CLH report

Proposal for Harmonised Classification and Labelling

**Based on Regulation (EC) No 1272/2008 (CLP Regulation),
Annex VI, Part 2**

Substance Name: Cadmium hydroxide

EC Number: **244-168-5**

CAS Number: **21041-95-2**

Index Number: **included in group entry 048-001-00-5**

Contact details for dossier submitter:

Swedish Chemicals Agency

Esplanaden 3a, P.O Box 2

SE-172 13 Sundbyberg, Sweden

kemi@kemi.se

+46 8 519 41 100

Version number: 2 **Date: 4 February 2015**

CONTENTS

Part A.

Part B.

Part A.

1 PROPOSAL FOR HARMONISED CLASSIFICATION AND LABELLING

1.1 Substance

Table 1: Substance identity

Substance name:	***Cadmium hydroxide***
EC number:	***244-168-5***
CAS number:	***21041-95-2***
Annex VI Index number:	***Included in group entry 048-001-00-5***
Degree of purity:	***> 80 - < 100 (typical value 98.5) % (w/w)***
Impurities:	***Nickel (catalyst) is present as NiSO4 (aq) at the concentration range ≥ 0.0 - ≤ 1.05 (typical value < 0.1) % (w/w).***

1.2 Harmonised classification and labelling proposal

Table 2: The current Annex VI entry and the proposed harmonised classification

	CLP Regulation
Current entry in Annex VI, CLP Regulation	Acute Tox. 4*; H302 Acute Tox. 4*; H312 Acute Tox. 4*; H332 Aquatic Acute 1; H400 Aquatic Chronic 1; H410
Current proposal for consideration by RAC	Carc. 1B; H350 Muta. 1B; H340 STOT RE 1; H372 (kidney, bone)
Resulting harmonised classification (future entry in Annex VI, CLP Regulation)	Carc. 1B; H350 Muta. 1B; H340 STOT RE 1; H372 (bone, kidney)

	Acute Tox. 4*; H302 Acute Tox. 4*; H312 Acute Tox. 4*; H332 Aquatic Acute 1; H400 Aquatic Chronic 1; H410

1.3 Proposed harmonised classification and labelling based on CLP Regulation

Table 3: Proposed classification according to the CLP Regulation

CLP Annex I ref	Hazard class	Proposed classification	Proposed SCLs and/or M-factors	Current classification [1)]	Reason for no classification [2)]
2.1.	Explosives	None		None	Hazard class not assessed in this dossier
2.2.	Flammable gases	None		None	Hazard class not assessed in this dossier
2.3.	Flammable aerosols	None		None	Hazard class not assessed in this dossier
2.4.	Oxidising gases	None		None	Hazard class not assessed in this dossier
2.5.	Gases under pressure	None		None	Hazard class not assessed in this dossier
2.6.	Flammable liquids	None		None	Hazard class not assessed in this dossier
2.7.	Flammable solids	None		None	Hazard class not assessed in this dossier
2.8.	Self-reactive substances and mixtures	None		None	Hazard class not assessed in this dossier
2.9.	Pyrophoric liquids	None		None	Hazard class not assessed in this dossier
2.10.	Pyrophoric solids	None		None	Hazard class not assessed in this dossier
2.11.	Self-heating substances and mixtures	None		None	Hazard class not assessed in this dossier
2.12.	Substances and mixtures which in contact with water emit flammable gases	None		None	Hazard class not assessed in this dossier
2.13.	Oxidising liquids	None		None	Hazard class not assessed in this dossier
2.14.	Oxidising solids	None		None	Hazard class not assessed in this dossier
2.15.	Organic peroxides	None		None	Hazard class not assessed in this dossier

2.16.	Substance and mixtures corrosive to metals	None		None	Hazard class not assessed in this dossier
3.1.	Acute toxicity - oral	None		Acute Tox. 4*; H302	Hazard class not assessed in this dossier
	Acute toxicity - dermal	None		Acute Tox. 4*; H312	Hazard class not assessed in this dossier
	Acute toxicity - inhalation	None		Acute Tox. 4*; H332	Hazard class not assessed in this dossier
3.2.	Skin corrosion / irritation	None		None	Hazard class not assessed in this dossier
3.3.	Serious eye damage / eye irritation	None		None	Hazard class not assessed in this dossier
3.4.	Respiratory sensitisation	None		None	Hazard class not assessed in this dossier
3.4.	Skin sensitisation	None		None	Hazard class not assessed in this dossier
3.5.	Germ cell mutagenicity	Muta. 1B; H340		None	Harmonised classification proposed
3.6.	Carcinogenicity	Carc. 1B; H350		None	Harmonised classification proposed
3.7.	Reproductive toxicity	None		None	Hazard class not assessed in this dossier
3.8.	Specific target organ toxicity –single exposure	None		None	Hazard class not assessed in this dossier
3.9.	Specific target organ toxicity – repeated exposure	STOT RE 1; H372 (kidney, bone)		None	Harmonised classification proposed
3.10.	Aspiration hazard	None		None	Hazard class not assessed in this dossier
4.1.	Hazardous to the aquatic environment	None		Aquatic Acute 1; H400 Aquatic Chronic 1; H410	Hazard class not assessed in this dossier
5.1.	Hazardous to the ozone layer	None		None	Hazard class not assessed in this dossier

[1)] Including specific concentration limits (SCLs) and M-factors
[2)] Data lacking, data inconclusive, data conclusive but not sufficient for classification, hazard class not assessed in this dossier, or harmonized classification proposed.

Labelling:

Signal word:

Danger

Hazard statements:

H340; H350; H372 (bone, kidney)

Precautionary statements:

No precautionary statements are proposed since precautionary statements are not included in Annex VI of Regulation EC no. 1272/2008.

Pictogram:

GHS08

Proposed notes assigned to an entry:

None.

2 BACKGROUND TO THE CLH PROPOSAL

2.1 History of the previous classification and labelling

There is no harmonised classification for cadmium hydroxide other than the harmonised classification justified by the Annex VI group entry with index number 048-001-00-5, i.e. Acute Tox. 4* (H302, H312, H332), Aquatic Acute 1 (H400) and Aquatic Chronic 1 (H410). However, specific harmonised classification exists for other cadmium compounds (see the Classification & Labelling Inventory (ECHA, 2015a)).

The registrant has classified cadmium hydroxide in:

- Carc. 1B; H350
- Muta. 2; H341
- Repr. 2; H361
- STOT RE 1; H372 (kidney, lung, bone) (Inhalation)
- Acute Tox. 2; H330
- Aquatic Acute 1; H400

- Aquatic Chronic 1; H410

2.2 Short summary of the scientific justification for the CLH proposal

In mammalian toxicity, the toxicity of inorganic cadmium compounds is regarded to result from the intrinsic properties of the Cd^{2+} ion. Conversely, it could be argued that the toxicity of any diffusible, and thus bioavailable, inorganic cadmium compound could be used to determine the intrinsic properties of the Cd^{2+} ion, i.e. information on toxicity could be read across from one cadmium compound to another (please refer to Section 4). Taken into consideration available data from the registration and reviews of cadmium toxicity by other regulatory bodies (JRC, 2007; EFSA, 2009; ATSDR, 2012), the dossier submitter concludes that cadmium hydroxide should be classified in:

- Carc. 1B; H350, since treatment related tumours were observed in two species (rat and mouse), in three different studies in one species (rat), in both sexes of one species (rat), and that tumours occurred at multiple sites and/or were of different types.
- Muta 1B; H340, since structural chromosome aberrations were induced in somatic cells of mice, micronuclei were induced in somatic cells of mice and rats, and that numerical and structural chromosome aberrations were induced in the germ cells of mice.
- STOT RE 1 (kidney, bone); H372, since significant toxicity in humans was demonstrated in kidney and bone

2.3 Current harmonised classification and labelling

2.3.1 Current classification and labelling in Annex VI, Table 3.1 in the CLP Regulation

Acute Tox. 4*; H302, H312, H332

Aquatic Acute 1; H400

Aquatic Chronic 1; H410

2.4 Current self-classification and labelling

2.4.1 Current self-classification and labelling based on the CLP Regulation criteria

Table 5: Self-classification according to the Classification and Labelling inventory January 23, 2015 (ECHA, 2015a).

Classification		Labelling			Specific Concentration limits, M-Factors	Notes	Number of Notifiers	Joint Entries
Hazard Class and Category Code(s)	Hazard Statement Code(s)	Hazard Statement Code(s)	Supplementary Hazard Statement Code(s)	Pictograms, Signal Word Code(s)				
Acute Tox. 4	H302	H302		GHS07 GHS09 Wng			23	
Acute Tox. 4	H312	H312						
Acute Tox. 4	H332	H332						
Aquatic Acute 1	H400							
Aquatic Chronic 1	H410	H410						
Acute Tox. 4	H302	H302		GHS07 GHS09 Wng		Note A Note 1	15	
Acute Tox. 4	H312	H312						
Acute Tox. 4	H332	H332						
Aquatic Acute 1	H400	H400						
Aquatic Chronic 1	H410	H410						
Acute Tox. 2	H330	H330		GHS06 GHS09 GHS08 Dgr	M(Chronic)=10 M=10		4	✔
Muta. 2	H341	H341						
Carc. 1B	H350	H350						
Repr. 2	H361	H361 (H361fd is						

		exact statement (translation of R60-61))						
STOT RE 1	H372 (kidney, lung, bone) (Inhalation)	H372						
Aquatic Acute 1	H400							
Aquatic Chronic 1	H410	H410						
		H410		GHS07 GHS09 Wng			2	
		H312						
		H400						
		H332						
		H302						

3 JUSTIFICATION THAT ACTION IS NEEDED AT COMMUNITY LEVEL

Cadmium hydroxide has CMR properties. Harmonised classification and labelling for CMR and respiratory sensitisation is a community-wide action under article 36 of the CLP regulation.

The reason for a need for action at Community level regarding STOT RE is differences in self-classification. The dossier submitter has focussed on toxicity in kidney and bone, since these organs are the most sensitive from a STOT RE perspective. Even though the lung is also a known target organ, the most sensitive effect caused by lung exposure is lung cancer, for which harmonised classification is proposed and, therefore, toxicity in the lung has not been evaluated with respect to specific target organ toxicity after repeated exposure in this CLH report.

Part B.

SCIENTIFIC EVALUATION OF THE DATA

1 IDENTITY OF THE SUBSTANCE

1.1 Name and other identifiers of the substance

Table 6: Substance identity

EC number:	244-168-5
EC name:	Cadmium hydroxide
CAS number (EC inventory):	21041-95-2
CAS number:	21041-95-2
CAS name:	Cadmium hydroxide
IUPAC name:	Cadmium dihydroxide
CLP Annex VI Index number:	Included in group entry 048-001-00-5
Molecular formula:	$Cd(OH)_2$
Molecular weight range:	146.4257

Structural formula:

1.2 Composition of the substance

Table 7: Constituents (non-confidential information)

Constituent	Typical concentration	Concentration range	Remarks
Cadmium hydroxide	98.5 % (w/w)	> 80 - < 100.0 % (w/w)	

Current Annex VI entry: included in the group entry 048-001-00-5

Table 8: Impurities (non-confidential information)

Impurity	Typical concentration	Concentration range	Remarks
Nickel	< 0.1 % (w/w)	≥ 0.0 - ≤ 1.05 % (w/w)	Ni is present as $NiSO_4$ (aq)

Current Annex VI entry: 028-009-00-5

Table 9: Additives (non-confidential information)

Additive	Function	Typical concentration	Concentration range	Remarks
-				

Current Annex VI entry: None

1.2.1 Composition of test material

1.3 Physico-chemical properties

Table 10: Summary of physico - chemical properties

Property	**Value**	**Reference**	**Comment (e.g. measured or estimated)**
State of the substance at 20°C and 101,3 kPa	The physical state of the substance is solid homogeneous powder, its colour is greenish white, it is odourless.	REACH registration (ECHA 2015b)	No guideline followed. Appearance and physical state were determined by visual inspection, odour by smell (organoleptic).
Melting/freezing point	The melting and decomposition of the material starts in nitrogen at 186°C and at 188°C in air.	REACH registration (ECHA 2015b)	EU Method A.1 (Melting / Freezing Temperature)
Boiling point		Data waived in REACH registration (ECHA 2015b)	
Relative density	The density of the substance is 4.73 g/cm3.	REACH registration (ECHA 2015b)	EU Method A.3 (Relative Density)
Vapour pressure		Data waived in REACH registration (ECHA 2015b)	
Surface tension		Data waived in REACH registration (ECHA 2015b)	
Water solubility	The experimentally determined average solubility at 20°C of Cd in the substance is 69.5 mg/l (slightly soluble). The corresponding value for the pure compound was also calculated with HSC 7.0 software. The obtained value was 2.5 mg/l. The calculated solubility product for $Cd(OH)_2$ was found to be in good agreement with the value found in the literature .	REACH registration (ECHA 2015b)	OECD Guideline 105 (Water Solubility)
Partition coefficient n-octanol/water		Data waived in REACH registration (ECHA 2015b)	
Flash point		Data waived in REACH registration (ECHA 2015b)	
Flammability		Data waived in REACH registration (ECHA 2015b)	
Explosive properties		Data waived in REACH registration (ECHA 2015b)	

Self-ignition temperature		Data waived in REACH registration (ECHA 2015b)	
Oxidising properties	No oxidation occurred, the sample is very stable	REACH registration (ECHA 2015b)	No guideline followed. The Pourbaix diagram of the substance was calculated using the EpH module of the HSC 7.0 program.
Granulometry	The D50 of the substance is 146 µm, the D80 is 384 µm.	REACH registration (ECHA 2015b)	ASTM E323-09 standard specification for perforated plate sieves for testing purposes.
Stability in organic solvents and identity of relevant degradation products		Data waived in REACH registration (ECHA 2015b)	
Dissociation constant		Data waived in REACH registration (ECHA 2015b)	
Viscosity		Data waived in REACH registration (ECHA 2015b)	

2 MANUFACTURE AND USES

2.1 Manufacture

Not relevant for this CLH report.

2.2 Identified uses

- Tonnage band: 1000-10 000 (ECHA, 2015b)
- Uses (Danish Environmental Protection Agency, 2013):
  - Component for production of inorganic cadmium compounds
  - Component for production of organic cadmium compounds
  - Component for production of inorganic pigments
  - Cadmium production by pyrometallurgy
  - Batteries / Fuel cells
  - Electrogalvanizing and electroplating
  - Laboratory reagent

3 CLASSIFICATION FOR PHYSICO-CHEMICAL PROPERTIES

Not evaluated in this report.

4 HUMAN HEALTH HAZARD ASSESSMENT

Equivalence between cadmium salts in mammalian toxicity

In mammalian toxicity, the toxicity of any inorganic cadmium compound, i.e. cadmium salt, is regarded to result from the intrinsic properties of the Cd^{2+} ion; see for example the European Union Risk Assessment Report (EU RAR) – Volume 74 cadmium metal, Part II Human Health (JRC, 2007). The solubility of a cadmium salt in body fluids at sites where exposure occurs is a factor affecting the bioavailability of the Cd^{2+} ion and, accordingly, the level of systemic exposure of the Cd^{2+} ion may be different for different cadmium salts. However, the solubility in water of a cadmium salt may not be indicative of its solubility in a certain body fluid. Plain examples of this are cadmium oxide (very low solubility in water), cadmium carbonate (very low solubility in water) and cadmium sulphide (practically insoluble in water), for which the solubility in artificial gastric juice (pH 1.47) has been demonstrated to be 94 %, 87 % and 5 %, respectively, and in artificial intestinal juice (pH 8.20) 0.151 %, 0.015 % and 0.112 %, respectively, after incubation for 2 hours at 37 °C (Wada et al., 1972). Information on solubility in artificial simulated body fluids is considered to be of importance for evaluating the bioavailability of a substance, as indicated by the following statement in section 1.3.2.1 of the ECHA guidance on the application of the CLP criteria (ECHA, 2013): "*Bioavailability of a substance or a mixture is normally assumed if there are in vitro studies available which show the solubility of a substance or mixture in body fluids or artificial simulated body fluids.*"

The high solubility of the above cadmium salts in artificial gastric juice compared to their solubility in water is related to the low pH of gastric juice caused by its content of hydrochloric acid. Thus, one characteristic of the gastric chyme is the occurrence of an excess of chloride ions derived from the gastric juice. This implies that, following dissociation of any cadmium salt in the gastric chyme, the Cd^{2+} ions would be encircled by chloride ions at a much higher concentration than that of its counter ion. Accordingly, the chemical conditions in the stomach and the proximal duodenum arising from oral administration of a cadmium salt would be comparable for all cadmium salts soluble in gastric juice. As the gastric chyme is expelled by the stomach into the duodenum, a low pH prevails in the proximal part of the duodenum, from which ionic cadmium can be absorbed either by simple diffusion or mediated by the metal-ion transporter DMT1 (Tallkvist et al. 2001, Park et al., 2002). Hence, it can be considered that the Cd^{2+} ion of cadmium oxide, cadmium carbonate and cadmium sulphide is bioavailable following oral exposure.

