg^{-1}_{ww}. Soil-earthworm BAF values are about 15 (dry weight concentration ratio) with values up to 150. All BCF and BAF values exhibit a pronounced decrease with increasing concentrations in the environment. The $PNEC_{oral}$ for birds and mammals is 0.16-0.3 mg kg^{-1}_{food} respectively based on chronic feeding studies. A large risk for secondary poisoning is predicted for earthworm eating mammals in the terrestrial environment using this PNEC value. The median BAF and typical soil concentrations predict food Cd concentrations that are about 15 fold above the $PNEC_{oral}$. This predicted risk at ambient concentrations is ascribed to overestimated bioavailable Cd when based on feeding studies where metal salts have been mixed with laboratory diets. An alternative approach for terrestrial wildlife was proposed based on measured tissue residues in field collected wildlife and on renal thresholds. About 20 studies were compiled and a critical soil Cd concentration was derived to protect wildlife from reaching renal thresholds. This critical soil Cd concentrations is 0.9 mg kg^{-1}_{dw} and is triggered by data on moles and shrews (both carnivorous) dwelling in acid soils. This critical soil Cd concentration is below the $PNEC_{soil}$ derived from direct toxicity tests (plants, invertebrates and microbial processes) confirming the general knowledge that Cd is more toxic to mammals than to plants or invertebrates.

3.3 RISK CHARACTERISATION

The RAR has identified several locations of Cd producers and Cd processors (for plating, stabilisers and pigments) where the predicted local concentrations in water and sediment exceed the PNEC. There are 2 sites showing PEC/PNEC ratios well above 10 for both water and sediment. The atmospheric Cd emissions at 3 Cd production sites are still elevated, and it is predicted that the soil Cd will be above the $PNEC_{soil}$ after 50 years of current emissions, even if it is assumed that current soil Cd concentrations are still at background (which is unlikely to be the case). There is potential toxicity of Cd in the STP's at all locations and this Cd toxicity should be assessed.

For the hypothetical local incineration plant (current scenario), no risk is expected for aquatic organisms when considering the contribution of NiCd batteries. For all municipal solid waste incinerated (Cd also from other sources besides batteries) a risk can be expected when the low dilution factor of 25 is applicable. No risk is predicted for the future hypothetical incineration plant for the aquatic organisms and sediment organisms if a dilution factor of 1,000 is applicable. Performing the exercise for different collection scenarios (10 and 75%) with a dilution factor of only 100 indicates also no risk for the aquatic compartment. No risks to the aquatic environment is observed for landfills emitting a leachate with a total cadmium content of 5-50 µg/L unless the leachate contains >50 µg Cd L^{-1} and is discharged immediately to the surface water. No risk for soil organisms is predicted for the hypothetical local incineration plant when considering the atmospheric Cd emissions.

The regional and continental risk characterisation is complicated by the inaccuracy of predicted values (see above) and the high variability of measured values. The predicted regional and continental concentrations for water and soil are below the PNEC whereas the

reverse is true for the river and lake sediments (see **Table 3.2**). The sediment PEC overestimates the current ambient sediment concentrations and which can partly be attributed to the fact that the PEC values are steady state concentrations which may only be achieved after several centuries. The predicted concentrations in soil are no such steady state concentrations because a more detailed mass balance model was adopted and with which predictions could be made for any time frame (here: 60 years).

Aquatic compartment (incl. sediment)

The averages, medians or geometric means (of ranges) of Cd concentrations of European rivers and lakes are between 0.04-4 (mean 0.6) times the PNECwater. The corresponding factors for 90th percentiles (sometimes 97.5th percentiles) are between 0.2-5 (mean 1.4). Some of the data may overestimate the dissolved concentrations because of unknown analytical methodology. Analytical quality of the data is important because the Cd PNEC is less than 10-fold above the limits of quantification in many monitoring systems. No risk is predicted for aquatic organisms in the soft waters (hardness below 40 mg $CaCO_3$/L) of the Swedish region for which a characterization could be made with the hardness corrected PNEC. The risk is uncertain outside the range of the water characteristics on which the soft water PNEC is based, that is below hardness 5 mg $CaCO_3$/L, i.e. extremely soft waters. As supporting information, the same PNEC was used for the sites with the extreme soft waters (10% of the data in Sweden) and that showed no risk due to Cd.

The Cd concentrations in sediments show risk factors of 0; hence no risk is predicted with the exception of a French region (Artois Picardie) if outliers are included in the data. Because of the local nature of this contamination, we propose that these outliers do not represent diffuse contamination at the regional scale and that the outliers should be excluded.

Terrestrial compartment

The average (or median) measured Cd concentrations in natural and agricultural soils have risk factors 0.1-0.7 (mean 0.3). Corresponding factors for the 90th or 95th percentiles are 0.3-1.8 (mean 1.0). The general population indirectly exposed to soil Cd via foodchain tranfer may, however, not be protected, even at average soil Cd concentrations (see below: risk characterisation to man via the environment).

Atmosphere

No data were found to make a risk assessment of Cd or CdO in the atmospheric compartment.

Secondary poisoning

Potential risk of Cd to terrestrial birds is predicted using soil-worm-bird or water-fish-bird modelling. However, concentrations of Cd in terrestrial birds (kidney and liver Cd concentrations) do not indicate Cd poisoning, even in contaminated areas and in top predators. Pelagic birds have reported kidney Cd concentrations above renal thresholds but no risk characterisation of marine environments was made here.

4 HUMAN HEALTH

4.1 HUMAN HEALTH (TOXICITY)

4.1.1 Exposure assessment

Uptake of cadmium can occur in humans via the inhalation of polluted air, the ingestion of contaminated food or drinking water and, to a minor extent, through exposure of the skin to dusts or liquids contaminated by the element.

In occupational settings where cadmium is produced or used, mainly inhalation exposure to cadmium metal and/or cadmium oxide may occur. Dermal exposure may occur when Cd metal or CdO powder/dust are handled or when maintenance of the production machinery involved in the process is necessary. Additional uptake can also occur as a consequence of contamination of food and tobacco (mainly in workers who eat or smoke at the workplace).

For the general population, non-occupationally involved in the cadmium industry, uptake of cadmium (not specifically Cd metal or CdO) occurs mainly via the ingestion of food or, to a lesser extent, of drinking water contaminated by cadmium. This environmental exposure results mainly from the release of significant quantities of cadmium compounds (not specifically Cd metal or CdO) to the environment and its transfer in soil, water and air. In industrial sites polluted by cadmium, inhalation of polluted air and/or ingestion of contaminated soil or dusts may also contribute to a significant exposure. Tobacco is an important additional source of cadmium uptake in smokers mainly by inhalation.

Finally, the consumer could be exposed (skin, inhalation or oral) through the use of consumption products, which may be the substance itself (cadmium metal and/or cadmium oxide), or a preparation, or an article containing the substance.

When available, biomarkers of exposure are preferably used to characterise exposure to cadmium oxide and/or cadmium metal because they better assesses the health risk through the evaluation of the internal exposure of the organism. Biomarkers of exposure offers several advantages over external monitoring (e.g. air monitoring, or estimates of food intakes) to estimate overall integrated health risks. The first advantage of biomarkers is that it is more directly related to the adverse health effects that one attempts to prevent than any external measurement or estimate. Secondly, biomarkers take into consideration absorption by all routes (lung, skin, gastrointestinal tract). Because of their capability to evaluate the overall exposure, whatever the route of entry, biomarkers offer moreover the advantage that they can be used to test the efficiency of various protective measures. Another advantage of biomarkers is the fact that non-occupational background exposure (residence, dietary habits, smoking, leisure activity etc.) may also be expressed at a biological level as the organism integrates this total external (environmental and occupational) exposure into one internal load. Finally, as cadmium is a cumulative toxicant, the use of a biological marker of the body burden (i.e. Cd-U) allows the long-term exposure to integrate.

Two biomarkers of exposure have mainly been used, i.e. the concentration of Cd in blood (Cd-B) and in urine (Cd-U). While Cd-B may be considered as a biomarker of mainly recent exposure, Cd-U mainly reflects the cadmium level in the body and in the kidney.

Occupational exposure

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 CdO dusts and fumes. Because the oxidation kinetics from metal to oxide is very fast, it is very unlikely that cadmium would be present in its metallic form in the fumes.

Different scenarios were considered:

1. the production of cadmium oxide where exposure to CdO is likely to occur at the first step of the process at the ovens (CdO fumes) and during packaging of the product and maintenance (CdO dust). Cadmium uptake may result from inhalation and dermal exposure, the latter possibly occurring during packaging, cleaning and maintenance operations,
2. the production of Cd metal (massive or powder) for which inhalation exposures to Cd metal dust, CdO fumes and dust is likely to be the highest during roasting, melting and casting of the solid cadmium metal, cleaning and maintenance operations. Dermal exposure is expected to occur during cleaning and maintenance activities,
3. the production of nickel-cadmium batteries entails inhalation exposure when the CdO and Cd metal powders are mixed with the bonding agent in the first step of the process and dermal exposure is expected to occur mainly during mixing, filling of pockets or impregnation of electrodes of/with Cd oxide powder. In the recycling industry, both inhalation and dermal exposure were likely but insufficiently documented,
4. the production of cadmium alloys entails a potential exposure to both CdO and Cd metal, mainly inhalation exposure to aerosols formed by emission of mixed alloy fumes (including volatilised cadmium). Direct unprotected handling of cadmium compounds does not occur, due to the fact that material is hot. However, dermal exposure due to dust contamination of equipment and surfaces, after cooling of material is possible,
5. the production of cadmium sulphide-based pigments where CdO and Cd metal are used as starting materials and where inhalation and/or dermal exposure may occur at several steps of the process due to direct handling or incidental contact,
6. the cadmium electroplating where exposure to both CdO and Cd metal (inhalation and/or dermal) may occur mainly during the preparation and manipulation of the baths,
7. the stabilisers industry where CdO or Cd metal are used as starting materials and may entail inhalation and dermal exposure,
8. when brazing, soldering with a solder containing cadmium or when welders are operating on material containing or plated with Cd metal, workers are exposed by inhalation to the solder fumes (CdO),
9. other diverse situations where potential exposure to CdO or Cd metal has been reported (steel and derived manufactured goods, including the scrap metal, foundry).

Occupational exposure data are summarised in the table below.

Table 4.1 Summary of occupational exposure data used in the risk characterisation

Production type	Mean exposure in air* (µg/m³)		Biomonitoring data			
			Urine (µg/g creat)		Blood (µg/L)	
	Typical value	Worst case	Typical value	Worst case	Typical value	Worst case
CdO production	15	150	10	70	1	3
Cd metal production	12	400	3	23	3	15
Ni-Cd batteries	50	320	3.5	20	2.3	80
Alloys		50	-	-	-	-
Pigments	22	80	4	10	4	10
Plating	5	10	-	-	-	-
Stabilisers		2				5
Brazing, soldering and welding	-	280 1,500-6,250§	-	-	-	-
Others	-	2	-	-	-	-

* Assumed to be 8-hour TWA concentrations
§ Acute and presumably accidental situations

Consumer exposure

Cadmium, its compounds and its alloys have been used in a variety of consumer materials corresponding to at least 5 scenarios of exposure:

Scenario 1: Active electrode material in nickel-cadmium batteries

Cadmium(oxide) in batteries is part of the internal structure (electrode) which is totally isolated and not accessible during handling and manipulation. The handling of batteries by the consumer is also likely to be rather infrequent and of very short duration. Therefore, although no measured data on consumer exposure are available, it can be concluded that consumer exposure to cadmium(oxide) from batteries is non-existent or negligible.

Scenario 2: Pigments used mainly in plastics, glasses and ceramics, enamels and artist's paints

Cadmium sulphide and cadmium sulphoselenide are used as bright yellow to deep red pigments in ceramics, glasses, enamels, plastics, and artists colours. Cadmium metal or cadmium oxide are used as starting material for the production of these pigments and, according to Industry, not present in the consumer's product.

Scenario 3: use of cadmium as stabilisers for plastics or polymers

Cadmium-based stabilisers are used to retard the degradation processes which occur in polyvinylchloride (PVC) and related polymers on exposure to heat and ultraviolet light (sunlight). These stabilisers consist of mixtures of barium, lead and cadmium organic salts, usually cadmium stearate or cadmium laurate, which are incorporated into the PVC before processing and which limit any degradation reaction. They ensure that PVC develops good initial colour and clarity and allow high processing temperatures to be employed. Cadmium oxide and cadmium metal are used as starting materials for the production of the cadmium organic salts but are not present, according to Industry, in the final consumer's product.

Scenario 4: Metal plating (steel and some non-ferrous metals)

The use of Cd in plating is restricted by EU legislation to those applications were it is essential for technical or safety reasons e.g. in aerospace, aeronautics, mining, offshore, safety devices, not easily available for the general consumer. No data are available on these specific uses to assess consumer exposure. However, because of its limited uses and the presence of cadmium in these latter applications under a massive metallic form not readily available for uptake, it can be concluded that for the consumer, the potential exposure to cadmium metal in plated products is very low.

Scenario: Component of alloys

Most of the Cd alloys are copper-cadmium alloys in which small amounts of cadmium metal are added to improve the mechanical properties e.g. contact wires in railways, overhead power lines etc. In the very limited other applications cadmium alloys are used basically in the industrial environment (as special fusible and joining alloys, in nuclear power plants). In these limited applications, it is expected that the potential for consumer exposure to cadmium in alloys is very low.

Brazing material containing up to 20% w/w Cd can be purchased by the consumer through Do-It-Yourself shops. One may assume that consumer uses of brazing material are likely to be infrequent and duration of exposure is expected to be shorter than in an industrial setting. In case of use by the consumer of such brazing sticks, mainly inhalation exposure should be considered.

Recent investigations in Denmark have shown that significant concentrations of cadmium (conceivably cadmium metal) were encountered in jewels ("silver" bracelets) imported from South and South East Asia and that release of cadmium from those jewels might reach significant levels. A very conservative assessment suggested that in case of exposure through such jewels, the uptake could be estimated to be somewhat less than 1 µg Cd/day.

Table 4.2 Summary and conclusions of scenario's of potential consumer exposure

Scenario	Consumer exposure	Involved Cd species
1: Ni-Cd batteries	Considered to be very low	Cd metal/CdO
2: Pigments		Cd compounds (Cd sulphide and Cd sulphoselenide)
-glass & enamels	Considered to be very low	
-plastics	Packaging not available for consumers	
-artist's paints	Might occur in some specific uses or if swallowed, penetrates skin etc.	
3: Stabilisers	Considered to be very low	Cd compounds (Cd laurate/stearate)
4: Metal plating	Very low	Cd metal
5: Alloys	Very low	Cd metal
brazing material	Conservative estimate: see occup. scenario	Cd metal/CdO
imported jewels	Conservative estimate: <1 µg/day	Cd metal

When Cd values are presented, they refer to total cadmium as no data on the speciation of cadmium are available. It is not possible to estimate the exposure of the consumer to individual compounds.

Beside these scenarios of potential consumer exposure, it should be reminded that consumers of cigarettes and other tobacco products are exposed to cadmium contained in tobacco leaves. The cadmium content in cigarettes is variable and results from the uptake of cadmium contained in soil and water by the tobacco plant and from deposition of cadmium on the leaves.