In more distal parts of the intestine the pH is higher due to the pH of the intestinal juice, in which the solubility of a cadmium salt would be lower, as reflected by the solubility in artificial intestinal juice of the three cadmium salts in the study referred to above (Wada et al., 1972). However, since a cadmium salt administered orally would dissociate already in the stomach when reaching the gastric chyme, it would enter into the distal part of the intestine in the ionic state. Consequently, this would mean that conditions in other parts of the intestine that might have an influence on the toxicity of a cadmium salt, for example the increase in pH occurring already in the distal duodenum, would be similar regardless of the cadmium salt used in a study.

Obviously, the conditions described above also apply to cadmium chloride, which is the cadmium salt that has been used in most experimental studies conducted to evaluate the toxicity of the Cd^{2+} ion in animals. Hence, results from oral studies with cadmium chloride would be relevant for evaluating the toxic hazards of any cadmium salt considered to be soluble in gastric juice.

Bioavailability of the Cd^{2+} ion following inhalation was observed in a carcinogenicity study in male Wistar (TNO/W75) rats exposed for 23 hours per day, 7 days a week for 18 months to cadmium chloride aerosols with cadmium concentrations of 0, 12.5, 25 and 50 µg/m^3 (Takenaka *et al*., 1983). After the end of the exposure period, the rats were observed for an additional 13 months before the study was ended. It is stated in the publication that the remaining cadmium concentrations in the lungs were relatively high at the end of the study and that they were almost at the same level as those observed in the livers.

Studies on absorption of cadmium chloride and cadmium sulphide in rats after inhalation exposure 6 hours per day during 10 days showed that, for each salt, 40 % of the deposited material was cleared during the exposure period and that, at 3 months after the last exposure (end of the study), 56 % and 81 % of the lung burden at the end of the exposure period was cleared for cadmium chloride and cadmium sulphide, respectively (Klimish, 1993). Accumulation of cadmium in the kidney at the end of the study was 35 % and 1 % for cadmium chloride and cadmium sulphide, respectively, indicating bioavailability for both, although the latter is practically insoluble in water.

Of the few existing studies addressing systemic toxicity following inhalation of cadmium oxide in animals, the study by Dunnick (1995) has the highest reliability. In this study systemic toxicity was demonstrated in rats by effects on fertility and reproductive organs (males and females) as well as by general and developmental toxicity, and in mice by general and developmental toxicity. According to the ECHA guidance on the application of the CLP criteria (ECHA, 2013), information on systemic toxicity is of importance for evaluating the bioavailability of a substance, as expressed in the following statement in section 1.3.2. of the guidance: "*In general, bioavailability is not explicitly evaluated in hazard classification – the observation of systemic toxicity implicitly demonstrates a degree of bioavailability.*" Hence, from the results of the study by Dunnick (1995), it can be considered that the Cd^{2+} ion of cadmium oxide, which has very low solubility in water, is bioavailable following inhalation exposure.

In conclusion, there is experimental support for bioavailability of the Cd^{2+} ion of cadmium salts with very low solubility in water, i.e. cadmium oxide, cadmium carbonate and cadmium sulphide after oral exposure, and cadmium oxide and cadmium sulphide after inhalation exposure. Hence, it is reasonable to consider that the Cd^{2+} ion of other water-soluble cadmium salts would also be bioavailable after oral and inhalation exposure, since the solubility of these cadmium salts in the body fluids at the sites of exposure would not be expected to be significantly lower than for the cadmium salts referred to above. Turned into a general concept, this would mean that any cadmium salt could in principle be used in experimental studies to evaluate the health hazards of the Cd^{2+} ion, although systemic toxicity of the Cd^{2+} ion may be more efficiently detected by using cadmium salts with high solubility in the body fluids at the sites of exposure, since this may result in higher systemic doses of the Cd^{2+} ion than those that would be obtained by using less soluble cadmium salts. Accordingly, it would be adequate to evaluate the health hazards of cadmium hydroxide by using data from other cadmium salts, of which cadmium chloride, which is highly soluble in water, has been used in most experimental studies.

On theoretical grounds it would be possible to argue that the counter ion of cadmium hydroxide could potentially contribute to the toxic effects to be evaluated. However, such potential contributions would not affect the classification for carcinogenicity and mutagenicity, since these classifications are based on animal studies in which animals were exposed to cadmium chloride (and in some studies also a few additional cadmium compounds), which is classified in the highest possible category based on animal data, i.e. Carc. 1B and Muta. 1B. Neither would the classification for specific target organ toxicity after repeated exposure be affected, since the proposed classification is based on studies in humans exposed to cadmium resulting in classification in the highest possible category, i.e. STOT RE 1.

The basis for the general concept presented above has also been expressed in a human health assessment for cadmium oxide produced by the National Industrial Chemicals Notification and Assessment Scheme under the Department of Health in Australia, in which it is stated that the high solubility of cadmium oxide in gastric juice means that water soluble cadmium salts such as cadmium chloride are appropriate analogues for orally administered cadmium oxide (NICNAS, 2013). A similar approach was presented in the EU RAR for cadmium metal (JRC, 2007) by stating that it is reasonable to assume that gastrointestinal absorption of cadmium oxide is not significantly different from that of other cadmium salts, mainly because of the high solubility of cadmium oxide in gastric juice and, therefore, data from studies conducted with other cadmium salts are judged relevant for assessing the gastrointestinal absorption of cadmium oxide. Further, in the Toxicological Profile for Cadmium produced by the Agency for Toxic Substances and Desease Registry (ATSDR, 2012) it is noted that the mechanism of action for an observed toxic effect involves the effect of the cadmium cation and that the cation is the same regardless of the anion species, and that cadmium oxide and cadmium carbonate (which are relatively insoluble in water but may dissolve at gastric pH) appear to be similar in absorption and toxicity to soluble cadmium.

4.1 Toxicokinetics (absorption, metabolism, distribution and elimination)

Please refer to Section 4 for relevant information.

4.2 Acute toxicity

Not evaluated in this report.

4.3 Specific target organ toxicity – single exposure (STOT SE)

Not evaluated in this report.

4.4 Irritation

Not evaluated in this report.

4.4.1 Eye irritation

Not evaluated in this report.

4.4.2 Respiratory tract irritation

Not evaluated in this report.

4.5 Corrosivity

Not evaluated in this report.

4.6 Sensitisation

4.6.1 Skin sensititsation

Not evaluated in this report.

4.6.2 Respiratory sensitisation

Not evaluated in this report.

4.7 Specific target organ toxicity – repeated exposure

Scientific reviews of repeated dose toxicity studies on cadmium compounds have been produced by several parties, for example, JRC (2007, EU RAR), EFSA (2009, Scientific Opinion of the Panel on Contaminants in the Food Chain on a request from the European Commission on cadmium in food) and ATSDR (2012, Toxicological Profile for Cadmium). Cadmium has been shown to affect many organs after repeated exposure. This CLH report will, however, only focus on the toxic effects on kidney and bone, since these organs are highlighted in scientific reviews as being critical target organs for cadmium-induced toxicity.

As is evident from the reviews referred to above, evidence for cadmium toxicity in kidney and bone is available from reliable studies in humans. Such evidence meets the criteria for a STOT RE classification in Category 1. Given that, results from studies in animals would not add any information necessary for the classification. Thus, summaries of studies in animals are not included in this CLH report. To summarise studies in humans demonstrating cadmium toxicity in kidney and bone, the study summaries from the scientific review produced by ATSDR (2012) have been incorporated into the CLH report (see Section 4.7.2).

4.7.1 Non-human information

Not evaluated in this CLH report for the reason stated in Section 4.7.

4.7.2 Human information

4.7.2.1 Effects on kidney

Table 10: Summary table of repeated dose toxicity studies relevant for classification as STOT RE according to the CLP regulation (adapted from ATSDR (2012))

Method	Results	Remarks	Reference
Oral exposure			
• Type of population: general population (Belgium); 1699 males, females, 20-80 years old • Effect biomarker: β2M, protein, NAG, amino acids, calcium	• Significant correlation between urinary cadmium and effect biomarkers • Dose-response relationship between urinary cadmium and prevalence of abnormal effect biomarker levels.	-	Buchet et al. (1990)
• Type of population: residents in cadmium-polluted area (includes occupationally exposed subjects (Sweden) • Effect biomarker: pHC	• Mean urinary cadmium level: 0.81 µg/g creatinine (M), 0.66 µg/g creatinine (F) • Linear relationship between urinary cadmium and pHC (relationship remained significant after removal of occupationally exposed subjects.	-	Järup et al. (2000)
• Type of population: general population (United States); 88 males, 71 females, 6-17 years old; 71 males, 80 females ≥18 years old • Effect biomarker: β2M, NAG, AAP, albumin	• 0.07 µg/g creatinine (M, child), 0.08 µg/g creatinine (F, child), 0.24 µg/g creatinine (M, adult), 0.23 µg/g creatinine (F, adult) • No significant associations (after correction for age, sex) between urinary cadmium and effects biomarkers in children. • Significant association after age and gender adjustment) between urinary cadmium and NAG and AAP in adults. • Dose-response relationship between urinary cadmium and NAG and AAP.	-	Noonan et al. (2002)
• Type of population: residents in cadmium-polluted area (Japan); 878 males, 972 females • Effect biomarker: β2M	• Dose-response relationship between cadmium in rice and effect biomarker.	-	Nogawa et al. (1989)
• Type of population: general population (Japan); 558 males, 743 females, ≥50 years old • Effect biomarker: β2M, total protein, NAG	• Mean urinary cadmium level: 1.3 µg/g creatinine (M), 1.3 µg/g creatinine (F) • Significant correlation between urinary cadmium and effect biomarkers (NAG was only significant in females). • Dose-response relationship between urinary cadmium and prevalence of abnormal effect biomarker levels	-	Yamanaka et al. (1998)
• Type of population: general population (Japan); 568 males, 742 females, ≥50 years old	• Mean urinary cadmium level: 2.2-3.4 µg/g creatinine (M), 2.8-3.9 µg/g creatinine (F)	-	Oo et al. (2000)

• Effect biomarker: total protein, NAG, β2M	• Significant correlation (with age adjustment) between urinary cadmium and effect biomarkers.		
• Type of population: general population (Japan); 1105 males, 1648 females, ≥50 years old • Effect biomarker: β2M, total protein, NAG	• Mean urinary cadmium level: 1.8 µg/g creatinine (M), 2.4 µg/g creatinine (F) • Significant correlation between urinary cadmium and protein and β2M. • Dose-response relationship between urinary cadmium and prevalence of abnormal effect biomarker levels.	-	Suwazono et al. (2000)
• Type of population: residents in cadmium-polluted area (China); 118 males, 170 females, high exposure group; 80 males, 158 females, moderate exposure group • Effect biomarker: β2M, RBP, albumin	• Mean urinary cadmium level: 11.18 µg/g creatinine (high exposure group), 3.55 µg/g creatinine (moderate exposure group) • Significant correlation between urinary cadmium and effect biomarkers. • Dose-response relationship between urinary cadmium and prevalence of abnormal effect biomarker levels.	-	Jin et al. (2002)
• Type of population: residents in cadmium-polluted area (China); 118 males, 170 females, high exposure group; 80 males, 158 females, moderate exposure group • Effect biomarker: β2M, NAG, NAG-B, RBP, albumin	• Dose-response relationship between urinary cadmium and prevalence of abnormal effect biomarker levels.	-	Jin et al. (2004a)
Inhalation exposure			
• Type of population: zinc-cadmium smelter workers (n=87)	• Effect: age-related decline in maximal GFR was exacerbated in workers with cadmium-induced microproteinuria. • Adverse effect level (U-Cd): 11.1 µg/g creatinine	-	Roels et al. (1991)
• Type of population: workers using cadmium pigments in plastic production or using cadmium in welding (n=27)	• Effect: significant increase in urinary β2M and NAG levels. • Adverse effect level (U-Cd): 5 µg/g creatinine	-	Verschoor et al. (1987)
• Type of population: cadmium alloy workers (n=164)	• Effect: higher incidence of increased urinary β2M levels (>250 µg/L cut-off) when urinary cadmium levels exceeded 10 µg/g creatinine on one or more occasions, as compared to workers who never exceeded the 10 µg/g	-	Toffoletto et al. (1992)

	creatinine level. • Adverse effect level (U-Cd): 10 µg/g creatinine		
• Type of population: cadmium smelter workers (n=53)	• Effect: significant increase in urinary protein and β2M levels. • Adverse effect level (U-Cd): 13.3 µg/g creatinine	-	Shaikh et al. (1987)
• Type of population: non-ferrous smelter workers (n=58)	• Effect: significant increase in urinary β2M, RBP protein, pHC, albumin, and transferrin levels. • Adverse effect level (U-Cd): >10 µg/g creatinine	-	Bernard et al. (1990)
• Type of population: workers exposed to cadmium pigment dust (n=58)	• Significant correlation between urinary cadmium and NAG levels. • Significant correlation with β2M at one of the two time points. • Adverse effect level (U-Cd): 1.1-1.4 µg/g creatinine	-	Kawada et al. (1989)
• Type of population: zinc-cadmium smelter workers (n=50)	• Significant association between urinary cadmium levels and urinary levels of NAG, albumin, and transferrin • At higher urinary cadmium levels (10 µg/g creatinine), there were significant associations with RBP and β2M. • Adverse effect level (U-Cd): 4 µg/g creatinine	-	Roels et al. (1993)
• Type of population: battery workers (n=561)	• 10 % prevalence of abnormal β2M levels (220 µg/g creatinine cut-off). • Adverse effect level (U-Cd): 1.5 µg/g creatinine for ≥60 years of age; 5 µg/g creatinine for <60 years of age	-	Järup and Elinder (1994)
• Type of population: alkaline battery factory workers (n=102)	• 10 % prevalence of renal dysfunction (β2M >380 µg/g creatinine; RBP >130 µg/g creatinine). • Adverse effect level (U-Cd): 10-15 µg/g creatinine.	-	Jakubowski et al. (1987)
• Type of population: workers at a factory using cadmium-containing solders (n=60)	• 25 % prevalence of abnormal β2M levels (300 µg/g creatinine cut-off). • Adverse effect level (U-Cd): 2-5 µg/g creatinine.	-	Elinder et al. (1985a)

• Type of population: workers at nickel-cadmium battery factory (n=92)	• Significant increase in pHC and NAG levels (after adjustment for age, gender, and race). • Adverse effect level (U-Cd): 5-10 µg/g creatinine.	-	Chia et al. (1992)
• Type of population: cadmium smelter workers (n=85)	• Significant increases in β2M and NAG levels and increased prevalence of abnormal levels of these biomarkers. • Adverse effect level (U-Cd): 5-10 µg/g creatinine.	-	Chen et al. (2006a, 2006b)
• Type of population: alkaline battery factory workers (n=141)	• 10 % prevalence of renal dysfunction (β2M >300 µg/g creatinine; RBP >300 µg/g creatinine). • Adverse effect level (B-Cd): 300 µg-years/L (30 years of 10 µg/L)	-	Jakubowski et al. (1992)
• Type of population: battery workers (n=440)	• Approximately 10 % prevalence of abnormal β2M levels (35 µg/mmol creatinine cut-off). • Adverse effect level (B-Cd): 5.6 µg/L; cumulative exposure 691 µg-years/m^3	-	Järup et al. (1988)
• Type of population: cadmium recovery plant workers (n=45)	• Significant association between cumulative exposure and urinary β2M, RBP, phosphate, and calcium and serum creatinine levels. • Adverse effect level: cumulative exposure 300 mg/m^3	-	Thun et al. (1989)
• Type of population: workers exposed to cadmium fumes (n=33)	• Increased urinary β2M and protein levels (mean 6375 µg/g creatinine and 246 mg/g creatinine, respectively) in 7 workers (mean in remaining 23 workers 53 µg/g creatinine and 34 mg/g creatinine) • Adverse effect level: cumulative exposure 1137 µg/m^3/years	-	Falck et al. (1983)

AAP = alanine aminopeptidase; β2M = β2-microglobulin; F = female; M = male; NAG = N-acetyl-β-glucosaminidase; pHC = human complex-forming glycoprotein, also referred to as α1M; RBP = retinol binding protein; U-Cd = urinary cadmium; B-Cd = blood cadmium; GFR = glomerular filtration rate

4.7.2.1.1 Oral exposure

Strong evidence is available that the kidney is one of the main target organs of cadmium toxicity following extended oral exposure. The effects are similar to those seen following inhalation exposure (see Section 4.7.2.1.2). Study summaries from ATSDR (2012) are reproduced below.

[Start of text from ATSDR (2012)]

Buchet et al. (1990) examined 1,699 non-occupationally exposed males and females (aged 20–80 years) living in Belgium. Urinary cadmium levels significantly correlated with urinary β2-microglobulin, retinol binding protein, NAG, amino acid, and calcium levels; the partial r2 values were 0.0036, 0.0210, 0.0684, 0.0160, and 0.0168, respectively. The probability that individuals would have abnormal values for the renal biomarkers (defined as >95th percentile for subjects without diabetes or urinary tract diseases and who did not regularly take analgesics) was estimated using logistic regression models with adjustments for age, gender, smoking, disease, and use of analgesics. It was estimated that >10% of β2-microglobulin, retinol binding protein, amino acid, and calcium values would be abnormal when 24-hour urinary cadmium levels were >3.05, 2.87, 2.74, 4.29, or 1.92 μg/24 hour, respectively.

Järup et al. (2000) examined 1,021 individuals living near a nickel-cadmium battery plant in Sweden for at least 5 years (n=799) or employed as battery workers (n=222). The mean urinary cadmium levels were 0.81 and 0.65 μg/g creatinine in males and females, respectively. Urinary cadmium levels were significantly associated with urinary human complex-forming glycoprotein (pHC; also referred to as α1-microglobulin) levels, after adjustment for age. The relationship remained statistically significant after removal of the cadmium workers from the analysis. The prevalence of abnormal pHC values (defined as exceeding the 95th percentile in a Swedish reference population; >7.1 and 5.3 mg/g creatinine for males and females, respectively) was estimated to increase by 10% at urinary cadmium levels of 1 μg/g creatinine. The European Chemicals Bureau (2007) recalculated the probability of HC proteinuria (using the raw data from Järup and associates) to account for the differences in age of the reference population (mean of 40 years) and study population (mean of 53 years). Based on these recalculations, the urinary cadmium level associated with a 10% increased probability of abnormal pHC values (20% total probability) was 2.62 μg/g creatinine for the total population. In the environmental exposed subgroup, a urinary cadmium level of 0.5 μg/g creatinine was associated with a 13% probability (doubling of the probability in reference population) of abnormal pHC values.

Noonan et al. (2002) examined residents in Pennsylvania living near a defunct zinc smelting facility (geometric mean urinary cadmium level of 0.14 μg/g creatinine) and a reference community located 10 miles from the facility (geometric mean urinary cadmium levels of 0.12 μg/g creatinine). The data from the two communities were pooled because there were no differences in urinary cadmium levels between them. β2-microglobulin, NAG, alanine aminopeptidase (AAP), and albumin levels were measured as biomarkers of renal dysfunction. The geometric mean urinary cadmium levels were 0.07 and 0.08 μg/g creatinine in 88 males and 71 females aged 6–17 years and 0.24 and 0.23 μg/g creatinine in 71 males and 80 females aged ≥18 years. No significant correlations between urinary cadmium levels and renal biomarkers were observed in the children, after adjustment for creatinine, age, and gender. In adults, significant correlations (after adjustment for creatinine, age, gender, smoking, and self-reported diabetes or thyroid disease) between urinary cadmium and NAG (partial correlation coefficient of 0.20, 95% CI of 0.05–0.36) and AAP (partial correlation coefficient of 0.21 and 95% CI of 0.05–0.36) were observed. Significant dose-effect relationships were also found for these two biomarkers. Urinary cadmium levels were not significantly associated with elevated levels of β2-microglobulin or albumin.

Nogawa et al. (1980; *presumably a typing error; the reference of 1989 is assumed to be correct; dossier submitter's note*) examined 878 males and 972 females aged ≥50 years living in the Kakehashi River basin in Japan; the Kakehashi River, cadmium polluted from an upstream mine, was used to irrigate rice fields. β2-Microglobulin measured in morning urine samples was used as a biomarker of renal dysfunction and cadmium intake was estimated from rice samples collected in 1974. Cadmium levels in rice were considered to be representative of cadmium intake because over 70% of the total cadmium intake has been shown to come from rice. Cadmium in the rice ranged from 0.10 to 0.69 μg/g. β2-Microglobulin levels were significantly higher in the study population compared to a reference population of 113 males and 161 females living in a nearby area. A significant dose-related association between total cadmium intake and prevalence of abnormal β2-microglobulin values (defined as β2-microglobulin levels of ≥1,000 μg/g creatinine) was found. The total cadmium intake, which resulted in a prevalence of abnormal β2-microglobulin levels equal to the control group, was 1,678 mg in males (prevalence in controls was 6.0%) and 1,763 mg in females (prevalence in controls was 5.0%). A further analysis of the exposed subjects (Hochi et al. 1995) found that the prevalence of abnormal β2-microglobulin levels (using a cut-off level of 1,000 μg/g creatinine) exceeded the prevalence in the reference population when cadmium intake was ≥2 g and the subjects were divided into subgroups by age. The prevalence of abnormal β2-microglobulin levels at a given cadmium intake increased with age.

Yamanaka et al. (1998) examined 558 males and 743 females aged ≥50 years living in a cadmium nonpolluted area in Japan. Urinary cadmium level was used as a biomarker of exposure and urinary β2-microglobulin, total protein, and NAG as biomarkers of renal dysfunction. The geometric mean urinary cadmium levels were 1.3 and 1.3 μg/g creatinine in males and females, respectively. Significant correlations (after adjustment for age) between urinary cadmium levels and total protein, β2-microglobulin, and NAG were found. Abnormal levels of renal biomarkers were defined as exceeding the 84% upper limit value calculated from a referent group of 2,778 non-exposed individuals; the cut-off values were 124.8 and 120.8 mg/g creatinine for total protein in males and females, 492 and 403 μg/g creatinine for β2-microglobulin, and 8.0 and 8.5 U/g creatinine for NAG. Dose-response relationships between urinary cadmium levels and prevalence of abnormal levels of β2-microglobulin, total protein, and NAG were found. The odds ratios (95% CI) were 6.589 (3.383–12.833), 3.065 (1.700–5.526), and 1.887 (1.090–3.268) for protein, β2-microglobulin, and NAG in males and 17.486 (7.520–40.660), 5.625 (3.032–10.435), and 2.313 (1.399–3.824) for protein, β2-microglobulin, and NAG in females.

Another study of residents living in a cadmium nonpolluted area of Japan examined 346 males and 529 females from one area (area A) and 222 males and 413 females in another area (area B); all subjects were ≥50 years of age and were not occupationally exposed to heavy metals (Oo et al. 2000). The geometric mean urinary cadmium levels were 2.2 and 2.8 μg/L in males and females in area A and 3.4 and 3.9 μg/L in area B. Significant correlations (with adjustment for age) were found between urinary cadmium and urinary levels of protein, β2-microglobulin (not significant in males in area B) and NAG levels. A significant association between urinary cadmium levels and the prevalence (cut-off levels from same referent population as Yamanaka et al. 1998) of abnormal levels of urinary protein (cut-off level of 113.8 and 96.8 μg/L in males and females), β2-microglobulin (378 and 275 μg/L) (only significant in females in area A), and NAG (8.0 and 7.2 μg/L). The odds ratios (95% CI) for an increase in prevalence of abnormal renal biomarkers were 8.810 (3.401–22.819) and 11.282 (3.301–38.362) for protein in males in areas A and B, respectively, 8.234 (3.696–18.343) and 23.901 (8.897–64.210) for protein in females in areas A and B; 2.558 (1.246–5.248) for β2-microglobulin in females in area A; 47.944 (14.193–161.954) and 9.940 (3.153–31.340) for NAG in males in areas A and B; and 72.945 (21.873–243.263) and 25.374 (9.452–68.117) for NAG in females in areas A and B.

In a re-examination of the populations studied by Yamanaka et al. (1998) and Oo et al. (2000), Suwazono et al. (2000) measured cadmium levels in blood and urine and urinary levels of total protein, β2-microglobulin, and NAG in 1,105 males and 1,648 females over the age of 50 years. The geometric mean concentrations of cadmium in urine were 1.8 and 2.4 μg/g creatinine in males and females, respectively, and blood cadmium levels were 2.0 and 1.8 ng/g in males and females. After adjustment for age, significant associations between urinary cadmium levels and urinary protein and β2-microglobulin in males and females were found. Additionally, blood cadmium levels were significantly associated with urinary protein and NAG levels in males and urinary protein, β2-microglobulin, and NAG levels in females. Cut-off levels (defined as the 84% upper limit values from 424 male and 1,611 female nonsmoking subjects) of 157.4 and 158.5 mg/g creatinine for protein in males and females, respectively, 507 and 400 μg/g creatinine for β2-microglobulin in males and females, respectively, and 8.2 and 8.5 μg/g creatinine for NAG in males and females, respectively, were used to evaluate the prevalence of abnormal levels of renal biomarkers. Logistic regression analysis demonstrated significant associations between urinary cadmium levels and increased prevalence of abnormal levels of total protein (odds ratio of 3.923, 95% CI of 2.2028–7.590) and β2-microglobulin (odds ratio of 2.259, 95% CI of 1.372–3.717) in males; in females, significant associations were found for total protein (odds ratio of 7.763; 95% CI of 4.231–14.243), β2-microglobulin (odds ratio of 2.259, 95% CI of 1.879–4.281), and NAG (odds ratio of 1.882, 95% CI of 1.311–2.702). For blood cadmium levels, the only significant association found was for an increased prevalence of abnormal total protein levels in females (odds ratio of 3.490, 95% CI of 1.661–7.331).

Jin et al. (2002) examined three populations living various distances from a nonferrous metal smelter. The geometric mean levels of urinary cadmium were 11.18 and 12.86 μg/g creatinine in males (n=294) and females (n=171) in the highly polluted area, 3.55 and 4.45 μg/g creatinine in males (n=243) and females (n=162) in the moderately polluted area, and 1.83 and 1.79 μg/g creatinine in males (n=253) and females (n=155) in the control area. Significant correlations were found between urinary (and blood) cadmium levels and renal biomarkers (β2-microglobulin, retinol binding protein, and albumin). Cut-off values for β2-microglobulin, retinol binding protein, and albumin of 300 μg/g creatinine, 300 μg/g creatinine, and 15 mg/g creatinine, respectively, were used to assess possible dose-response relationships (no additional information was provided); although 300 μg/g creatinine was reported as the cut-off values for β2-microglobulin, subsequent analysis of this data set (Jin et al. 2004a) reported a cut-off value of 800 μg/g creatinine. Significant dose-response relationships between urinary (and blood) cadmium and the prevalence of abnormal levels of renal markers of kidney dysfunction were found.

[End of text from ATSDR (2012)]

4.7.2.1.2 Inhalation exposure

Strong evidence is available that the kidney is one of the main target organs of cadmium toxicity following extended inhalation exposure. The effects are similar to those seen following oral exposure (see Section 4.7.2.1.1). Study summaries from ATSDR (2012) are reproduced below.

[Start of text from ATSDR (2012)]

One of the first signs of kidney effects is tubular dysfunction characterized by an increased urinary excretion of low-molecular-weight proteins such as β2-microglobulin, human complex-forming glycoprotein (pHC) (also referred to as α1-microglobulin), and retinol binding protein or increased urinary levels of intracellular enzymes such as N-acetyl-β-glucosaminidase (NAG) (European Chemicals Bureau 2007 (*in this CLH report cited as JRC, 2007; dossier submitter's note*); Järup et

al. 1998). Numerous occupational exposure studies have reported increases in urinary levels of these biomarkers (Bernard et al. 1990; Chen et al. 2006a, 2006b; Chia et al. 1992; Elinder et al. 1985b; Falck et al. 1983; Jakubowski et al. 1987, 1992; Järup and Elinder 1994; Järup et al. 1988; Kawada et al. 1989; Roels et al. 1993; Shaikh et al. 1987; Thun et al. 1989; Toffoletto et al. 1992; Verschoor et al. 1987). At higher exposure levels, increased urinary levels of high-molecular-weight proteins such as albumin have been reported (Bernard et al. 1979, 1990; Chen et al. 2006a, 2006b; Elinder et al. 1985b; Mason et al. 1988; Roels et al. 1989, 1993; Thun et al. 1989), but there is some debate as to whether this represents glomerular damage (Bernard et al. 1979; Roels et al. 1989) or severe tubular damage (Elinder et al. 1985a; Mason et al. 1988; Piscator 1984).

Chronic exposure to very high cadmium levels can result in glomerular damage resulting in decreases in glomerular filtration rate (GFR) (Friberg 1950; Järup et al. 1995; Roels et al. 1991). Järup et al. (1995) found a dose-response relationship between blood cadmium levels and GFR in cadmium workers. At blood cadmium levels of 5.6 to <8.4 μg/L, 33.3% of the workers had decreased GFR (defined as <80% of referents); whereas all subjects with blood cadmium levels of ≥8.4 μg/L exhibited a decreased GFR.

Another study did not find alterations in GFR in workers with urinary cadmium levels of approximately 11 μg/g creatinine; however, an exacerbation of the age-related decline in maximal GFR was observed (Roels et al. 1991). Other studies reported increases in serum creatinine levels, which are suggestive of impaired GFR (Roels et al. 1989; Thun et al. 1989).