Humans exposed via the environment

The general population is exposed to Cd via food intake, smoking, soil and dust ingestions, inhalation and drinking water. The average dietary Cd intake values in EU range from 7-32 μg day^{-1} with a tendency to find lowest values in Scandinavian countries and highest values in Mediterranean countries. Estimates of Cd intake by women are generally lower than those for men. The upper percentiles (95^{th} or higher) of dietary Cd intake range between 24 and 40 μg day^{-1}. Typical groups with high dietary Cd intake are these with preference for shellfish or mushrooms. Almost all dietary Cd is derived from soil with the exception of marine food. Food crops absorb Cd mainly from soil through root uptake and the fraction air-borne Cd can generally be neglected. However, air-borne Cd may be a significant source of Cd for crops grown in areas where atmospheric Cd deposition is at least tenfold higher than in rural areas. This situation may still occur near point sources in Europe.

Human nutrition studies generally observe weak effects of dietary Cd intake on body burden in the general population whereas nutritional factors (mainly Fe status) have a more significant impact. The gastrointestinal (GI) absorption rate for cadmium in the general population is <5%. Individuals with low iron stores may absorb much more Cd via the GI route, on average 2 times more, and absorption rates up to 10% have been reported. A validation of a toxicokinetic model showed that a 3% absorption rate (at $t_{1/2}$=13.6 y) most adequately describes body burden Cd (urinary Cd concentrations=Cd-U) measured in the general population (predicted/observed ratio 0.9-1.3), even for upper percentile values. This 3% absorption rate is a 'best fit' parameter while acknowledging that individuals with larger absorption rates exist. However, this best fit parameter may indicate that it is incorrect to apply the largest absorption rates on also the largest dietary Cd intake values and for a lifetime exposure.

Table 4.3 Estimated daily Cd up take in adults through environmental exposure in areas at ambient Cd concentrations (Scenario's 1-2) and near point sources with largest atmospheric Cd emissions in EU (Scenario 3)

Scenario 1: Adults with sufficient body iron stores	
Source	Cd uptake (μg day^{-1})
Air	0.025 -0.075
Soil and dust	0.021
Smoking	0.5-2.0
Drinking water	< 0.06
Dietary intake	0.21-0.96
Sum	Non smokers: 0.32-1.12 Smokers: 0.82-3.12

Table 4.3 continued overleaf

Table 4.3 continued Estimated daily Cd up take in adults through environmental exposure in areas at ambient Cd concentrations (Scenario's 1-2) and near point sources with largest atmospheric Cd emissions in EU (Scenario 3)

Scenario 2: Adults with depleted body iron stores	
Source	Cd uptake (µg day^{-1})
Air	0.025 -0.075
Soil and dust	0.042
Smoking	0.5-2.0
Drinking water	< 0.12
Dietary intake	0.42-1.92
Sum	Non smokers: 0.53-2.08 Smokers: 1.03-4.08
Scenario 3: Near point sources (adults with sufficient body iron stores)	
Source	Cd uptake (µg day^{-1})
Air	0.15-5
Soil and dust	0.24
Drinking water	< 0.06
Dietary intake	0.51 –1.02
Sum	Non-smokers : 1.05-1.55 (30 $ng.m^{-3}$) Non smokers: 5.9-6.4 (1,000 $ng.m^{-3}$)

Combined exposure

For occupationally exposed people, all or not living nearby an emitting plant and possibly also exposed via consumer goods, the dominant exposure route is presumably the inhalation route especially when the occupational exposure is high.

In case the occupational exposure is low, the oral route may become predominant as this is the case in people indirectly exposed to the substance (generic) via the environment. Parameters used to assess exposure in occupational settings reflect the cadmium body burden (Cd-U) which integrates all sources and routes of exposure (occupational/inhalation + environmental/oral). Therefore, the issue of combined exposure is intrinsically covered when biological parameters of exposure are used for the risk assessment.

4.1.2 Effects assessment

Toxicokinetics, metabolism and distribution

The main toxicokinetic parameters are summarised in the table below. These figures relate to cadmium element (generic) and are not specifically derived from studies performed with Cd metal or CdO.

Table 4.4 Most significant toxicokinetic parameters in humans

		modifying factors
Absorption		
Oral	1.4-25 µg/d	
	5% of ingested dose; (max. 10%) (animal and humans)	
		↑ with low iron status
		↑ with low Zn, Ca or protein diet
		↓ with presence of Zn contamination
		age (newborn >)
	toxicokinetic model : 3% best fit	including low iron status
Inhalation	fumes: 25-50% (humans) dusts: 10-30% (humans)	depending on particle size
Dermal	< 1% (animal)	
Cd-B	non-smokers: < 1 µg/l smokers: < 5 µg/l	
		females>males
		↓ (hemodilution) or ↑ (relative depletion of iron stores) during pregnancy
	cord blood : 50% maternal blood	
Body burden	5-30 mg at 50 years (general population)	↑ with age
	non-smokers: 15 mg smokers: 30-40 mg	females>males
	kidney + liver = 50% kidney = 33%	ratio kidney/liver ↓ with intensity of exposure
	kidney cortex: 10-50 ppm (smokers = 2-3 x non-smokers) (newborn about 3 ppm)	
	cortex: whole kidney ratio: 1.25	
	liver: 0.5-5 ppm	
	placenta: 5-10 ppm	
Cd-U	0.01% of body burden/day	
	< 2 µg/g creat	↑ with age
		smokers > non-smokers
		females>males
		↑ with kidney damage

Table 4.4 continued overleaf

Table 4.4 continued Most significant toxicokinetic parameters in humans

		modifying factors
Absorption		
Effects of smoking		
	inhalatory absorption: 50%	
	20 cig/d = 3 µg Cd/d	
	Cd-B: 2-5-fold increase	
	body burden: 2-3-fold increase	
	Cd-U: 1.5-fold increase	

Acute toxicity

CdO is toxic by the oral and inhalation routes.

LD_{50} oral values (rat and mouse) range from 72 to 300 mg CdO/kg (63-259 mg Cd/kg) and from 50 to 400 mg Cd/kg for water-soluble compounds. Experiments using cadmium compounds provide additional information about the target organs of ingested cadmium at acute toxicity doses: targets were the proximal parts of the intestinal tract (Andersen et al., 1988). The emetic threshold dose for cadmium (element) in drinking water has been estimated to be in the order of 15 mg/l. The no-effect level of a single oral dose for humans is estimated at 3 mg elemental Cd and the lethal doses range from 350 to 8,900 mg.

According to the LD_{50} values, a classification as T ; R25 is considered justified.

In animals, acute inhalation exposure to cadmium oxide aerosols was found to produce pulmonary inflammation and oedema. Several biochemical changes have been shown to parallel the morphological alterations. Minimal CT_{50} was 450 mg CdO x min/m^3 for CdO fumes but the reliability of this figure may be questioned. Concentrations above 5 mg/m³ have caused clear pulmonary damage (destruction of lung epithelial cells, resulting in pulmonary oedema, tracheo-bronchitis, and pneumonitis). The lowest dose (LOAEL) reported to cause mild pulmonary damage (hypercellularity indicative of hyperplasia) in experimental animals was an 3-hour exposure to 0.5 mg/m^3 CdO fumes, and is considered as reliable data.

Acute poisonings and, in some cases, deaths have been reported among workers shortly after exposure to fumes when cadmium metal or cadmium-containing materials were heated to high temperatures. The compound involved in such accidental, acute cases is predominantly a freshly formed fume of cadmium oxide. At an early stage, the symptoms may be confused with those of "metal fume fever". However, these conditions are different, with Cd-lung leading to delayed pulmonary oedema and possibly death. Subjects who survive the acute cadmium poisoning may recover without damage, although some authors have reported delayed development of lung impairment. Cadmium concentrations in air were not reported in most case-reports. It has been estimated that an 8-hour exposure to 5 mg/m^3 may be lethal and an 8- hour exposure to 1 mg/m^3 is considered as immediately dangerous for life.
A classification for acute toxicity by inhalation seems appropriate: T; R23.

Available information does not allow to derive a N(L)OAEL for acute dermal exposure to CdO or Cd metal. However, acute toxicity effects of cadmium via the dermal route are not expected to be significant as uptake of soluble and less-soluble cadmium compounds applied on the skin appears to be very low (see above).

No classification for acute toxicity by dermal route is required.

Irritation

No specific data were located regarding the irritation potential of CdO or Cd metal on the skin, eye or respiratory tract neither in animals nor in humans. Based on the effects observed after acute and repeated inhalation exposure, it seems possible that CdO (as fumes) is irritant for the respiratory tract in animals as well as in humans.

The base-set is formally incomplete. However, given the carcinogenic properties of the substance, it is supposed that risk reduction measures are in place to prevent irritation, if any, to occur. There is therefore little benefit expected from an additional effort to clarify the need to label CdO/Cd metal for skin, eye or respiratory tract irritation; no classification for irritation is proposed.

Corrosivity

No studies were located regarding corrosive effects on the skin, the eye and the respiratory tract in humans after exposure to cadmium oxide and/or cadmium metal.

Sensitisation

Examination of the available experimental and human studies leaves the picture unclear as to whether CdO or Cd metal have skin sensitisation properties. A skin sensitisation test with CdO and/or Cd metal, conform with the current regulatory standards, would be formally requested. However, given the carcinogenic properties of the substance, it is supposed that risk reduction measures are in place to prevent sensitisation, if any, to occur. In addition, the overall evidence from available data on other cadmium compounds in humans -including the fact that for cadmium (oxide) no effects are reported in occupational practice- does not warrant a classification of cadmium oxide as skin sensitiser. CdO/Cd metal are apparently not respiratory sensitisers and should not be classified for respiratory sensitisation.

Repeated dose toxicity

A substantial body of information is available indicating that the lung, kidney and bone are the target organs upon repeated exposure to CdO in occupational settings (mainly by inhalation). Environmental exposure to Cd (generic, not specifically CdO), mainly by the oral route, is associated with bone and kidney toxicity.

Long-term inhalation exposure of experimental animals to CdO results in similar effects as seen upon acute exposures, i.e. pneumonia accompanied by histopathologic alterations and changes in the cellular and enzymatic composition of the bronchoalveolar fluid. Some tolerance to cadmium appears to develop so that lung lesions developed after a few weeks of exposure do not progress, and may even recover after longer exposure. Multiple mechanisms could explain this tolerance, including the synthesis of lung metallothionein and proliferation of type II cells. Identified NOAELs are: 0.025 mg CdO/m^3 in F344/N rats exposed for 13 weeks and 0.01 mg Cd/m^3 in hamsters exposed for 16 months. No study specifically using cadmium metal dust or powder was located.

Several authors concluded that, in humans, long-term inhalation exposure to cadmium (generic) leads to decreased lung function and emphysema. Chronic obstructive airway disease has been reported to lead in severe cases to an increased mortality. A moderate increase in residual volume was observed in workers exposed to cadmium fumes (CdO) at a cumulative exposure of < 500 µg Cd/m^3x years (Cortona et al., 1992). This increase in

residual volume is considered a critical effect. The LOAEL derived from this study is 3.1 µg Cd/l (Cd-U) taking into consideration that this value is for CdO fumes and may not necessarily apply to CdO dust. No study in humans specifically exposed to cadmium metal dust or powder was located.

The bone tissue is another target organ for the general and occupational populations exposed to cadmium compounds, including CdO and/or Cd metal. The hazard is relatively well identified both in experimental and epidemiological studies. *In vitro* studies have demonstrated that cadmium compounds (not specifically CdO or Cd metal) might exert a direct effect on bone affecting both bone resorption and formation, and inducing calcium release. In animals, cadmium has been shown to affect bone metabolism. These effects have manifested themselves as osteopetrosis, osteosclerosis, osteomalacia and/or osteoporosis and have been produced experimentally in several species. The most severe form of bone disease caused by cadmium intoxication is Itai-Itai disease which associated in the past kidney and bone lesions in aged Japanese women. Thus there are solid experimental and clinical arguments to demonstrate that chronic Cd poisoning is associated with bone lesions, generally in association with overt kidney damage. Overall, however, because most of the experimental studies were designed to explore the pathogenesis of Itai-Itai disease and because animals were generally exposed during a relatively short period with relatively high doses of Cd they do not allow to derive a robust NOAEL relevant for humans exposed chronically to low doses via the diet or by inhalation. In most experimental studies, bone effects were accompanied or preceded by renal damage induced by the Cd-treatment. Young age (growing bones), gestation, lactation, and ovariectomy (used as an animal model of menopause) appeared to exacerbate Cd-induced bone toxicity.

In humans, the mechanism of bone toxicity is not fully elucidated and types of bone lesions associated with cadmium exposure are not clearly identified. One likely mechanism is disturbance of bone metabolism but another explanation is that Cd-induced kidney damage and/or hypercalciuria might promote osteoporosis and osteoporotic fractures. Results in the general Swedish population suggest a LOAEL of 3 nmol Cd/mmol creatinine or 3 µg/g creatinine (not specifically CdO or Cd metal). This threshold would be in line with the idea that bone effects follow or are accompanied by kidney dysfunction which appears within the same range of body burden (2 µg Cd/g creatinine).

In workers exposed to cadmium compounds (not specifically CdO or Cd metal), clinical bone disease has been described but the number of cases is limited. One cross-sectional study reported results compatible with a role of cadmium in the genesis of osteoporosis in exposed workers but no critical Cd dose could be derived.

The kidney is another target organ for cadmium (not specifically CdO or Cd metal) toxicity following repeated exposure by the oral or inhalation routes. Numerous studies in rats, mice, rhesus monkeys and rabbits have indicated that exposure to cadmium compounds administered orally or by inhalation causes kidney damage including increase or decrease of relative kidney weight, histological (necrosis of the proximal tubules, interstitial renal fibrosis) and functional changes (reduced glomerular filtration rate, proteinuria).The first manifestation of cadmium nephrotoxicity in occupationally exposed subjects (mainly by inhalation) is usually a tubular dysfunction associated with an increased urinary excretion of low molecular weight (LMW) proteins such as protein HC, ß2M and RBP. An effect on the glomerulus may also be observed in cadmium-exposed workers, as indicated by increased urinary excretion of high molecular weight (HMW) proteins including albumin, immunoglobulins G or transferrin.

In workers occupationally exposed to cadmium, a Cd body burden corresponding to a Cd-U of 5 µg/g creatinine constitutes a LOAEL based on the occurrence of LMW proteinuria (Roels et al., 1993). There is consensus in the literature concerning the health significance of this threshold because of the frequent observation of irreversible tubular changes above this value and in view of its association with further renal alteration.

In the general population (mainly exposed by the oral route), based on the most recent studies conducted in Europe, it appears that renal effects can be detected for Cd body burdens below 5 µg Cd/g creatinine and even from 2 µg Cd/g creatinine (LOAEL). These studies detected associations between Cd body burden and LMW proteinuria but also urinary calcium excretion and its possible relationship with bone effects. There is, however, a lingering scientific debate about the health significance of the changes observed at Cd-U levels < 5µg/g creatinine and this was reflected in the contrasting views of experts during the TMs.

Although mortality studies were not able to detect an excess of end-stage renal diseases in populations exposed to cadmium compounds, a recent epidemiological study suggests that the incidence of renal replacement therapy is increased in a population with occupational/environmental exposure to Cd.