[End of text from ATSDR (2012)]

4.7.2.2 Effects on bone

Table 11: Summary table of repeated dose toxicity studies relevant for classification as STOT RE according to the CLP regulation (adapted from ATSDR (2012))

Method	Results	Remarks	Reference
Oral exposure			
• Type of population: women environmentally exposed to cadmium (Sweden)	• Mean urinary cadmium level: 0.52 µg/L • Negative relationship between urinary cadmium levels and bone mineral density.	-	Åkesson et al. (2005)
• Type of population: residents in cadmium-polluted area (Sweden)	• Significant decreases in bone mineral density for >60 years of age with blood cadmium levels of ≥0.56 µg/L.	-	Alfvén et al. (2002)
• Type of population: Subjects, of which approximately 10 % were environmentally or occupationally exposed to cadmium (Sweden)	• Increased risk of bone fractures for >50 years of age with urinary cadmium levels of >2 µg/g creatinine.	-	Alfvén et al. (2004)
• Type of population: Subjects, of which approximately 10 % were environmentally or occupationally exposed to cadmium (Sweden)	• Increased risk of osteoporosis among men >60 years of age with urinary cadmium levels of >5 µg/g creatinine.	-	Alfvén et al. (2000)
• Type of population: residents living near zinc smelters (Belgium)	• Decrease in proximal and distal forearm bone density of approximately 0.1 g /cm^2 was associated with a two-fold increase in urinary cadmium level in postmenopausal women.	-	Staessen et al. (1999)
• Type of population: women living near zinc smelters	• Suggestive evidence that cadmium has a direct osteotoxic effect.	-	Schutte et al. (2008)
• Type of population: residents in cadmium-polluted area (Poland)	• Significant decrease in bone mineral density in males with urinary cadmium levels of >2 µg/g creatinine.	-	Trzcinka-Ochocka et al. (2010)
• Type of population: residents in cadmium-polluted area (China)	• Significant increases in prevalence of low forearm bone mineral density in postmenopausal women with urinary cadmium levels of >20 µg/g creatinine. • Significant increases in prevalence of low forearm bone mineral density in men, premenopausal women, and postmenopausal women with blood cadmium levels of >20 µg/g creatinine.	-	Nordberg et al. (2002)
• Type of population: residents in cadmium-polluted area (China)	• Increase in bone fractures in males (mean urinary cadmium level 9.20 µg/g creatinine) and females (mean urinary cadmium level 12.86	-	Wang et al. (2003)

	µg/g creatinine)		
• Type of population: residents in cadmium-polluted area (China)	• Significant dose-response relationship between urinary cadmium levels and and the prevalence of osteoporosis.	-	Jin et al. (2004b), Wang et al. (2003), Zhu et al. (2004)
• Type of population: residents in areas with moderate or heavy cadmium pollution ten years after the source of rice was switched to commercially available rice from cadmium-nonpolluted areas (China)	• Significant decreases in forearm bone mineral density in women from the moderately polluted area and in men from the heavily polluted area. • Decreases in bone mineral density in women 60-69 or ≥70 years old from both polluted areas, and in men ≥70 years old from the heavily polluted area. • Significantly higher prevalence of osteoporosis in women from the polluted areas which increased with urinary cadmium levels.	-	Chen et al. (2009)
• Type of population: residents in cadmium-polluted area (China)	• Higher prevalence of osteoporosis in women with renal dysfunction or tubular damage • Significantly lower bone mineral density levels in women with tubular damage • No significant associations between the prevalence of osteoporosis or bone mineral density and alterations in renal biomarkers in men.	-	Chen et al. (2011)
• Type of population: residents living near an industrial comples (Korea)	• Significant associations between high urinary cadmium levels (≥1.0 µg/g creatinine) and osteopenia • Bone mineral density negatively associated with urinary cadmium levels.	-	Shin et al. (2011)
• Type of population: health-survey population (Sweden)	• Significantly lower urinary cadmium levels bone mineral density in postmenopausal women with elevated urinary cadmium levels (median 1.1 µg/g creatinine) compared to women with low urinary cadmium levels (median 0.36 µg/g creatinine) • Significant changes of biomarkers indicative of increased bone resorption in the high urinary cadmium group.	-	Engström et al. (2009)

• Type of population: general population (USA)	• Significant association between urinary cadmium levels and osteopenia and osteoporosis in adults with urinary cadmium levels of >1 µg/g creatinine.	-	Wu et al. (2010)
• Type of population: general population (USA)	• 43 % increased risk of osteoporosis in women ≥50 years of age with urinary cadmium levels of 0.50-1.00 µg/g creatinine, as compared to women with urinary cadmium levels of <0.50 µg/g creatinine.	-	Gallagher et al. (2008)
Inhalation exposure			
• Case study: alkaline battery workers	• Osteomalacia observed	-	Adams et al. (1969)
• Case study: battery plate maker	• Osteomalacia observed	-	Blainey et al. (1980)
• Case study: cadmium workers	• Hypercalciuria and osteomalacia observed	-	Kazantzis 1979
• Case study: cadmium-exposed workers	• Hypercalciuria and calcium deficit observed	-	Scott et al. (1980)

4.7.2.2.1 Oral exposure

Strong evidence is available that bone is one of the main target organs of cadmium toxicity following extended oral exposure. The effects are similar to those seen following inhalation exposure (see Section 4.7.2.2.2). Study summaries from ATSDR (2012) are reproduced below.

In several studies of populations exposed to elevated levels of cadmium in the diet, the occurrence of osteomalacia, osteoporosis, bone fractures and decreased bone mineral density have been established. The first observation of an association between these types of bone effects and cadmium exposure was reported in residents living in the cadmium-contaminated area of the Jinzu River basin in Japan. The condition was termed Itai-Itai desease (Tsuchiya, 1969a, b). Studies of populations living in other areas of Japan and in other countries, and of populations exposed to low levels of cadmium, have confirmed the association between cadmium exposure and bone effects.

[Start of text from ATSDR (2012)]

In a study of Swedish women environmentally exposed to cadmium, a significant negative relationship between urinary cadmium levels and bone mineral density was observed (Åkesson et al. 2005); the mean urinary cadmium level of the population was 0.52 µg/L. In Swedish residents living in an area with known cadmium pollution from battery manufacturing facilities, significant associations were noted between blood cadmium levels and bone mineral density and between urinary cadmium levels and risk of fractures and osteoporosis. There were significant decreases in bone mineral density in environmentally exposed subjects older than 60 years of age with blood cadmium levels of ≥0.56 µg/L (Alfvén et al. 2002). Increases in the risk of bone fractures were observed in subjects (approximately 10% of all subjects examined had environmental and occupational exposure to cadmium) older than 50 years of age with urinary cadmium levels >2 µg/g creatinine; no significant associations were found in subjects under 50 years of age (Alfvén et al.

2004). Another study of this population found significant increases in the risk of osteoporosis among men >60 years of age with urinary cadmium levels ≥5 μg/g creatinine; however, an increased risk of osteoporosis was not observed in women (Alfvén et al. 2000). A Belgian study in which residents living near zinc smelters found a 2-fold increase in cadmium exposure (as assessed via urinary cadmium levels) was associated with a decrease in proximal and distal forearm bone density of approximately 0.1 g/cm^2 among postmenopausal women (Staessen et al. 1999). For women with urinary cadmium levels >1 μg/day, the incidence of bone fracture was 13.5 per 1,000 person-years. Another study of a subset of the women living near a zinc smelters (Schutte et al. 2008) provides suggestive evidence that cadmium has a direct osteotoxic effect. Significant associations between urinary cadmium levels and the levels of two pyridinium crosslinks of collagen (urinary levels of hydroxylysylpyridinoline and lysylpyridinoline), proximal forearm bone mineral density, and serum parathyroid hormone levels were found. In almost all of the examined women, urinary levels of retinol binding protein were below the cut-off level of 338 μg/day, suggesting no cadmium-induced effect on renal tubular function. Several biomarkers of bone damage were examined in a subsequent follow-up study of some of the women (Schutte et al. 2008) only 1 of the 294 women examined had evidence of renal dysfunction (increased retinol binding protein). Significant associations between urinary cadmium excretion and two biomarkers of bone resorption (urinary hydroxylysylpyridinoline and lysylpyridinoline) were found. Although significant associations between urinary cadmium levels and biomarkers of renal dysfunction were observed in Polish adults living in a cadmium-polluted area, the only association between urinary cadmium and bone biomarkers was a significant decrease in bone mineral density among males with urinary cadmium levels of ≥2 μg/g creatinine (Trzcinka-Ochocka et al. 2010). Similar results have been observed in several studies of residents living in areas of China with moderate or high cadmium pollution levels (Jin et al. 2004b; Nordberg et al. 2002; Wang et al. 2003; Zhu et al. 2004). There were significant increases in the prevalence of low forearm bone mineral density in postmenopausal women with urinary cadmium levels >20 μg/g creatinine and in men, premenopausal women, and postmenopausal women with blood cadmium levels >20 μg/L (Nordberg et al. 2002). An increase in bone fractures was observed in males and females over the age of 40 years living in the area of high cadmium exposure (mean urinary cadmium levels in the area were 9.20 and 12.86 μg/g creatinine in the males and females, respectively) (Wang et al. 2003). A significant dose-response relationship between urinary cadmium levels and the prevalence of osteoporosis was observed (Jin et al. 2004b; Wang et al. 2003; Zhu et al. 2004); the Jin et al. (2004b) study found that 23 of the 31 subjects with osteoporosis also exhibited signs of renal dysfunction. A subsequent study by this group examined 316 male and female residents living in areas with moderate or heavy cadmium pollution 10 years after the source of rice was switched to commercially available rice from nonpolluted areas (Chen et al. 2009). As in the earlier studies, significant decreases in forearm bone mineral density were observed in the women living in the moderately polluted area and in the men and women living in the heavily polluted areas. When the subjects were divided by age, decreases in bone mineral density were observed in women 60–69 or ≥70 years old in both cadmium polluted areas and in men ≥70 years living in the heavily polluted area. A significantly higher prevalence of osteoporosis was also observed in women living in the polluted areas and the prevalence increased with increasing urinary cadmium levels. In another study of this population, Chen et al. (2011) found a higher prevalence of osteoporosis (assessed in 2006) among women with renal dysfunction (urinary albumin >15 mg/g creatinine and urinary NAG ≥12 IU/g creatinine; renal biomarkers assessed in 1998) or tubular damage (urinary NAG ≥12 IU/g creatinine); no significant association was found for glomerular damage (urinary albumin ≥15 mg/g creatinine). Significantly lower bone mineral density levels were also found in women with tubular damage, as compared to those without tubular damage. In men, no significant associations between the prevalence of osteoporosis or bone mineral density and alterations in renal biomarkers were found. Chen et al. (2011) also compared the change in bone mineral damage from 1998 to

2006 in subjects with and without evidence of kidney damage and found a significantly greater decrease in bone mineral damage among women with tubular damage. In a study of adults living near an industrial complex in Korea, significant associations between high urinary cadmium levels (≥1.0 μg/g creatinine) and osteopenia were observed in males and females (Shin et al. 2011). Bone mineral density was also negatively associated with urinary cadmium levels.

In a substudy of a population-based health survey in Sweden (Engström et al. 2009), a significantly lower bone mineral density was observed in postmenopausal women with elevated urinary cadmium levels (median of 1.1 μg/g creatinine, 5–95th percentile of 0.69–1.7 μg/g creatinine) as compared to women with low urinary cadmium levels (median of 0.36 μg/g creatinine; 5–95th percentile of 0.18–0.73 μg/g creatinine). Significant decreases in serum parathyroid hormone levels and increases in urinary deoxypyridinoline levels (indicative of increased bone resorption) were also found in the high urinary cadmium group; however, there were no significant alterations in serum 1,25-dihydroxyvitamin D levels Significant elevations in biomarkers of renal dysfunction (urinary NAG and pHC and estimated glomerular filtration rate) were also in the high urinary cadmium group. In the U.S. general population (using data collected during NHANES III, 1988–1994), a significant association was found between urinary cadmium levels and osteopenia and osteoporosis among adults with urinary cadmium levels of >1 μg/g creatinine (Wu et al. 2010). Using the same NHANES data set, Gallagher et al. (2008) found a 43% increased risk of osteoporosis (hip bone mineral density defined) (odds ratio of 1.43; 95% CI of 1.02–2.00) among women ≥50 years of age with urinary cadmium levels of 0.50–1.00 μg/g creatinine, as compared to women with urinary cadmium levels of <0.50 μg/g creatinine.

[End of text from ATSDR (2012)]

4.7.2.2.2 Inhalation exposure

Strong evidence is available that bone is one of the main target organs of cadmium toxicity following extended inhalation exposure. The effects are similar to those seen following oral exposure (see Section 4.7.2.2.1). Study summaries from ATSDR (2012) are reproduced below.

[Start of text from ATSDR (2012)]

Case studies indicate that calcium deficiency, osteoporosis, or osteomalacia can develop in some workers after long-term occupational exposure to high levels of cadmium (Adams et al. 1969; Blainey et al. 1980; Bonnell 1955; Kazantzis 1979; Scott et al. 1980).

[End of text from ATSDR (2012)]

4.7.3 Other relevant information

4.7.4 Short summary and overall relevance of the provided information on specific target organ toxicity – repeated exposure

In humans, significant associations between cadmium levels in urine and biomarkers for kidney damage, i.e. excretion of low molecular weight proteins (such as β2-microglobulin, human complex forming glycoprotein (pHC) (also referred to as α1-microglobulin), and retinol binding protein), increased levels of intracellular enzymes (for example, N-acetyl-β-glucosaminidase (NAG)) and increased excretion of calcium), or significant increases in the prevalence of abnormal levels of these biomarkers, have been observed in numerous reliable studies of workers occupationally exposed to cadmium (Roels et al., 1991; Verschoor et al., 1987; Toffoletto et al., 1992; Shaikh et

al., 1987; Bernard et al., 1990; Kawada et al., 1989; Roels et al., 1993; Järup and Elinder, 1994; Jakubowski et al., 1987; Elinder et al., 1985a; Chia et al., 1992; Chen et al., 2006a, b; Jakubowski et al., 1992; Järup et al., 1988; Thun et al., 1989; Falck et al., 1983) and in numerous reliable studies of people living in areas contaminated with cadmium (Buchet et al., 1990; Järup et al., 2000; Noonan et al., 2002; Nogawa et al., 1989; Yamanaka et al., 1998; Oo et al., 2000; Suwazono et al., 2000; Jin et al., 2002; Jin et al., 2004a). Hence, relevant information on kidney toxicity of cadmium after oral and inhalation repeated exposure is available in humans and, accordingly, the dossier submitter considers that there is sufficient evidence to conclude that cadmium is toxic to the kidney in humans.

In humans, the occurrence of osteomalacia, osteoporosis, bone fractures and decreased bone mineral density have been established in numerous reliable studies of populations exposed to elevated levels of cadmium in the diet (Åkesson et al., 2005; Alfvén et al., 2000, 2002, 2004; Staessen et al., 1999; Schutte et al., 2008; Trzcinka-Ochocka et al., 2010; Nordberg et al., 2002; Wang et al., 2003; Jin et al., 2004b; Zhu et al., 2004; Chen et al., 2009, 2011; Shin et al., 2011; Engström et al., 2009; Wu et al., 2010; Gallagher et al., 2008), and similar effects have been observed in in reliable case studies of workers occupationally exposed to cadmium (Adams et al. 1969; Blainey et al. 1980; Bonnell 1955; Kazantzis 1979; Scott et al. 1980). Hence, relevant information on bone toxicity of cadmium after oral and inhalation repeated exposure is available in humans and, accordingly, the dossier submitter considers that there is sufficient evidence to conclude that cadmium is toxic to bone in humans.

In this connection, the dossier submitter would like to point out that it is discussed in the literature whether or not effects on bone are linked to effects on kidney, since the occurrence of effects on bone usually are recorded at the same dose level as effects on kidney (see ATSDR, 2012). In a recent publication by Åkesson et al. (2014) it is concluded that available data point toward a direct effect of cadmium on bone, since low-level environmental exposure to cadmium seems to mobilise minerals from bone, even in the absence of cadmium-induced renal tubular dysfunction.

In mammalian toxicity, the toxicity of cadmium is regarded to result from the intrinsic properties of the Cd^{2+} ion. As outlined in Section 4, it is reasonable to assume that the Cd^{2+} ion is bioavailable after oral and inhalation exposure of cadmium hydroxide. Hence, the toxic effects of cadmium observed in the studies summarised above are relevant also for cadmium hydroxide. Accordingly, it is concluded that cadmium hydroxide is toxic to kidney and bone in humans after oral and inhalation repeated exposure.

4.7.5 Comparison with the CLP criteria

According to the criteria in the CLP regulation, Annex I: 3.9.2.2, classification in Category 1 is reserved for substances that have produced significant toxicity in humans or that, on the basis of evidence from studies in experimental animals, can be presumed to have the potential to produce significant toxicity in humans following repeated exposure. Further, in Annex I: 3.9.2.10.2 of the CLP regulation it is stated tate that, when well-substantiated human data are available showing a specific target organ toxic effect that can be reliably attributed to repeated or prolonged exposure to a substance, the substance shall normally be classified. Positive human data, regardless of probable dose, predominates over animal data. On consideration of the human data referred to in this CLH report, they are considered to demonstrate significant toxicity in humans in kidney and bone.