It is plausible that the lower LOAEL in the general population exposed by the oral route is the reflection of an interaction of Cd exposure with pre-existing or concurrent renal diseases that are less prevalent in mainly healthy young individuals in occupational settings. As workers exposed to Cd may, however, suffer from such disease during or after their occupational career, it appears prudent to recommend that they should be offered the same degree of health protection than individuals from the general population. For this reason, a single LOAEL of 2 µg/g creatinine is used in the Risk Characterisation section, both for oral and inhalation exposure.

Evidence for cardiovascular toxicity resulting from oral and inhalation exposure to CdO and other Cd compounds (chloride, acetate) in animals is suggestive of a slight effect on blood pressure. Results from human studies do not speak for the hypothesis that cadmium may cause hypertension as a result of occupational or environmental exposure. If cadmium does affect blood pressure, the magnitude of the effect is small compared to other determinants of hypertension. Overall, the weight of evidence suggests that cardiovascular effects are not a sensitive end point indicator for CdO toxicity.

Exposure to cadmium compounds can cause liver damage in animals but generally only after high levels of exposure. There is little evidence for liver damage in humans exposed to cadmium (including CdO or Cd metal).

Cadmium-induced haematological effects reported in experimental animals (anaemia) exposed to very high doses of Cd compounds (not specifically CdO) are unlikely to be of concern for occupational or general population exposure.

Evidence from experimental systems indicates a potential neurotoxic hazard for cadmium (not CdO or Cd metal specifically) in adult rats. In humans, heavy occupational exposure to cadmium dust has been associated with olfactory impairments and studies performed on a limited number of occupationally-exposed subjects are suggestive of an effect of Cd on the peripheral and central nervous system but these findings should be confirmed by independent investigators before firm conclusions can be reached. In the young age, there is some experimental indication that Cd exposure (not specifically CdO or Cd metal) can affect the developing brain. This aspect has not received sufficient attention in humans in view of (1)

the very well-characterised neurotoxic potential of other heavy metals (e.g. lead), and of (2) the increased gastro-intestinal absorption of Cd in the very young age.

Overall, based on the concurrence of epidemiological studies indicating both kidney and bone effects in the general population at body burden below 5µg Cd/g creatinine, a single LOAEL of 2 µg/g creatinine is considered for the risk characterisation. It should be recognised, however, that uncertainties remain as to the accuracy of this value. The clinical significance of the biochemical changes observed at these levels is also subject to a scientific debate.

Overall, the weight of evidence of cadmium compounds adverse effects on multiple organ sites supports the classification as T; R 48/23/25.

Genotoxicity

Data from experimental systems indicate that cadmium, in certain forms, has genotoxic properties and it is reasonable to assume that these properties may also apply to CdO and Cd metal. Three possible and *a priori* non-mutually exclusive mechanisms have been identified: 1) direct DNA damage, 2) oxidative damage and 3) inhibition of DNA repair. With regard to human exposure to Cd and compounds, data are conflicting but seem to indicate a genotoxic potential, at least in occupational settings, but it is unclear whether these effects are solely attributable to Cd. Studies performed in environmentally exposed populations do not allow to identify the type of cadmium compound(s) to which subjects were exposed but it cannot be excluded, based on the available data, that cadmium (including CdO and Cd metal by assimilation) might exert genotoxic effects in populations exposed via the oral route.

Overall, a classification as Muta cat 3 (Xn; R68) seemed appropriate.

Carcinogenicity

CdO is carcinogenic in animals (especially lung tumors in rat inhalation studies) (Glaser et al., 1990). The possibility that, in humans, cadmium might cause a risk of lung cancer by inhalation is suggested by several epidemiological studies but the possible contribution of confounding factors (mainly co-exposure to other carcinogens) could not be clearly defined (Verougstraete et al., 2003). Overall, however, the weight of evidence collected in genotoxicity tests, long-term animal experiments and epidemiological studies leads to conclude that CdO has to be considered at least as a suspected human carcinogen (lung cancer) upon inhalation exposure. There is no indication or evidence that CdO acts as a carcinogen in the general population exposed by the oral route. It would therefore seem logical to maintain the Carc.cat 2 (T; R49, i.e. may cause cancer by inhalation) classification.

However, the CMR WG reviewed the classification and agreed (May 2002) to classify CdO with Carc.Cat 2; R45 (may cause cancer): i.e. carcinogenic potential irrespective of the exposure route (ECBI/42/02 Rev2).

Cadmium metal is a carcinogen when injected in experimental animals. No study was specifically conducted with cadmium metal in animals exposed by inhalation or in humans specifically exposed to this species, which does not allow to sufficiently document its carcinogenic potential.

In the absence of specific information for Cd metal, but given the Cat 2 (T; R45) classification of CdF_2, $CdSO_4$, $CdCl_2$ and the Cat 2 (T; R49) classification proposed for CdO, a Cat 2 (T; R49, i.e. may cause cancer by inhalation) classification was proposed cadmium metal by analogy. However, the CMR WG reviewed the classification and agreed (May 2002) to

classify Cd metal with Carc.Cat 2; R45 (may cause cancer): i.e. carcinogenic potential irrespective of the exposure route (ECBI/42/02 Rev2).

Toxicity for reproduction

Effects on reproductive organs and fertility

Effects on reproductive organs and fertility have been noted in experimental studies at high doses of CdO and Cd compounds (oral: LOAEL 1 mg/kg/d and inhalation NOAEL 0.1 mg/m³). Epidemiological studies do not speak for an association between exposure to CdO/Cd metal and relevant effects on fertility or reproductive organs. A classification for effects on fertility and sex organs of cadmium metal and cadmium oxide seems appropriate: category 3, (R 62)

Developmental effects

Further information is needed to better document the possible effect of low doses of CdO on the developing brain of young children suggested in experimental animals. Based on the human data available, there is no indication of a potential developmental effect of CdO or Cd metal. No classification for developmental effects was proposed by the TM. Based on the same data, the CMR WG (May, 2002) agreed, however, to classify Cd metal and CdO in category 3 (substances which cause concern for humans owing to possible developmental toxic effects) and to label the compounds with R63 (possible risk of harm to the unborn child), as a compromise decision of the diverging views of the MSs, considering the effects in animal testing with water soluble Cd compounds and acknowledging that possible differences in physical-chemical properties (bio-availability) may exist and that general toxicity cannot be ruled out.

4.1.3 Risk characterisation

Workers

Acute exposure Cd/CdO

Table 4.5 Acute exposure Cd/CdO

Scenario	Critical concentration 437.5 µg Cd/m³ (3-hour TWA)		
	Cd air (µg/m³) worst case 8-hour TWA*	MOS	CcI
CdO production	150	3	iii
Cd metal production	400	1	iii
Batteries	no CdO fumes	-	ii
Alloys	50	9	iii
Pigments	no CdO fumes	-	ii
Plating	10	44	ii
Stabilisers	no CdO fumes	-	ii
Brazing, soldering and welding	1,500-6,250	<<1	iii
Others	2	220	ii

* Assuming that pneumonitis is a concentration-related effect and that Haber's rule is not applicable

A minimal MOS of 10 is recommended here.

Conclusion (iii) for all scenarios with production and/or use of Cd/CdO and with potential exposure to CdO fumes, except "plating" and "others" for which **conclusion (ii**) is proposed.

Repeated dose toxicity

Renal and bone effects

Table 4.6 Repeated dose toxicity: kidney and bone (critical Cd-U: 2µg/g creat)

Scenario	Critical Cd-U 2 µg/g creatinine		
	Cd-U typical (µg/g creatinine)	MOS	CcI
CdO production	10	0.20	iii
Cd metal production	3	0.66	iii
Batteries	3.5	0.60	iii
Alloys	-	-	iii*
Pigments	4	0.50	iii
Plating	-	-	iii*
Stabilisers	-	-	iii*
Brazing, soldering and welding	-	-	iii*
Others	-	-	iii*

* By extrapolation from other scenarios

The amplitude of the calculated MOS indicates a cause for concern in several scenarios. For most scenarios for which Cd-U data are not available (Alloys, Plating, Stabilisers, Brazing, soldering and welding and Others), airborne measurements indicate a lower exposure than in Cd/CdO production, Batteries and Pigments, suggesting a relatively lower level of concern.

On the basis of available data, it is concluded that Cd/CdO is of concern under typical occupational exposure conditions (**conclusion iii**) for all scenarios.

Genotoxicity

As long as the mechanism of genotoxicity is not completely elucidated it must be assumed that Cd compounds are direct acting genotoxic substances and that it is prudent to consider that there is no threshold exposure level below which effects will not be expressed.

Conclusion (iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

Carcinogenicity

Risks cannot be excluded, as the substance is considered as a non-threshold carcinogen. Given the serious and irreversible nature of the effect and the fact that it is not possible to exclude the risk of this being expressed at occupational levels, there is cause of concern across all industrial uses, leading to **conclusion (iii)**.

Reprotoxicity

a. Effects on fertility and sex organs

Calculated MOS values are reported below and, on the basis of a minimal MOS of 10, indicate a cause for possible concern in 3 scenarios (typical and/or RWC). It can however be expected that measures already in place or that will be implemented to prevent repeated dose toxicity (respiratory, kidney, bone or carcinogenicity) will be protective for reproductive organs also. The MOS calculated for the scenarios Plating (typical and RWC), Stabilisers and Others (RWC) do not lead to concern.

Conclusion (iii) for scenarios CdO production, Cd metal production, Batteries and Pigments, Alloys.

Conclusion (ii) for scenarios Plating, Stabilisers and Others.

Fertility and sex organs: Cd-air (typical value)

Table 4.7 Fertility and sex organs: Cd-air (typical value)

NOAEL Cd air : 100 µg/m³		
Scenario	Cd air typical (µg/m³)	MOS
CdO production	15	6.6
Cd metal production	12	8.3
Batteries	50	2
Alloys	-	-
Pigments	22	4.5
Plating	5	20
Stabilisers	-	-

Fertility and sex organs: Cd-air (reasonably worst case value)

Table 4.8 Fertility and sex organs: Cd-air (reasonably worst case value)

	NOAEL Cd air : 100 µg/m³	
Scenario	Cd air RWC (µg/m³)	MOS
CdO production	150	0.66
Cd metal production	400	0.25
Batteries	320	0.31
Alloys	50	2
Pigments	80	1.25
Plating	10	10
Stabilisers	2	50
Brazing, soldering and welding	280	0.35
Others	2	50

b. Developmental effects

Based on the data available in occupational settings, there is no indication of a potential developmental effect of CdO. Further information is, however, needed to better document the possible effect of low doses of CdO on neurobehavioural performances suggested in experimental animals (see 4.1.2.9.2). However, in view of the concerns expressed for several other health effects, including repeated dose toxicity and carcinogenicity, it is urgent to address these issues adequately and to implement appropriate control measures without delay.

Conclusion (i) "on hold" There is a need for further information and/or testing.

Consumers

Among the 5 scenarios examined, CdO is involved only for the manufacture of Ni-Cd batteries (Scenario 1). In this case, consumer exposure is considered non-existent or negligible. A **conclusion (ii)** is therefore proposed.

Among the 5 scenarios examined, Cd metal is involved in 3 of them.

Based on a limited number of release tests and although variation in the results was high, dermal exposure to Cd metal is possible under Scenario 5 (imported jewellery). Beside local irritation and or sensitisation, if any, the risk of systemic effects must be considered under this exposure scenario for which an internal dose of 1 µg/day constitutes a very conservative estimate. Indeed, the absorption of cadmium through the skin is roughly and conservatively estimated at 1% and uncertainties exist in extrapolating Cd absorbed via the skin to Cd-U. Assuming lifetime exposure, an uptake of 1 µg/day might lead to a Cd-U of 0.5 µg/g creatinine which would lead to a MOS of 4, compared to the LOAEL of 2 µg/g creatinine (repeated dose toxicity, kidney and bone effects). Because of the very conservative nature of this scenario, it is very unlikely that it might represent, in itself, a serious cause of concern for the consumers. A **conclusion (ii)** might therefore be suggested for these endpoints. However, as cadmium is a cumulative toxicant, any additional source of significant exposure should be avoided or reduced as much as possible.

As the NOAEL for effects on fertility and reproductive organs is 1 mg/kg/d (rat; oral route), there is at least 3 orders of magnitude difference with the doses estimated in this scenario and it can be concluded that there is no cause for concern for this endpoint. **Conclusion (ii)** is reached for effects on fertility and reproductive organs.

Further information is needed to better document possible effects of low dose Cd on neurobehavioural performances suggested in experimental studies.

Conclusion (i) "on hold" There is a need for further information and/or testing.

Acute and infrequent inhalation exposure (mainly to CdO fumes) is likely to occur when using Cd-containing brazing sticks. Detailed exposure data are not available. A cross-reading with the occupational exposure scenario (Scenario 9) is therefore suggested, and a risk of acute respiratory effect cannot be excluded. A **conclusion (iii)** might therefore be suggested for these types of use.

Following the decision of the CMR WG for Cd metal, a carcinogenic potential cannot be excluded irrespective of the route of exposure, and a **conclusion (iii)** applies for these two scenarios (imported jewellery and brazing sticks). Along the same line, a **conclusion (iii)** also applies for genotoxicity.

The likelihood, the amplitude and the intensity of exposure under these scenarios should also be taken into account when considering the need for risk reduction measures

Concerning the consumer use of Ni-Cd batteries (Scenario 1), consumer exposure is considered to be non-existent or negligible. A **conclusion (ii)** is therefore proposed.

Humans exposed via the environment

On the basis of the available studies, it appears probable that the earliest health effects (HC microproteinuria, bone changes) may occur in the general population for Cd-U $\geq$ 2 µg/g creatinine (LOAEL).

The margins of safety (MOS) between the lowest effect level and the predicted exposure is 1-6 for the non-smoking general population and 0.5-2.5 in the smoking population. Measured Cd-U values in the general population show MOS $\geq$ 3 for more than 50% of the population while the Cd-U values of about 5% of the population has MOS < 1.0. It should be noted that the environmental population surveys included smokers and ex-smokers which, most likely, contributed largely to the highest values.The MOS for the non-smoking population cannot be estimated precisely and there is a need for data to characterise Cd exposure specifically in the non-smoking population. A MOS of 3 or more is considered as sufficiently protective for the general population.