In view of these considerations, the evidence referred to is deemed to match the criteria for classification of cadmium hydroxide in Category 1 (kidney and bone) for specific target organ toxicity-repeated exposure.

Where no evidence is available from human studies, or from anmimal studies that can support a presumption that significant toxicity in humans will be produced following repeated exposure, classification in Category 2 is based on animal studies providing evidence that a substance can be presumed to have the potential to be harmful to human health following repeated exposure. Since evidence for significant toxicity is available from human studies, classification in Category 2 is not justified.

The available evidence shows that cadmium toxicity is produced following oral or inhalation exposure. Data supporting that other routes of exposure would not produce toxicity is not available, and thus no route of exposure should be specified.

4.7.6 Conclusions on classification and labelling for STOT RE

Cadmium hydroxide should be classified in STOT RE 1 (kidney, bone); H372.

4.8 Germ cell mutagenicity (Mutagenicity)

In mammalian toxicity, the toxicity of cadmium salts is regarded to result from the intrinsic properties of the Cd^{2+} ion. Therefore, the term cadmium used in this section refers to the Cd^{2+} ion.

4.8.1.1 Non-human information

4.8.1.1.1 In vitro data

Studies on the mutagenic potential of cadmium *in vitro* have been reviewed by the International Agency for Research on Cancer (IARC, 1993, 2012) and the Agency for Toxic Substances and Disease Registry (ATSDR, 2012). The available data show that cadmium induces chromosome aberrations and gene mutations in cultured mammalian cells, while most studies on the induction of gene mutations in bacteria produced negative results. This overall picture of the results is reflected in the conclusions presented in the reviews referred to above, which involve that cadmium causes chromosome aberrations and gene mutations in mammalian cells *in vitro*. The dossier submitter agrees with this conclusion.

4.8.1.1.2 In vivo data

Table 12: Summary table of relevant in vivo mutagenicity/genotoxicity studies

Method	Results	Remarks	Reference
• Test material: cadmium chloride • Study type: bone-marrow chromosome aberration test, bone-marrow micronucleus test and sister chromatid exchange test in bone-marrow • Test animals: male Swiss albino mice • Administration: intraperitoneal injection • Doses: 0, 0.42, 0.84, 1.68, 3.37 or 6.75 mg/kg bw	• Bone-marrow chromosome aberration test: positive • Bone-marrow micronucleus test: positive • Sister chromatid exchange test in bone-marrow: positive	• Key study • Reliability code: 2 • Experimental result	Mukherjee et al. (1988)
• Test material: cadmium chloride • Study type: bone-marrow chromosome aberration test, bone-marrow micronucleus test, sister chromatid exchange test in bone-marrow and spermatogonial chromosome aberration test • Test animals: white Swiss mice • Administration: intraperitoneal injection • Doses: 0, 1.9, 5.7 or 9.5 mg/kg bw (bone-marrow chromosome aberration test); 0, 1.9, 5.7 or 7.6 mg/kg bw (micronucleus test and sister chromatid exchange test); 0, 0.9, 1.9, 5.7 or 9.5 mg/kg bw (spermatogonial chromosome aberration test)	• Bone-marrow chromosome aberration test: positive • Bone-marrow micronucleus test: positive • Sister chromatid exchange test in bone-marrow: positive • Spermatogonial chromosome aberration test: positive	• Key study • Reliability code: 2 • Experimental result	Fahmy and Aly (2000)
• Test material: cadmium chloride • Study type: bone-marrow micronucleus test • Test animals: male Swiss albino mice • Administration: intraperitoneal injection • Doses: 0, 0.025, 0.05, 0.1, 0.25, 0.5, 1.0 or 2.0 mg/kg bw	• Positive	• Key study • Reliability code: 2 • Experimental result	Jagetia and Adiga (1994)
• Test material: cadmium chloride • Study type: erythrocyte micronucleus assay and alkaline comet assay • Test animals: Wistar rats • Administration: oral or subcutaneous injection • Doses: 0.5 mg/kg bw daily for 9	• Erythrocyte micronucleus test: positive • Alkaline comet assay: equivocal	• Key study • Reliability code: 2 • Experimental result	Kašuba et al. (2002)

days (oral) or 0.5 mg/kg bw (single subcutaneous injection)			
• Test material: cadmium chloride • Study type: alkaline comet assay in nasal epithelial cells, lung, whole blood, liver, kidney, bone marrow, brain and testicle • Test animals: male CD-1 mice • Administration: inhalation • Doses: 0.08 µg/cm^3,60 minutes inhalation twice a week (for exposure groups 2-4 below); four exposure groups, i.e. 1 (single inhalation), 2 (two weeks of exposure, three inhalations), 3 (three weeks of exposure, five inhalations), 4 (four weeks of exposure, seven inhalations)	Positive in all tissues	• Key study • Reliability code: 2 • Experimental result	Valverde et al. (2000)
• Test material: cadmium chloride • Study type: alkaline comet assay • Test animals: male Swiss Albino mice • Administration: oral • Doses: 0, 0.5, 1.0, 2.0, 4.0, 8.0, 16.0, 32.0, 64.0 or 128.0 mg/kg bw	Positive	• Key study • Reliability code: 2 • Experimental result	Devi et al. (2001)
• Test material: cadmium chloride • Study type: oocyte aneuploidy test • Test animals: female golden hamsters • Administration: subcutaneous injection • Doses: 0, 1, 2 or 4 mg/kg bw	Positive	• Key study • Reliability code: 2 • Experimental result	Watanabe et al. (1979)
• Test material: cadmium chloride • Study type: blastocyst aneuploidy test • Test animals: female ddY/F mice • Administration: subcutaneous injection • Doses: 0, 1.5 or 3.0 mg/kg bw	Positive	• Key study • Reliability code: 2 • Experimental result	Watanabe and Endo (1982)
• Test material: cadmium chloride • Study type: oocyte aneuploidy test • Test animals: female CD-1 mice • Administration: subcutaneous injection • Doses: 0, 2, 4 or 6 mg/kg bw	Negative	• Key study • Reliability code: 2 • Experimental result	Mailhes et al. (1988)
• Test material: cadmium chloride • Study type: spermatocyte	Positive	• Key study • Reliability code: 2	Miller and Adler (1992)

aneuploidy test • Test animals: male (102/E1 x C3H/E1)F_1 mice • Administration: intraperitoneal injection • Doses: 0, 1, 3 or 6 mg/kg bw		• Experimental result	
• Test material: cadmium chloride • Study type: dominant lethal test • Test animals: male ICR/Ha Swiss mice • Administration: intraperitoneal injection • Doses: 5.4 or 7.0 mg/kg bw (one experiment) and 1.35 or 2.70 mg/kg bw (another experiment)	Negative	• Key study • Reliability code: 2 • Experimental result	Epstein et al. (1972)
• Test material: cadmium chloride • Study type: dominant lethal test and heritable translocation test • Test animals: male BALB/*c* mice • Administration: intraperitoneal injection • Doses: 0 or 1.75 mg/kg bw	• Dominant lethal test: negative • Heritable translocation test: negative	• Key study • Reliability code: 2 • Experimental result	Gilliavod and Léonard (1975)
• Test material: cadmium chloride • Study type: dominant lethal test • Test animals: female (101 x C_3H)F_1 mice • Administration: intraperitoneal injection • Doses: 0 or 2 mg/kg bw	• Dominant lethal test: negative	• Key study • Reliability code: 2 • Experimental result	Suter (1975)
• Test material: cadmium chloride • Study type: dominant lethal test • Test animals: male Sprague-Dawley rats • Administration: oral • Doses: 0, 0.1, 1 or 10 mg/kg bw/day for 9 weeks	• Dominant lethal test: negative	• Key study • Reliability code: 2 • Experimental result	Sutou et al. (1980a, 1980b)

Studies in somatic cells

In a study by Mukherjee et al. (1988), the mutagenicity/genotoxicity of cadmium in male Swiss albino mice exposed to cadmium chloride by intraperitoneal injection was evaluated using the bone-marrow chromosome aberration test, the bone-marrow micronucleus test and the sister chromatid exchange test in bone-marrow. Mice (5 per dose group in the chromosome aberration test and sister chromatid exchange test; 4 per dose/sampling group in the micronucleus test), 8-10 weeks old, were administered a dose of cadmium chloride of 0, 0.42, 0.84, 1.68, 3.37 or 6.75 mg/kg bw. Mitomycin C was used as a positive control.

In the chromosome aberration test, bone marrow was sampled 24 hours after the intraperitoneal injection of cadmium chloride. Scoring of chromosome aberrations was done in 60 metaphase cells

(only with 40 chromosomes) per animal. The frequency of metaphases with chromosome aberrations (gaps excluded) at the doses 0, 0.42, 0.84, 1.68, 3.37 and 6.75 mg/kg bw was 0.996, 4.32, 5.12, 5.60 and 6.6 %, respectively, and the number of chromosome aberrations per cell at the corresponding concentrations was 0.009, 0.043, 0.0512, 0.056, 0.066 and 0.093, respectively. The increases with dose in the frequency of cells with chromosome aberrations and in the number of chromosome aberrations per cell were statistically significant (P<0.05), as were pairwise comparisons between the negative control and single dose groups as regards the number of chromosome aberrations per cell.

In the micronucleus test, bone marrow was sampled 24 and 48 hours after the intraperitoneal injection of cadmium chloride. From each animal 500 polychromatic erythrocytes were scored for the presence of micronuclei, and 1000 erythrocytes per animal were scored to determine the ratio of PCE/NCE (polychromatic/normochromatic erythrocytes) as a measure of cytotoxicity. At the dose of 0, 0.42, 0.84, 1.68, 3.37 and 6.75 mg/kg bw the frequency of polychromatic erythrocytes with micronuclei at the sampling time 24 hours was 0.2, 0.25, 0.30, 0.35, 0.45 and 0.60 %, respectively, and at the sampling time 48 hours the frequency at the corresponding doses was 0.15, 0.20, 0.25, 0.30, 0.35 and 0.45 %, respectively. At both sampling times the increase with dose in the frequency of polychromatic erythrocytes with micronuclei were statistically significant (P<0.05), as was the pairwise comparison between the negative control and the 6.75 mg/kg bw dose group. No statistically significant effects on the ratio of PCE/NCE were observed.

In the sister chromatid exchange test, bone-marrow cells were sampled 24 hour after the intraperitoneal injection of cadmium chloride. Examination of sister chromatid exchanges was done in 20 metaphase cells (only with 40 chromosomes) per animal. To evaluate effects on cell proliferation, frequencies of first-, second- and third-generation metaphases was determined in 100 consecutive metaphases per animal to calculate a proliferation rate index. At the dose of 0, 0.42, 0.84, 1.68, 3.37 and 6.75 mg/kg bw the number of sister chromatid exchanges per cell was 2.30, 2.79, 3.07, 3.50, 4.82 and 5.53, respectively. The increase with dose in the number of sister chromatid exchanges per cell was statistically significant (P<0.0001). Pairwise comparison between the negative control and single dose groups showed that the increases in the number of sister chromatid exchanges per cell were statistically significant (P<0.05) for all doses except the lowest (0.42 mg/kg bw). No statistically significant effects on bone marrow cell replication were established in the analyses of the proliferation rate index.

In a study by Fahmy and Aly (2000), the mutagenicity/genotoxicity of cadmium in white Swiss mice exposed to cadmium chloride by intraperitoneal injection was evaluated using the bone-marrow chromosome aberration test (8-12 weeks old mice), the bone-marrow micronucleus test (6-8 weeks old mice) and the sister chromatid exchange test in bone-marrow (3-4 months old mice). In the chromosome aberration test, mice (5 per dose group) were administered a single dose of cadmium chloride of 0, 1.9, 5.7 or 9.5 mg/kg bw, and in the micronucleus test and the sister chromatid exchange tests, mice (5 per dose group) were administered a single dose of cadmium chloride of 0, 1.9, 5.7 or 7.6 mg/kg bw, and

In the bone-marrow chromosome aberration test, bone marrow was sampled 24 hours after the intraperitoneal injection of cadmium chloride. For the treatment with the dose 9.5 mg/kg bw, additional sampling was done at 12 and 48 hours. Mitomycin *c* was used as a positive control. Scoring of chromosome aberrations was done in 75-100 metaphase plates per animal. At the 24 hours sampling time the frequency of metaphases with chromosome aberrations (gaps excluded) at the doses 0, 1.9, 5.7 and 9.5 mg/kg bw was 1.75, 3.28, 5.75 and 11.00 %, respectively. For the two highest doses the increase in the frequency of cells with chromosome aberrations was statistically significant (P<0.01) as compared to the negative control, and the values show that the increase was dose related. At the highest dose 9.5 mg/kg bw, the frequency of cells with chromosome aberrations

in the additional samples taken at 12 and 48 hours after treatment was 8.00 and 5.25 %, respectively. The increases were statistically significant (P<0.01) as compared to the negative control. However, both values were lower than 11.00 % observed for cells sampled 24 hours after the treatment. Polyploidy and endomitosis was observed in treated groups only.

In the bone-marrow micronucleus test, bone marrow was sampled 24 hours after the intraperitoneal injection of cadmium chloride. Mitomycin *c* was used as a positive control. A statistically significant increase in the frequency of polychromatic erythrocytes with micronuclei as compared to the negative control value of 0.57 % was observed at all doses of cadmium chloride, i.e. at 1.9, 5.7 and 7.6 mg/kg bw a frequency of 1.3 (P<0.05), 1.6 (P<0.05) and 2.1 (P<0.01) %, respectively, was observed. The values demonstrate that the increase was dose related. Bone marrow toxicity was induced at the two highest doses, as indicated by statistically significant increases in the frequency of polychromatic erythrocytes as compared to the negative control, confirming that the test substance reached the target cells.

In the sister chromatid exchange test, bone-marrow cells were sampled for examination for sister chromatid exchanges in 40 well-spread metaphases per animal. Mitomycin *c* was used as a positive control. The mean number of sister chromatid exchanges per cell at the doses 0, 1.9, 5.7 and 7.6 mg/kg bw was 4.6, 5.44, 6.67 and 7.35. The increase in the mean number of sister chromatid exchanges per cell was statistically significant at the mid (P<0.05) and high (P<0.01) dose as compared to the negative control, and the values show that the increase was dose related.

In a study by Jagetia and Adiga (1994), the mutagenicity of cadmium in male Swiss albino mice exposed to cadmium chloride by intraperitoneal injection was evaluated by the bone-marrow micronucleus test. Mice (4 per exposure group), 6-8 weeks old, were administered a dose of cadmium chloride of 0, 0.025, 0.05, 0.1, 0.25, 0.5, 1.0 or 2.0 mg/kg bw. Bone marrow was sampled from the animals at 24 hours after the administration of cadmium chloride. A minimum of 2000 polychromatic erythrocytes in each animal were scored for the presence of micronuclei, and at least 4000 erythrocytes per animal were scored to determine the ratio of PCE/NCE (polychromatic/normochromatic erythrocytes) as a measure of cytotoxicity. At the dose of 0, 0.025, 0.05, 0.1, 0.25, 0.5, 1.0 and 2.0 mg/kg bw the frequency of polychromatic erythrocytes with micronuclei was 2.28, 3.41, 4.68, 5.34, 6.46, 7.00, 7.90 and 8.67 per 1000 cells, respectively. The frequency increased in a dose-related manner. In comparisons with the negative control, statistically significant increases were established at 0.05 mg/kg bw (P<0.05) and at 0.1, 0.25, 0.5, 1.0 and 2.0 mg/kg bw (P<0.01). A dose-related decline in the PCE/NCE ratio was observed, and the decrease was statistically significant at 0.25 mg/kg bw (1.08) and higher doses (0.87, 0.85, 0.80), as compared to the negative control (1.40).

In a study by Kašuba et al. (2002), the mutagenicity/genotoxicity of cadmium in 6 days old suckling Wistar rats exposed orally to cadmium chloride and in 5 days old suckling Wistar rats exposed subcutaneously to cadmium chloride was evaluated with the erythrocyte micronucleus assay and the alkaline comet assay. Rats (10 per dose group) were orally administered daily doses of cadmium of 0.5 mg/kg bw as cadmium chloride for 9 days, or subcutaneously administered a single injection cadmium of 0.5 mg/kg bw as cadmium chloride. Rats were sacrificed at the age of 16 days, whereupon blood was sampled for analyses with the erythrocyte micronucleus assay and the comet assay.

In the micronucleus assay, 10 animals were analysed in each exposed group and scoring of micronuclei was done in 2000 reticulocytes per animal. In animals exposed to cadmium chloride, a statistically significant (P<0.05) increase in the mean number of micronuclei was observed as compared to the negative control (5 animals analysed). The mean number of micronuclei was 16.6 and 14.3 in orally and subcutaneously exposed groups, respectively, and 3.2 in the negative control.

In the comet assay, 4 orally exposed and 3 subcutaneously exposed animals were analysed and scoring of comet tail intensity and comet tail length was done in 100 cells per animal. No increase in comet tail intensity was observed in groups exposed to cadmium chloride as compared to the negative control (5 animals analysed). However, a statistically significant ($P<0.05$) increase in comet tail length was observed in exposed groups as compared to the negative control. The comet tail length was 59.68 and 58.42 in orally and subcutaneously exposed groups, and 21.17 in the negative control. Due to the lack of an increase in tail intensity, the result of the study is considered to be equivocal.

In a study by Valverde et al. (2000), the genotoxicity of cadmium in male CD-1 mice exposed to cadmium chloride by inhalation was evaluated by the comet assay in nasal epithelial cells, lung, whole blood, liver, kidney, bone marrow and brain. Mice (4 per exposure group), 45 days old, were exposed to cadmium chloride at the concentration of 0.08 µg/cm^3. The duration of each inhalation treatment was 60 minutes, and groups receiving multiple treatments were treated twice a week. The study involved four exposure groups, i.e. 1, single inhalation; 2, two weeks of exposure, three inhalations; 3, three weeks of exposure, five inhalations; 4, four weeks of exposure, seven inhalations. For each group, two control animals exposed to deionised water for the same time were used. Animals were sacrificed 24 hours after the last treatment, and immediately thereafter blood was sampled and the nasal septum, lung, liver, kidney, femur and brain were removed. Scoring of comet tail length as a measure of DNA damage was done in 100 cells/tissue/animal.

After the first exposure, a statistically significant increase in comet tail length was observed in all tissues except the kidney, in which a statistically significant increase was first observed after two weeks of exposure. In the nasal epithelial cells, lung, bone marrow and brain the level of DNA damage remained rather constant during the exposure period of four weeks, while in the liver, kidney and leucocytes a remarkable increase in DNA damage was observed in the last week of exposure. The viability of cells was >80 % in all tissues as determined by the trypan blue exclusion technique.

In a study by Devi et al. (2001), the genotoxicity of cadmium in male Swiss Albino mice exposed to cadmium chloride by oral intubation was evaluated with the alkaline comet assay. Mice (5 per dose group), four weeks of age, were administered a single dose of cadmium chloride of 0, 0.5, 1.0, 2.0, 4.0, 8.0, 16.0, 32.0, 64.0 or 128.0 mg/kg bw. Cyclophosphamide was used as a positive control. Blood was sampled from the animals at 24, 48, 72 and 96 hours after the administration of cadmium chloride. Following completion of electrophoresis 50 leucocytes from each animal were scored for comet tail length as an estimate of DNA damage. Cell viability ranged from 92 to 96 %, as determined by the trypan blue exclusion technique. At the 24 hours sampling time a statistically significant ($P<0.05$) increase in mean comet tail-length was observed at all nine dose levels as compared to the negative control. Moreover, a clear dose-response relationship was observed, with an approximate 14-fold increase in mean comet tail-length at the highest dose as compared to the negative control. At the later sampling times, i.e. 48, 72 and 96 hours, a gradual decrease in mean comet tail-length with time was observed at all dose levels.

Studies in germ cells

In a study by Watanabe et al. (1979), the mutagenicity of cadmium in female golden hamsters (*Mesocricetus auratus*) exposed to cadmium chloride by subcutaneous injection was evaluated by scoring chromosome aberrations in meiotic metaphase II oocytes. Hamsters (20 per dose group), 8-12 weeks old, were administered a dose of cadmium chloride of 0, 1, 2 or 4 mg/kg bw 5 hours before the time of estimated ovulation. The animals were anaesthetised 12 hours after treatment, whereupon oocytes were extracted for cytogenetic analysis. Oocytes with adequately spread meiotic

metaphase II plates were examined for structural and numerical chromosome aberrations. In total, 536 oocytes from cadmium-treated groups and the control group were analysed. Only numerical chromosome aberrations were observed, i.e. hypohaploidy (n-1), hyperhaploidy (n+1) and diploidy (2n). In addition, meiotic anaphase I oocytes with two separate haploid chromosome sets and no degenerated polar body occurred in cadmium treated hamsters. The overall frequency of oocytes with numerical chromosome aberrations at the dose of 0, 1, 2 and 4 mg/kg bw was 2.8, 3.7, 27.6 and 26.3 %, respectively. The increase with dose in the overall frequency of oocytes with numerical chromosome aberrations was statistically significant ($P<0.01$). Pairwise comparison between the negative control and single dose groups showed that the increases in the overall frequency of oocytes with numerical chromosome aberrations were statistically significant ($P<0.01$) at the two highest doses. Statistically significant increases were also observed for specific chromosome aberrations, except hypohaploidy.

In a study by Watanabe and Endo (1982), the mutagenicity of cadmium in female ddY/F mice exposed to cadmium chloride by subcutaneous injection was evaluated by scoring blastocycts (preimplantation embryos) for numerical chromosome aberrations. Mice were induced to superovulate by treatment with pregnant mare's serum and human chorionic gonadotropin. Three hours after the superovulation treatment and mating, the females were administered a dose of cadmium chloride of 0, 1.5 or 3.0 mg/kg bw. Animals were sacrificed about 82 hours after mating, whereupon blastocysts were flushed from the uterus. Metaphase cells of the blastocycts were analysed for numerical chromosome aberrations. The frequency of blastocysts with numerical chromosome aberrations (hypodiploidy, hyperdiploidy and triploidy) at the dose of 0, 1.5 and 3.0 mg/kg bw was 3.3, 12.3 and 15.9 %, respectively. The increase in numerical chromosome aberrations was statistically significant ($P<0.05$) at the high dose.

In a study by Mailhes et al. (1988), the mutagenicity of cadmium in female CD-1 mice exposed to cadmium chloride by subcutaneous injection was evaluated by scoring hyperploidy in meiotic metaphase II oocytes. Mice (50 per dose group), 8-12 weeks old, were induced to superovulate by treatment with pregnant mare's serum and human chorionic gonadotropin, and immediately thereafter mice were administered a dose of cadmium chloride of 0, 2, 4 or 6 mg/kg bw. The animals were sacrificed 17 hours after treatment, whereupon oocytes were extracted for cytogenetic analysis. No increase in hyperploidy was observed.

In a study by Miller and Adler (1992), the mutagenicity of cadmium in male (102/E1 x C3H/E1)F_1 mice exposed to cadmium chloride by intraperitoneal injection was evaluated by scoring spermatocytes for aneuploidy. Mice (6 per dose group), 10-14 weeks old, were administered a dose of cadmium chloride of 0, 1, 3 or 6 mg/kg bw. Colcemid and econazole were used as positive controls. Germ cells were sampled from the animals 6, 14 and 22 hours after the intraperitoneal injection of cadmium chloride. Scoring of hypoploidy and hyperploidy was done in 100 meiotic metaphase II cells per animal. With the cadmium chloride doses of 1, 3 and 6 mg/kg bw, 0.7-0.8 % of the meiotic metaphase II cells had more than 20 chromosomes, i.e. were hyperploid, compared to 0.3 % in the negative control. For none of the individual dose groups a statistically significant difference from the frequency in the positive control group could be demonstrated, but a statistically significant ($P<0.05$) induction of hyperploidy was established when all dose groups were compared to the negative control group by the Cochran-Armitage trend test. A statistically significant ($P<0.01$) induction was also established for hypoploidy when all dose groups were compared to the negative control group by the trend test.

In a study by Fahmy and Aly (2000), the mutagenicity of cadmium in white Swiss mice exposed to cadmium chloride by intraperitoneal injection was evaluated by the spermatogonial chromosome aberration test. Mice (5 per dose group), 8-12 weeks old, were administered a single dose of cadmium chloride of 0, 0.9, 1.9, 5.7 or 9.5 mg/kg bw. Cyclophosphamide was used as a positive

control. Germ cells were sampled from the animals 12 days after the intraperitoneal injection of cadmium chloride. Scoring of chromosome aberrations was done in 75-100 metaphase plates per animal. The results showed that male mice spermatogenesis is sensitive to cadmium chloride, as demonstrated by reduction in the number of spermatocytes at the lower doses and failure of spermination at the highest dose of 9.5 mg/kg bw. The frequency of spermatocytes with chromosome aberrations (X-Y univalents, autosomal univalent, fragments and translocations) at the doses 0, 0.9, 1.9 and 5.7 mg/kg bw was 4.0, 4.25, 6.0 and 8.5 %, respectively. The increase in spermatocytes with chromosome aberrations was statistically significant ($P<0.05$) at the dose of 5.7 mg/kg bw. There was an increase in both numerical and structural aberrations; however the majority of the aberrations were numerical.

In a study by Epstein et al. (1972), the mutagenicity of cadmium in male ICR/Ha Swiss mice exposed to cadmium chloride by intraperitoneal injection was evaluated by the dominant lethal test. Male mice (7 and 9 in the low and high dose group, respectively), 8-10 weeks old, were in one experiment administered a dose of cadmium chloride of 5.4 or 7.0 mg/kg bw and, in another experiment, 1.35 or 2.70 mg/kg bw. The negative control group consisted of 10 males. Each male was mated with 3 untreated females, 8-10 weeks old, which were replaced weekly for 8 consecutive weeks. Females were dissected and analysed. No increase in dominant lethals was observed in any of the experiments.

In a study by Gilliavod and Léonard (1975), the mutagenicity of cadmium in male BALB/*c* mice exposed to cadmium chloride by intraperitoneal injection was evaluated with the dominant lethal test and the heritable translocation assay. Male mice (number not specified), 11-13 weeks old, were administered a dose of cadmium chloride of 0 or 1.75 mg/kg bw. In the dominant lethal test each male was mated with 3 untreated females (age not specified), which were replaced weekly for 3 consecutive weeks. Females were dissected and analysed. No increase in dominant lethals was observed. In the heritable translocation assay, germ cells were sampled from 120 F_1 males from matings between cadmium chloride treated males and untreated females. From each F_1 male 25 spermatocytes were analysed for the occurrence of translocations. No translocations were observed.

In a study by Suter (1975), the mutagenicity of cadmium in female (101 x C_3H)F_1 mice exposed to cadmium chloride by intraperitoneal injection was evaluated by the dominant lethal test. Mice (85 females), age not indicated, were administered a dose of cadmium chloride of 0 or 2 mg/kg bw and were mated 0.5-4.5 days later. A negative control group of 79 females was included. Females were sacrificed 12-15 days after copulation and were then dissected and analysed. No increase in dominant lethals was observed.

In a study by Sutou et al. (1980a, 1980b), the mutagenicity of cadmium in male Sprague-Dawley rats orally exposed to cadmium chloride was evaluated using the dominant lethal test. Rats (14 per dose group), 4 weeks old, were administrated a dose of cadmium chloride of 0, 0.1, 1 or 10 mg/kg bw/day for 9 weeks and were then mated with 2 females per week for 6 weeks. Pregnant females were sacrificed on the 13th day of gestation and were thereafter dissected and analysed. No increase in dominant lethals was observed.

In a study by Valverde et al. (2000), the genotoxicity of cadmium in male CD-1 mice exposed to cadmium chloride by inhalation was evaluated by the comet assay in the testicle. Mice (4 per exposure group), 45 days old, were exposed to cadmium chloride at the concentration of 0.08 µg/cm^3. The duration of each inhalation treatment was 60 minutes, and groups receiving multiple treatments were treated twice a week. The study involved four exposure groups, i.e. 1, single inhalation; 2, two weeks of exposure, three inhalations; 3, three weeks of exposure, five inhalations; 4, four weeks of exposure, seven inhalations. For each group, two control animals exposed to deionised water for the same time were used. Animals were sacrificed 24 hours after the last

treatment, and immediately thereafter the testicles were removed. Scoring of comet tail length as a measure of DNA damage was done in 100 cells/animal.

After the first exposure, a statistically significant increase in comet tail length was observed. The level of DNA damage remained rather constant during the exposure period of four weeks. The viability of cells was >80 % as determined by the trypan blue exclusion technique.

4.8.1.2 Human information

To investigate the mutagenic potential of cadmium in somatic cells (peripheral blood lymphocytes) in humans, studies have been performed in workers from different occupational fields (i.e. cadmium plant; alkaline battery factory; manufacture of cadmium pigments; production of cadmium, zinc, silver and copper alloys; smelter; zinc industry; zinc smelting plant), and in people living in cadmium-polluted areas. In some of the studies an increase in the frequency of chromosome aberrations was observed. However, from the evaluation of the studies in the EU RAR (2007) it is apparent that the studies were afflicted with shortcomings regarding study designs, exposure assessments or consideration of confounding factors limiting their value as evidence for a causal relationship between exposure to cadmium and mutagenicity. The dossier submitter agrees with the view presented in the EU RAR (2007) regarding the imperfect quality of the studies. Hence, the data would not be sufficient for the purpose of classification according to CLP and, therefore, summaries of the studies have not been included in the present CLH report.

No studies on the mutagenic potential of cadmium in germ cells of humans are available.

4.8.2 Other relevant information

4.8.3 Summary and discussion of mutagenicity

The mutagenic potential of cadmium has been investigated *in vitro* in bacterial cells and mammalian cells, and *in vivo* in somatic cells of mice and rats and in germ cells of mice, rats and golden hamsters. Studies in somatic cells of humans were generally afflicted with shortcomings limiting their value as evidence for a causal relationship between exposure to cadmium and mutagenicity. Hence, the data would not be sufficient for the purpose of classification according to CLP and, therefore, the studies have not been evaluated in the present CLH report. No studies on the mutagenic potential of cadmium in germ cells of humans are available.

Results from studies *in vitro* showed that cadmium induces chromosome aberrations and gene mutations in cultured mammalian cells, while most studies on the induction of gene mutations in bacteria produced negative results (IARC, 1993, 2012; ATSDR, 2012).

Cadmium chloride induced chromosome aberrations in somatic cells *in vivo* after intraperitoneal injection, as demonstrated by positive results from cytogenetic studies in the bone marrow of mice (Mukherjee et al., 1988; Fahmy and Aly, 2000) and micronucleus studies in the bone marrow of mice (Mukherjee et al., 1988; Jagetia and Adiga, 1994; Fahmy and Aly, 2000). In rats, a micronucleus study in blood was positive after oral administration of cadmium chloride (Kasuba et al., 2002).

Cadmium chloride induced DNA damage in somatic cells *in vivo* detected by the alkaline comet assay, as demonstrated by positive results from a study in blood of mice after oral administration (Devi *et al*., 2001), and a study in nasal epithelial cells, lung, whole blood, liver, kidney, bone marrow and brain of mice exposed by inhalation (Valverde et al., 2000). One study in blood of orally exposed mice produced equivocal results (Kasuba et al., 2002).

Cadmium chloride induced sister chromatid exchanges in somatic cells *in vivo* after intraperitoneal injection, as demonstrated by positive results from studies in mice (Mukherjee et al., 1988; Fahmy and Aly, 2000).

Cadmium chloride induced numerical and structural chromosome aberrations in germ cells *in vivo*, as demonstrated by positive results from studies in mice exposed by intraperitoneal injection (Miller and Adler, 1992; Fahmy and Aly, 2000) and subcutaneous injection (Watanabe and Endo, 1982). One study on numerical chromosome aberrations in germ cells of mice exposed to cadmium chloride by subcutaneous injection was negative (Mailhes et al., 1988).