Table 4.9 Cd-uptake for individuals indirectly exposed via the environment and measured Cd-U values in European samples of the general population

		Critical dose : 2 µg/g creatinine	
Scenario		Cd-U (µg/g creatinine)	MOS
1a.	Adults non-smokers	0.16-0.56	12.2-3.58
1b.	Adult smokers	0.41-1.56	4.88-1.28
2a.	Adults depl. iron stores, non-smokers	0.26-1.04	7.72-2.00
2b.	Adults depl. iron stores, smokers	0.51-2.04	3.92-0.98
3.	Adults, near point source, non-smokers	2.95-3.20 0.44-0.7	0.68-0.62 4.5-2.85
Measured data			
Buchet et al. 1990		GM 0.84	2.4
Hotz et al. 1999		GM M : 0.6 P95 2.1 GM F : 0.9	3.4 1.0 2.2
Scenarios 1,2 and 3		P95 3.6	0.6
Järup et al. 2000		Mean M : 0.82 P10 : 0.18 P90 : 1.80 Mean F : 0.66 P10 : 0.21	2.4 11.0 1.2 3.0 10
Scenarios 1,2and3		P90 : 1.30	4.0

Table 4.9 continued overleaf

Table 4.9 continued Cd-uptake for individuals indirectly exposed via the environment and measured Cd-U values in European samples of the general population

	Critical dose : 2 µg/g creatinine	
Scenario	Cd-U (µg/g creatinine)	MOS
Measured data		
Fiolet et al. 1999 (RIVM)	GM : 0.44	6.4
	Median : 0.34	5.8
Scenarios 1 and 2	P95 : 1.35	1.4
Umwelt Bundes Amt. 2000	Median 0.18	11.0
	P10 : 0.06	33.4
	P90 : 0.55	3.6
	P95 : 0.74	2.8
Scenarios1 and 2	P98 : 1.10	1.8
NHNES 1999 (CDC, US)	GM : 0.29	6.6
	P10 : 0.11	18
	P25 : 0.17	11.8
	P50 : 0.27	7.4
	P75 : 0.46	4.2
Scenarios 1 and 2	P90 : 0.74	2.8

Current diffuse emissions of Cd to agricultural soil through atmospheric deposition and the use of P fertilisers are predicted to have a small effect on future soil Cd concentrations (EU mean: 6% increase in 60 years). Dietary exposure to Cd may also increase slightly and 6 EU scenarios have been calculated to estimate future risk to the general population. These scenarios reflect different 'average' regions in Europe. The choice for regional average rather than local worst cases conditions is not considered as a major drawback for a risk assessment of diffuse emissions because Cd mainly occurs via food groups such as cereals and potatoes. These food groups are unlikely to be consumed by individuals from one location throughout a lifetime. The 6 scenarios account for soil type affecting Cd transfer, the Cd mass balance in soil controlling the soil Cd trend and the dietary habits determining the fraction Cd exposure impacted by soil Cd. It is predicted that the Cd exposure in 4 scenario's will eventually lead to Cd exposure with a MOS < 3 (and which is considered not acceptable) whereas the 2 Scandinavian scenario's yield acceptable MOS >3 for the average population. Smoking is excluded from this analysis because regular smokers have a Cd exposure equivalent to a MOS<3 irrespective of the scenario.

Two major remarks should be added to this conclusion. First, these conclusions are valid for the average population in 6 scenario's and not for all sections of the general population. We recall that the current Cd exposure is equivalent to MOS < 1.0 in about 5% of the population that includes smokers (this percentile is unknown in the non-smoking population). The distribution of Cd exposure around the mean for the non smoking population is probably mostly related to dietary habits and nutritional factors. This warrants that existing food surveillance programs should be continued. Secondly, it is imperative to note that the choice of the LOAEL has a large impact on the conclusion of this risk assessment. The assessment uses the LOAEL value of Cd-U = 1 µg Cd/g creatinine derived from a Swedish population study (Järup et al., 2000). The rapporteur of the present document has made an official request to Sweden (agreed at the Technical Meeting of September, 2002) to obtain the detailed calculations leading to this LOAEL because this study is of such a critical importance.

However, no such details have been submitted. A risk characterisation using the LOAEL value for a comparable endpoint (Cd-U = 2 µg Cd/g creatinine) based on a Belgian population study (Buchet et al., 1990) leads to the conclusion that MOS > 3 in all scenario's.

Respiratory toxicity

Under Scenario 3, the most important route of exposure could be inhalation near cadmium metal producing plants (reasonable worst case estimate of 1 µg Cd/m³). At those exposure levels, respiratory effects cannot be excluded and a **conclusion (iii)** is proposed for Scenario 3.

Carcinogenicity/genotoxicity in the general population

There is no evidence that Cd when given by the oral route increases the risk of cancer in the general population and the TM agreed formerly to propose a **conclusion (ii)** for Scenarios 1 and 2.

In view of the possibility of significant inhalation exposure for populations living nearby certain emitting sources, **conclusion (iii)** was proposed by the rapporteur and supported by the TM for Scenario 3. Following the decision of the CMR WG for Cd/CdO, a carcinogenic potential cannot be excluded irrespective of the route of exposure, and a **conclusion (iii)** applies to all scenarios. Along the same line, a **conclusion (iii)** also applies for genotoxicity.

Reprotoxicity

a. Effects on fertility and reproductive organs

The NOAEL (1 mg Cd/kg/d) derived from experimental studies is three orders of magnitude greater than environmental exposure (µg/kg/d), which is judged sufficient to protect the general population (composite MOS of 100 to account for interspecies extrapolation (10) and variability in humans (10)).

Conclusion (ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

b. Developmental effects

Based on the data available in the general population, there is no indication of a potential developmental effect of Cd. Further information is needed to better document the possible effect of low doses of Cd on neurobehavioural performances suggested in experimental animals.

Conclusion (i) "on hold" There is a need for further information and/or testing.

Combined exposure

For occupationally exposed people, all or not living nearby an emitting plant and possibly also exposed via consumer goods, the dominant exposure route is presumably the inhalation route especially when the occupational exposure is high.

In case the occupational exposure is low, the oral route may become predominant as this is the case in people indirectly exposed to the substance (generic) via the environment.

In all these cases, because of the use of biomarkers of exposure that integrate all possible routes, the risk characterisation conducted for the workers and the exposure via the

environment also includes “combined exposure”. Thus, the results of risk characterisation for those populations will not differ from those already derived under the mentioned sections.

As cadmium is a cumulative toxicant, any additional source of significant exposure (e.g. jewellery see consumer exposure) should be avoided or reduced as much as possible.

4.2 HUMAN HEALTH (PHYSICO-CHEMICAL PROPERTIES)

The physicochemical properties of cadmium metal and cadmium oxide are well known and there is a general consensus as to the values of the particular physicochemical parameters relating to each of these substances. Note that the testing on pyrophoric properties of cadmium metal powder[38], as requested by the MSR and the TM, was recently performed by Industry on a voluntary basis.

Due to the relatively low melting and boiling point, these substances, when heated sufficiently can give rise to irritative fumes. For exposure and risk related to this property, reference is made to the relevant subsections in Section 4.1 (human toxicity).

Given the level of control in manufacture and use – extensive legislative instruments being already in place e.g. at the workplace - the risks from physicochemical properties are small.

Overall risk assessment for physicochemical properties is **Conclusion (ii)**.

5 RESULTS

5.1 ENVIRONMENT

Aquatic compartment (incl. sediment)

Conclusion (iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

Conclusion (iii) is reached because:

- concern for the local aquatic ecosystem at 5 Cd production (cadmium metal: 1 site) or Cd processing (2 pigments producing sites, plating and alloy) sites/scenarios;
- concern for the local aquatic ecosystem at 1 recycling site,
- concern for a landfill site leaching directly to surface water with a cadmium concentration of 50 µg/L;
- concerns for waters in the UK and the Walloon region of Belgium based on the regional averages of the 90th percentiles of measured Cd concentrations in rivers and lakes;
- concern for sediment dwelling organism for Cd plating and Cd alloys sector;
- concern for sediment dwelling organism at 4 sites (1 Cd metal production, 2 Cd pigment production and 1 Cd recycler) and 4 disposal scenarios (1 MSW incineration, 3 MSW landfill) if the lowest regional 10th percentile of the EU regions (German data from 3 river systems) from the acid volatile sulphides database is used for the bioavailability correction.
- concern for on-site and off-site STP cannot be excluded for plating and alloy industry;
- concerns for the micro-organisms of the STP for one NiCd battery recycling plant discharging its effluent to an off-site STP.

Conclusion (i) There is a need for further information and/or testing.

Conclusion (i) is reached because:

- the AVS and organic carbon based normalisation should be further validated to refine the risk characterisation to benthic organisms1 (on local as well as on regional level).