Cadmium chloride administered by intraperitoneal injection did not induce dominant lethals in germ cells of mice (Epstein et al., 1972; Gilliavod and Léonard, 1975; Suter, 1975) and rats (Sutou et al., 1980), or heritable translocations in mice (Gilliavod and Léonard, 1975).

The dossier submitter considers that there is sufficient evidence to conclude that cadmium induces structural chromosome aberrations and micronuclei in somatic cells *in vivo*, and numerical and structural chromosome aberrations in germ cells *in vivo*. The potential to induce numerical chromosome aberrations in germ cells, and observations of polyploidy and endomitosis in somatic cells, suggests that also the aneugenic potential of cadmium contributed to the induction of micronuclei observed in somatic cells. The potential of cadmium to induce chromosome aberrations was not detected in germ cells using the dominant lethal test. However, the dominant lethal test is generally considered to be rather insensitive.

The positive results from *in vivo* genotoxicity studies measuring the induction of DNA damage (comet assay) and sister chromatid exchanges in somatic cells are in agreement with the positive results from the *in vivo* mutagenicity studies referred to above.

In mammalian toxicity, the toxicity of cadmium salts is regarded to result from the intrinsic properties of the Cd^{2+} ion. As outlined in Section 4, it is reasonable to assume that the Cd^{2+} ion is bioavailable after oral and inhalation exposure of cadmium hydroxide. Hence, the mutagenic effects of other cadmium salts, such as cadmium chloride used in the studies summarised above, are relevant also for cadmium hydroxide. Accordingly, it is concluded that cadmium hydroxide is mutagenic in germ cells of experimental animals.

4.8.4 Comparison with criteria

According to the criteria in the CLP Regulation, Annex I: 3.5.2.2, classification in Category 1A is reserved for substances known to induce heritable mutations in the germ cells of humans. No studies on the mutagenic potential of cadmium in germ cells of humans are available. Therefore, classification in Category 1A is not justified.

Where no evidence from human studies is available, classification in Category 1B or 2 is based on the type of evidence that is available from animal studies and *in vitro* studies. Classification in Category 1B is for substances for which there are positive results from *in vivo* heritable germ cell mutagenicity tests in mammals; or positive results from *in vivo* somatic cell mutagenicity tests in mammals, in combination with some evidence that the substance has potential to cause mutations in germ cells; or positive results from tests showing mutagenic effects in the germ cells of humans, without demonstration of transmission to progeny (i.e. substances to be regarded as if they induce heritable mutations in the germ cells of humans). Classification in Category 2 is for substances for which there is positive evidence obtained from experiments in mammals and/or in some cases from *in vitro* experiments, obtained from somatic cell mutagenicity tests *in vivo* in mammals; or other *in vivo* somatic cell genotoxicity tests which are supported by positive results from *in vitro*

mutagenicity assays (i.e. substances which cause concern for humans owing to the possibility that they may induce heritable mutations in the germ cells of humans). On consideration of the *in vivo* data referred to in this CLH report, they are considered to demonstrate positive results from *in vivo* somatic cell mutagenicity tests in mammals, in combination with some evidence that the substance has potential to cause mutations in germ cells. This is based on the facts that structural chromosome aberrations were induced in somatic cells of mice, micronuclei were induced in somatic cells of mice and rats, and that numerical and structural chromosome aberrations were induced in the germ cells of mice.

In view of these considerations, the evidence referred to is deemed to match the criteria for classification of cadmium hydroxide as a Category 1B mutagen.

4.8.5 Conclusions on classification and labelling

Cadmium hydroxide should be classified in Muta. 1B (H340).

4.9 Carcinogenicity

In mammalian toxicity, the toxicity of cadmium salts is regarded to result from the intrinsic properties of the Cd^{2+} ion. Therefore, the term cadmium used in this section refers to the Cd^{2+} ion.

4.9.1 Non-human information

Table 13: Summary table of relevant carcinogenicity studies

Method	Results	Remarks	Reference
• Test material: cadmium chloride • Test animals: male Wistar (WF/NCr) rats • Administration: oral (diet) • Doses: 0, 25, 50, 100 and 200 ppm in the diet for 77 weeks	Positive: increases in the incidences of proliferative lesions in the prostate, leukemia (large granular lymphocytes) and testicular tumours (interstitial cell tumours).	• Key study • Reliability code: 2 • Experimental result	Waalkes and Rehm (1992)
• Test material: cadmium chloride • Test animals: male Wistar (TNO/W75) rats • Administration: inhalation • Doses: 0, 12.5, 25 and 50 µg/m^3 for 23 hours per day, 7 days a week for 18 months	Positive: increase in the incidence of primary lung carcinomas (mostly adenocarcinomas but also epidermoid carcinomas and mucoepidermoid carcinomas).	• Key study • Reliability code: 2 • Experimental result	Takenaka et al. (1983)
• Test materials: cadmium chloride, cadmium sulphate, cadmium sulphide, cadmium oxide dust and cadmium oxide fume • Test animals: Wistar (BOR-WISW) rats • Administration: inhalation • Doses: 0, 30 and 90 µg/m^3 (cadmium chloride, cadmium oxide dust); 0 and 90 µg/m^3 (cadmium sulphate); 0, 90, 270, 810 and 2430 µg/m^3 (cadmium sulphide); 0, 10 and 30 µg/m^3 (cadmium oxide fume) for 22 hours per day, 7 days a week for up to 18 months	Positive: all cadmium compounds increased the incidence of primary lung tumours (mostly adenomas and adenocarcinomas but bronchioalveolar adenomas and squamous-cell carcinomas were also observed in a few rats)	• Key study • Reliability code: 2 • Experimental result	Glaser et al. (1990)
• Test material: cadmium chloride, cadmium sulphate, cadmium sulphide, cadmium oxide dust and cadmium oxide fume • Test animals: female Han:NMRI mice, and male and female Hoe:SYHK Syrian golden hamsters • Administration: inhalation • Doses: 0, 30 and 90 µg/m^3 (cadmium chloride, cadmium sulphate); 0 and 90 µg/m^3 (cadmium sulphate); 0, 90, 270 and 1000 µg/m^3 (cadmium sulphide); 10, 30, 90 and 270 µg/m^3 (cadmium oxide dust); 10, 30 and 90 µg/m^3 (cadmium oxide fume); mice were exposed for 9 or 18 hours per day, 5 days a	• Mice: positive; cadmium oxide dust and cadmium oxide fume increased the incidence of lung tumours (histopathological types not reported) • Syrian golden hamster: negative	• Key study • Reliability code: 2 • Experimental result	Heinrich et al. (1989)

week for 6 to 69 weeks, and Syrian golden hamsters for 19 or 8 hours per day, 5 days a week for 13 to 65 weeks			

4.9.1.1 Carcinogenicity: oral

The effect of chronic dietary zinc deficiency on the carcinogenicity of cadmium given to male Wistar (WF/NCr) rats in the diet was evaluated in a study by Waalkes and Rehm (1992). Rats, two weeks of age, were exposed for 77 weeks to cadmium at 0, 25, 50, 100 and 200 ppm as cadmium chloride mixed with a zinc-adequate diet or a marginally zinc-deficient diet (28 rats/exposed group and 56 rats from pooled controls).

The incidence of proliferative lesions (hyperplasia and adenoma) in the prostate was significantly higher in rats exposed to 50 ppm cadmium in both the zinc-adequate group (22.7 %) and the zinc-deficient group (15.4 %), as compared to controls (1.9 %). A clear dose response of the proliferative lesions was not observed.

The incidence of leukaemia (large granular lymphocytes) was significantly higher in rats exposed to 50 and 100 ppm cadmium, but not 200 ppm, in the zinc-adequate group, as compared to controls. In the zinc-deficient group the incidence of leukaemia increased with the dose of cadmium, but the difference in incidence was statistically significant only for rats exposed to 200 ppm, as compared to controls. The incidence of leukaemia in controls was 5.4 %, and the highest incidence observed in a cadmium-exposed group was 28 %.

The incidence of testicular tumours (interstitial cell tumours) was significantly higher in rats exposed to 200 ppm cadmium in the zinc-adequate group (22.2 %), as compared to controls (3.6 %).

4.9.1.2 Carcinogenicity: inhalation

Rat

The carcinogenicity of cadmium in male Wistar (TNO/W75) rats after inhalation exposure to cadmium chloride was evaluated in a study by Takenaka et al. (1983). Rats, six weeks of age, were exposed for 23 hours per day, 7 days a week for 18 months to cadmium chloride aerosols with cadmium concentrations of 0, 12.5, 25 and 50 µg/m^3 (40 rats/exposed group and a control group of 41 rats). After the end of the exposure period, the rats were observed for an additional 13 months before the study was ended.

During the course of the study, autopsy of dead or dying rats was carried out as soon as possible after they had been detected. At the end of the study, surviving rats were sacrificed and autopsied. All rats were subjected to histopathological examination.

The incidence of primary lung carcinomas (mostly adenocarcinomas but also epidermoid carcinomas and mucoepidermoid carcinomas) showed an exposure-related increase starting at 20 months of the study. For all exposed groups the difference in incidence was statistically significant, as compared to the incidence in the control group. The incidences were 0 % (0/38), 15 % (6/39), 53 % (20/38) and 71 % (25/35) in the experimental groups exposed to aerosols with cadmium concentrations of 0, 12.5, 25 and 50 µg/m^3, respectively. Rats with multiple lung tumours were frequently observed, and several tumours showed metastases or were regionally invasive. The incidence of adenomatous hyperplasia was also increased by cadmium exposure.

In a study of similar design as the study by Takenaka *et al.* (1983) above, Glaser et al. (1990) evaluated the carcinogenicity of cadmium in male and female Wistar (BOR-WISW, formerly called TNO/W75) rats after inhalation exposure to cadmium chloride, cadmium sulphate, cadmium sulphide, cadmium oxide dust and cadmium oxide fume. Rats, nine weeks of age, were exposed for 22 hours per day, 7 days a week for up to 18 months to aerosols of the cadmium compounds with cadmium concentrations as shown in Table 14. A few experimental groups were exposed discontinuously for 40 hours a week for 6 months. These groups are not included in this study summary. After the end of the exposure period, groups of 20-40 rats were kept and observed until death or up to an additional 13 months, at which time the study was ended. The exposure and observation periods were terminated if mortality during these periods reached 25 % and 75 %, respectively. All rats were subjected to histopathological examination.

Table 14 Incidence of primary lung tumours in rats exposed to cadmium (adapted from Glaser et al. 1990)

Experimental group	Cadmium concentration in aerosol (µg/m^3)	Exposure period (months)	Observation period (months)	Animals with lung tumours/animals examined	Animals with lung tumours (%)
Males					
Control	0	0	31	0/40	0
Cadmium chloride	30	18	30	15/20	75
	90	6	30	11/20	55
Cadmium sulphate	90	14	31	11/20	55
Cadmium sulphide	90	18	30	17/20	85
	270	16	30	14/20	70
	810	7	30	11/20	55
	2430	4	30	7/16	44
Cadmium oxide dust	30	18	31	28/39	72
	90	7	31	12/39	31
Cadmium oxide fume	10	18	31	0/40	0
	30	18	31	8/38	21
Females					
Control	0	0	31	0/20	0
Cadmium chloride	30	18	31	13/18	72
	90	6	29	3/18	17
Cadmium sulphate	90	18	29	18/20	90
Cadmium sulphide	90	18	31	15/20	75
	270	16	30	16/19	84
	810	10	29	13/20	65

	2430	3	31	6/19	32
Cadmium oxide dust	30	18	31	15/20	75
	90	11	31	14/19	74

All cadmium compounds increased the incidence of primary lung tumours (mostly adenomas and adenocarcinomas but bronchioalveolar adenomas and squamous-cell carcinomas were also observed in a few rats) above that in controls (see Table 14). The highest incidence (90 %) was observed in females exposed to cadmium sulphate (90 µg/m^3). Generally, there was no difference between males and females.

Mouse

The carcinogenicity of cadmium in female Han:NMRI mice after inhalation exposure to cadmium chloride, cadmium sulphate, cadmium sulphide, cadmium oxide dust and cadmium oxide fume was evaluated in a study by Heinrich et al. (1989). Groups of 48 mice, age unspecified, were exposed for 9 or 18 hours per day, 5 days a week for 6 to 69 weeks to aerosols of the cadmium compounds with cadmium concentrations of 30 and 90 µg/m^3 (cadmium chloride), 30 and 90 µg/m^3 (cadmium sulphate), 90, 270 and 1000 µg/m^3 (cadmium sulphide), 10, 30, 90 and 270 µg/m^3 (cadmium oxide dust), and 10, 30 and 90 µg/m^3 (cadmium oxide fume). The total duration of experiments was 71-107 weeks. In some experimental groups the exposure was terminated when the mortality started to increase. All mice were subjected to histopathological examination.

Statistically significant increases in the incidence of lung tumours (histopathological types not reported) above that in the control group was observed in the experimental groups exposed to cadmium as cadmium oxide fumes at 30 µg/m^3 (29.6 % versus 20.0 % tumour bearing mice in the control group) and 90 µg/m^3 (34.0 % versus 14.6 % tumour bearing mice in the control group), and in the experimental group exposed to cadmium as cadmium oxide dust at 10 µg/m^3 (26.1 % versus 14.6 % tumour bearing mice in the control group).

Syrian hamster

The carcinogenicity of cadmium in male and female Hoe:SYHK Syrian golden hamsters after inhalation exposure to cadmium chloride, cadmium sulphate, cadmium sulphide, cadmium oxide dust and cadmium oxide fume was evaluated in a study by Heinrich et al. (1989). Groups of 24 male and 24 female Syrian hamsters, age unspecified, were exposed for 19 or 8 hours per day, 5 days a week for 13 to 65 weeks to aerosols of the cadmium compounds with cadmium concentrations of 30 and 90 µg/m^3 (cadmium chloride), 30 and 90 µg/m^3 (cadmium sulphate), 90, 270 and 1000 µg/m^3 (cadmium sulphide), 10, 30, 90 and 270 µg/m^3 (cadmium oxide dust), and 10, 30 and 90 µg/m^3 (cadmium oxide fume). The total duration of experiments was 60-113 weeks for males and 61-87 weeks for females. In some experimental groups the exposure was terminated when the mortality started to increase. All mice were subjected to histopathological examination.

In none of the exposed groups an increase in the incidence of lung tumours was observed. In only six of the exposed groups (males and females combined) was there one or, in one case, two animals with a papilloma or a polypoid adenoma of the trachea. One papilloma was also found in the control group.

4.9.1.3 Carcinogenicity: dermal

No studies were located regarding carcinogenicity after dermal exposure to cadmium compounds.

4.9.1.4 Carcinogenicity: other routes

Subcutaneous administration

The carcinogenicity of cadmium in DBA/2NCr and NFS/NCr mice after subcutaneous administration of cadmium chloride was evaluated in a study by Waalkes and Rehm (1994). Groups of 30-40 mice, 8 weeks old, were administered a dose of 0 or 40 µmol/kg bw once, or once per week for 16 weeks. Statistically significant increases in lymphomas, lung tumours and injection-site sarcomas were observed.

The carcinogenicity of cadmium in male Wistar [Crl:(WI)BR] rats after subcutaneous administration of cadmium chloride was evaluated in a study by Waalkes *et al.* (1988). Groups of 30 rats, 6 weeks old, were administered a single dose of 0, 10, 2.5, 5.0, 10.0, 20.0 or 40.0 µmol/kg bw. Statistically significant increases in injection-site sarcomas, testis (interstitial cell) tumours and prostate tumours in rats were observed.