Conclusion (ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

Conclusion (ii) is reached because:

- no risk is predicted for the aquatic ecosystem at one NiCd recycling site because there are no emissions to water at this site;
- no risk is predicted for the aquatic ecosystem at one Cd metal production site, three NiCd battery producing sites, one Cd pigments producing site and all (two) Cd stabiliser production sites emitting to the aquatic compartment;
- no risk is anticipated for aquatic organisms at 2 of the 5 Ni-Cd producing plants because they are not emitting to the aquatic compartment;

- no risk is anticipated for aquatic organisms at a hypothetical landfill currently releasing a leachate with 5 µg/L of cadmium directly or indirectly in the aquatic environment;
- no risks to aquatic organisms are anticipated for current hypothetical incinerator (equipped with an on-site WWTP) total Cd emissions discharging in a river with a dilution factor of 100 to 1,000. Removal of Ni-Cd batteries in the MSW has a negligible influence on the calculated risk ratios.
- no concern for sediment dwelling organism is expected for Cd metal/CdO production plants, Cd pigments producing plants, Cd stabiliser producing plants (that are included in the update document of the RA on Cd metal/CdO, reference year 2002; these update data and assessment overwrite the data and assessment regards the same scenarios reported in the overall RAR on Cd/CdO, reference year 1996);
- no concern for sediment dwelling organism is expected for Ni-Cd battery production and recycling plants that are included in the TRAR (reference year 1999/2000);
- no concern for sediment dwelling organism is expected for present and future scenarios for local incineration plants and MSW landfill sites included in the TRAR (reference year 1999/2000);
- no concern for sediment dwelling organism is expected for Ni-Cd battery production and recycling plants based on the data for 2002;
- no concern for sediment dwelling organism is expected for measured regional and continental Cd concentrations in sediments beased on 90th percentile of regional Cd data from Belgium, France Spain Sweden and The Netherlands.

The Cd bioavailability has been taken into account for deriving this **conclusion (ii)**. Without such bioavailability correction, regional and local risk is predicted in some of these regions/locations. The bioavailability correction is based on the concentration of available acid volatile sulphides (AVS) in the sediment, which reduce the toxicity in sediment (i.e. reduced risk with increasing AVS concentration). The AVS concentration is the 10^{th} percentile of regional values (for Belgium and The Netherlands) and, for other regions and all local sites, the lowest regional 10^{th} percentile of the EU regions (German data from 3 river systems). That 10^{th} percentile may be revised (and conclusions as well) if other AVS data become available which is recommended given the relatively limited EU coverage of regional AVS data (only 6 countries).

- no risk for micro-organisms if the hypothetical landfill site is discharging a leachate with a cadmium concentration of 5µg/L to a STP;
- no risk for micro-organisms if the hypothetical incinerator plant (equipped with an on-site WWTP) is discharging to a STP.

Terrestrial compartment

Conclusion (iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

Conclusion (iii) is reached because:

- concern for cadmium plating and alloy production sites;
- concern for one region (UK) based on the 90th percentiles of measured Cd concentrations of European soils.

Conclusion (ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

Conclusion (ii) is reached because:

- modelled regional soil Cd concentrations that include natural soil, industrial soil and 8 different agricultural scenarios are all below the PNECsoil. All these modelled values are total concentrations that are expected after 60 years (agricultural soils) or far beyond that (natural and industrial soils) with current regional emissions to soil. The starting concentrations are EU average values for the ambient concentrations. If 90th percentiles of measured concentrations would have been used in such calculations, then risk cannot be excluded.

Atmosphere

No environmental risk characterisation was done for the atmosphere.

Secondary poisoning

Conclusion (iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

Conclusion (iii) is reached because:

- a regional risk cannot be excluded in one region (UK) based on the 90th percentile of measured Cd concentrations of European soils.

Conclusion (**ii)** There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

Conclusion (ii) is reached because

- modelled local soil data do not indicate a risk for secondary poisoning ;
- field data (body burden: kidney and liver Cd data) of birds (excluding pelagic birds) do not indicate Cd poisoning, even in top predators. No risk to mammals is predicted from modelled regional soil Cd concentrations.

5.2 HUMAN HEALTH

5.2.1 Human health (toxicity)

Workers

Conclusion (i) There is a need for further information and/or testing.

Conclusion (i) is reached because of:

- concerns for possible neurotoxic effects, especially on the developing brain.

Conclusion (i) "on hold" There is a need for further information and/or testing.

The information requirements are further epidemiological and experimental information to identify more precisely the nature of the effects, the characterisation of the exposure and the mechanism of action related to neurotoxicity. These investigations should mainly focus on effects on the developing brain (prenatal and early childhood exposure). Effects on the adult nervous system should also be characterised.

Conclusion (iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

Conclusion (iii) is reached because:

- at the mentioned exposure levels, health risks (acute toxicity; respiratory irritation; kidney and bone repeated dose toxicity; genotoxicity; carcinogenicity, effects on fertility and reproductive organs) cannot be excluded upon inhalation exposure arising from all industrial uses.

Consumers

Conclusion (iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

Conclusion (iii) is reached because among the examined scenarios:

- acute respiratory effect and concerns for genotoxicity/carcinogenicity cannot be excluded when using Cd-containing brazing sticks (DIY);
- dermal exposure to Cd metal is possible when wearing (imported) jewellery and in this case, in a very conservative estimate, it cannot be excluded that consumer exposure may represent cause of concern for the relevant endpoints associated with carcinogenicity/genotoxicity.

Conclusion (i) There is a need for further information and/or testing.

Conclusion (i) is reached because:

- concerns for possible neurotoxic effects, especially on the developing brain.

The collection of this additional information should, however, not delay the implementation of appropriate control measures needed to address the concerns expressed for several other health endpoints including repeated dose toxicity and carcinogenicity.

Conclusion (i) "on hold"

The information requirements are further epidemiological and experimental information to identify more precisely the nature of the effects, the characterisation of the exposure and the mechanism of action related to neurotoxicity. These investigations should mainly focus on effects on the developing brain (prenatal and early childhood exposure). Effects on the adult nervous system should also be characterised.

Conclusion (ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

Conclusion (ii) is reached because among the examined scenarios, Cd metal is involved for the manufacture of Ni-Cd batteries and, in this case, consumer exposure is considered to be nonexistent or negligible.

Humans exposed via the environment

Conclusion (iii) There is a need for limiting the risks; risk reduction measures which are already being applied shall be taken into account.

Conclusion (iii) is reached because of:

- concerns for respiratory toxicity as a consequence of exposure (mainly by inhalation) that may arise near some point sources.
- concerns for kidney and bone repeated dose toxicity as a consequence of environmental exposure arising in adults who smoke or/and with depleted body iron stores, or/and living near point sources.
- concerns for genotoxicity and carcinogenicity as a consequence of environmental exposure arising from all scenarios, since the substance is considered as a non-threshold carcinogen.

Conclusion (i) There is a need for further information and/or testing.

Conclusion (i) is reached because of:

- concerns for possible neurotoxic effects, especially on the developing brain.

The collection of this additional information should, however, not delay the implementation of appropriate control measures needed to address the concerns expressed for several other health endpoints including repeated dose toxicity and carcinogenicity.

Conclusion (i) "on hold".

The information requirements are further epidemiological and experimental information to identify more precisely the nature of the effects, the characterisation of the exposure and the mechanism of action related to neurotoxicity. These investigations should mainly focus on effects on the developing brain (prenatal and early childhood exposure). Effects on the adult nervous system should also be characterised.

Combined exposure

See conclusions for workers, consumers and/or for humans exposed via the environment.

5.2.2 Human health (risks from physico-chemical properties)

Conclusion (ii) There is at present no need for further information and/or testing and no need for risk reduction measures beyond those which are being applied already.

Conclusion (ii) is reached because given the level of control in manufacture and use, the risks from physicochemical properties are small.

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