4.9.2 Human information

To investigate the carcinogenic potential of cadmium in humans, several occupational cohort studies have been performed, involving workers in cadmium recovery plants, copper-cadmium alloys plants, nickel-cadmium batteries plants and cadmium processing plants. In some of the studies increases in lung cancer risk for the workers were observed. However, most of the studies were afflicted with shortcomings limiting their value as evidence for a causal relationship between exposure to cadmium and cancer, as concluded both in the EU RAR (2007) and the IARC Monograph Volume 100 (C) (2012). In particular, (i) lack of historical data on exposure to cadmium and the inability to classify workers according to a quantitative index of cumulative exposure, (ii) confounding effect of occupational exposure to other potential carcinogens (e.g. nickel, arsenic, welding fumes, mineral oils, lead, zinc, beryllium and other metals), and (iii) insufficient control of non-occupational cancer-risk factors, of which the most important is tobacco smoking, constrains the assessment of cancer risk from exposure to cadmium in the studies. The dossier submitter agrees with the view presented in the EU RAR (2007) and the IARC Monograph Volume 100 (C) (2012) regarding the imperfect quality of the studies and therefore concludes that the data of the studies would not be sufficient for classification with Carc. 1A. Accordingly, summaries of the occupational cohort studies would not add information decisive for the classification, and they have therefore not been included in the present CLH report.

Epidemiological studies on cadmium carcinogenicity assessing the risk for cancer in the prostate (occupational cohort studies, studies of people residing in cadmium-contaminated areas and case-control studies of individuals with prostate cancer), the kidney, the bladder, the breast and the endometrium (case-control studies) are reported in the EU RAR (2007) and the IARC Monograph Volume 100 (C) (2012). In some of the studies increases in cancer risks were observed that may be the result of an association with cadmium exposure. However, the studies suffer from shortcomings regarding study designs, exposure assessments or consideration of confounding factors, and therefore the data of the studies would not be sufficient for the purpose of classification. Accordingly, summaries of the studies would not add information decisive for the classification, and they have therefore not been included in the present CLH report.

Despite the shortcomings of the studies highlighted in the IARC Monograph Volume 100 (C) (2012), it is concluded in the monograph that there is sufficient evidence in humans for the carcinogenicity of cadmium and cadmium compounds. Notwithstanding this conclusion, the dossier submitter is of the opinion that the data of the available studies in humans would not be sufficient

for classification with Carc. 1A according to CLP, since the criteria for this classification require that it is largely based on human evidence from studies establishing a causal relationship between human exposure to a substance and the development of cancer (known human carcinogen). The view of the dossier submitter is that this requirement has not been met, since it cannot be ruled out with reasonable confidence that the positive association between the exposure to cadmium and cancer observed in some of the studies is a result of chance, bias or confounding.

4.9.3 Other relevant information

4.9.4 Summary and discussion of carcinogenicity

The carcinogenic potential of cadmium has been investigated in rats, mice and Syrian hamsters. To investigate this potential in humans, numerous epidemiological studies have been performed. The studies in humans were generally afflicted with shortcomings limiting their value as evidence for a causal relationship between exposure to cadmium and cancer. Hence, the data would not be sufficient for the purpose of classification according to CLP and, therefore, the studies have not been evaluated in the present CLH report.

In rats, oral exposure to cadmium chloride induced proliferative lesions (hyperplasia and adenoma) in the prostate, leukaemia (large granular lymphocytes) and testicular tumours (interstitial cell tumours) (Waalkes and Rehm, 1992).

In rats, inhalation exposure to cadmium chloride aerosols induced primary lung carcinomas (mostly adenocarcinomas but also epidermoid carcinomas and mucoepidermoid carcinomas) and adenomatous hyperplasia (Takenaka *et al.*, 1983).

In rats, cadmium chloride, cadmium sulphate, cadmium sulphide, cadmium oxide dust and cadmium oxide fume all induced primary lung tumours (mostly adenomas and adenocarcinomas but bronchioalveolar adenomas and squamous-cell carcinomas were also observed in a few rats) after inhalation exposure (Glaser et al., 1990).

In mice, cadmium oxide dust and cadmium oxide fume, but not cadmium chloride, cadmium sulphate, cadmium sulphide, induced lung tumours (histopathological types not reported) after inhalation exposure (Heinrich *et al.*, 1989).

In Syrian hamsters, cadmium chloride, cadmium sulphate, cadmium sulphide, cadmium oxide dust and cadmium oxide fume did not induce tumours after inhalation exposure (Heinrich *et al.*, 1989).

In mice, subcutaneous injection of cadmium chloride induced lymphomas, lung tumours and injection-site sarcomas (Waalkes and Rehm, 1994).

In rats, subcutaneous injection of cadmium chloride induced injection-site sarcomas, testis (interstitial cell) tumours and prostate tumours (Waalkes *et al.*, 1988).

The dossier submitter considers that there is sufficient evidence to conclude that cadmium is carcinogenic after oral and inhalation exposure in rats, and after inhalation exposure in mice. In mammalian toxicity, the toxicity of cadmium salts is regarded to result from the intrinsic properties of the Cd^{2+} ion. As outlined in Section 4, it is reasonable to assume that the Cd^{2+} ion is bioavailable after oral and inhalation exposure of cadmium hydroxide. Hence, the carcinogenic effects of other cadmium salts observed in the studies summarised above are relevant also for cadmium hydroxide. Accordingly, it is concluded that cadmium hydroxide is carcinogenic in experimental animals.

4.9.5 Comparison with criteria

According to the criteria in the CLP Regulation, Annex I: 3.6.2.1, classification in Category 1A is reserved for substances known to have carcinogenic potential for humans. Since the available studies in humans were generally afflicted with shortcomings limiting their value as evidence for a causal relationship between exposure to cadmium and cancer, the data are not of sufficient quality for the purpose of classification. Therefore, classification in Category 1A is not justified.

Where no evidence from human studies is available, classification in Category 1B or 2 is based on the strength of evidence from animal studies. Classification in Category 1B is for substances for which there is sufficient evidence to demonstrate animal carcinogenicity (presumed human carcinogen), and Category 2 is for substances for which there is limited evidence of carcinogenicity in animal studies (suspected human carcinogen). On consideration of the animal data referred to in this CLH report, they are considered to demonstrate sufficient evidence of carcinogenicity in animals. This is based on the facts that treatment related tumours were observed in two species (rat and mouse), in three different studies in one species (rat), in both sexes of one species (rat), and that tumours occurred at multiple sites and/or were of different types.

In view of these considerations, the evidence referred to is deemed to match the criteria for classification of cadmium hydroxide as a Category 1B carcinogen. There is no ground to specify any specific route of exposure for the classification.

4.9.6 Conclusions on classification and labelling

Cadmium hydroxide should be classified in Carc. 1B (H350).

4.10 Toxicity for reproduction

Not evaluated in this report.

4.11 Other effects

Not evaluated in this report.

5 ENVIRONMENTAL HAZARD ASSESSMENT

Environmental effects are not evaluated in this report.

6 OTHER INFORMATION

7 REFERENCES

Adams RG, Harrison JF and Scott P (1969) The development of cadmium-induced proteinuria, impaired renal function, and osteomalacia in alkaline battery workers. Q J Med 152:425-443.

Åkesson A, Lundh T, Vahter M, Bjellerup P, Lidfeldt J, Nerbrand C, Samsioe G, Strömberg U and Skerfving S (2005) Tubular and glomerular kidney effects in Swedish women with low environmental cadmium exposure. Environ Health Perspect 113(11):1627-1631.

Åkesson A, Barregard L, Bergdahl IA, Nordberg GF, Nordberg M and Skerfving S (2014) Non-renal effects and the risk assessment of environmental cadmium exposure. Environ Health Perspect http://dx.doi.org/10.1289/ehp.1307110.

Alfvén T, Elinder CG, Carlsson MD, Grubb A, Hellström L, Persson B, Pettersson C, Spång G, Schütz A and Järup L (2000) Low-level cadmium exposure and osteoporosis. J Bone Miner Res 15(8):1579-1586.

Alfvén T, Järup L and Elinder C (2002) Cadmium and lead in blood in relation to low bone mineral density and tubular proteinuria. (Erratum in: Environ Health Perspect 110(9):A505). Environ Health Perspect 110(7): 699-702.

Alfvén T, Elinder CG, Hellström L, Lagarde F and Järup L (2004) Cadmium exposure and distal forearm fractures. J Bone Miner Res 19(6):900-905.

ATSDR (Agency for Toxic Substances and Disease Registry) (1998) Toxicological Profile for Cadmium. U.S. Department of Health and Human Services.

ATSDR (Agency for Toxic Substances and Disease Registry) (2012) Toxicological Profile for Cadmium (Update). U.S. Department of Health and Human Services.

Bernard A, Buchet JP, Roels H, Masson P and Lauwerys R (1979). Renal excretion of proteins and enzymes in workers exposed to cadmium. Eur J Clin Invest 9:11-22.

Bernard AM, Roels H, Cardenas A Lauwerys R (1990) Assessment of urinary protein 1 and transferrin as early markers of cadmium nephrotoxicity. Br J Ind Med 47:559-565.

Blainey JD, Adams RG, Brewer DB and Harvey TC (1980) Cadmium-induced osteomalacia. Br J Ind Med 37:278-284.

Bonnell JA (1955) Emphysema and proteinuria in men casting copper-cadmium alloys. Br J Ind Med 12:181-197.

Buchet JP, Lauwerys R, Roels H, Bernard A, Bruaux P, Claeys F, Ducoffre G, de Plaen P, Staessen J, Amery A, et al. (1990) Renal effects of cadmium body burden of the general population. Lancet 336:699-702.

Chen L, Jin T, Huang B, Chang X, Lei L, Nordberg GF and Nordberg M (2006a) Plasma metallothionein antibody and cadmium-induced renal dysfunction in an occupation population in China. Toxicol Sci 91(1):104-112.

Chen L, Jin T, Huang B, Nordberg G and Nordberg M (2006b) Critical exposure level of cadmium for elevated urinary metallothionein: An occupational population study in China. Toxicol Appl Pharmacol 215(1):93-99.

Chen X, Zhu G, Jin T and Gu S (2009) Effects of cadmium on forearm bone density after reduction of exposure for 10 years in a Chinese population. Environ Int 35(8):1164-1168.

Chen X, Zhu G, Jin T, Lei L and Liang Y (2011) Bone mineral density is related with previous renal dysfunction caused by cadmium exposure. Environ Toxicol Pharmacol 32(1):46-53.

Chia KS, Tan AL, Chia SE, Ong CN and Jeyaratnam J (1992) Renal tubular function of cadmium exposed workers. Ann Acad Med Singapore 21(6):756-759.

Danish Environmental Protection Agency (2013) Survey of cadmium and cadmium compounds, A LOUS Review Report, Environmental Project No. 1471.

Devi KD, Banu BS, Mahboob M, Jamil K and Grover P (2001) In vivo genotoxic effect of cadmium chloride in mice leukocytes using comet assay. Teratog Carcinog Mutagen 21: 325-333.

Dunnick JK (1995). NTP technical report on toxicity studies of cadmium oxide administrated by inhalation to F344/N rats and B6C3F1 mice. NIH Publication 95-3388. Report no: 39.

ECHA (2013) Guidance on the Application of the CLP Criteria. Guidance to Regulation (EC) No 1272/2008 on classification, labelling and packaging (CLP) of substances and mixtures. Version 4.0, November 2013. European Chemicals Agency, Helsinki.

ECHA (2015a) http://echa.europa.eu/web/guest/information-on-chemicals/cl-inventory-database

ECHA (2015b) http://apps.echa.europa.eu/registered/data/dossiers/DISS-9eab95b6-ffd3-35a1-e044-00144f67d031/AGGR-a5c56c1b-cbbe-4dec-bed5-788cb3c8f60f_DISS-9eab95b6-ffd3-35a1-e044-00144f67d031.html#L-b57e962d-4164-44d6-be4c-cd29010b8ba7

EFSA (European Food Safety Authority) (2009) Scientific Opinion of the Panel on Contaminants in the Food Chain on a request from the European Commission on cadmium in food. The EFSA Journal 980: 1-139.

Elinder CG, Edling C, Lindberg E, Kågedal B and Vesterberg O (1985a) Assessment of renal function in workers previously exposed to cadmium. Br J Ind Med 42:754-760.

Elinder CG, Edling C, Lindberg E, Kågedal B and Vesterberg O (1985b) β2-Microglobulinuria among workers previously exposed to cadmium: Follow-up and dose-response analyses. Am J Ind Med 8:553-564.

Engström A, Skerving S, Lidfeldt J, Burgaz A, Lundh T, Samsioe G, Vahter M, Åkesson A (2009) Cadmium-induced bone effect is not mediated via low serum 1,25-dihydroxy vitamin D. Environ Res 109(2):188-192.

Epstein SS, Arnold E, Andrea J, Bass W and Bishop Y (1972) Detection of chemical mutagens by the dominant lethal assay in the mouse. Toxicol Appl Pharmacol 23: 288-325.

Fahmy MA and Aly FA (2000) In vivo and in vitro studies on the genotoxicity of cadmium chloride in mice. J Appl Toxicol 20: 231-238.

Falck FY Jr, Fine LJ, Smith RG, McClatchey KD, Annesley T, England B and Schork AM (1983) Occupational cadmium exposure and renal status. Am J Ind Med 4:541-549.

Friberg L (1950) Health hazards in the manufacture of alkaline accumulators with special reference to chronic cadmium poisoning. Acta Med Scand 138(Suppl 240):1-124.

Gallagher CM, Kovach JS and Meliker JR (2008) Urinary cadmium and osteoporosis in U.S. Women ≥50 years of age: NHANES 1988-1994 and 1999-2004. Environ Health Perspect 116(10):1338-1343.

Gilliavod N and Léonard A (1975) Mutagenicity tests with cadmium in the mouse. Toxicology 5: 43-47.

Glaser U, Hochrainer D, Otto FJ and Oldiges H (1990) Carcinogenicity and toxicity of four cadmium compounds inhaled by rats. Toxicol Environ Chem 27: 153-162.

Heinrich U, Peters L, Ernst He, Rittinghausen S, Dasenbrock C and König H (1989) Investigation on the carcinogenic effects of various cadmium compounds after inhalation exposure in hamsters and mice. Exp Pathol 37: 253-258.

Hochi Y, Kido T, Nogawa K, Kito H and Shaikh ZA (1995) Dose-response relationship between total cadmium intake and prevalence of renal dysfunction using general linear models. J Appl Toxicol 15:109-116.

IARC (International Agency for Research on Cancer) (1993) Cadmium and Cadmium Compounds. In: IARC Monagraphs, Volume 58, Beryllium, Cadmium, Mercury and Exposures in the Glass Manufacturing Industry. Edited by IARC LYON. IARC. United Kingdom, 119-237.

IARC (International Agency for Research on Cancer) (2012) Cadmium and Cadmium Compounds. **In:** IARC Monagraphs, Volume 100 (C), A Review of Human Carcinogens: Metals, Arsenic, Fibres and Dusts. Edited by IARC LYON, 121-145.

Jagetia GC and Adiga SK (1994) Cadmium chloride induces dose-dependent increases in the frequency of micronuclei in mouse bone marrow. Mutat Res 306: 85-90.

Jakubowski M, Trojanowska B, Kowalska G, Gendek E, Starzyński Z, Krajewska B and Jajte J (1987) Occupational exposure to cadmium and kidney dysfunction. Int Arch Occup Environ Health 59:567-577.

Jakubowski M, Razniewska G, Halatek T and Trzcinka-Ochocka M (1992) Integrated index of occupational exposure to cadmium as a predictor of kidney dysfunction. Cadmium in the human environment: Toxicity and carcinogenicity. IARC Sci Publ 118:319-324.

Järup L and Elinder CG (1994) Dose-response relations between urinary cadmium and tubular proteinuria in cadmium-exposed workers. Am J Ind Med 26(6):759-769.

Järup L, Elinder CG and Spang G (1988) Cumulative blood-cadmium and tubular proteinuria: A dose-response relationship. Int Arch Occup Environ Health 60:223-229.

Järup L, Persson B, Elinder CG (1995**)** Decreased glomerular filtration rate in solderers exposed to cadmium. Occup Environ Med 52:818-822.

Järup L, Berglund M, Elinder CG, Nordberg G and Vahter M (1998). Health effects of cadmium exposure - a review of the literature and a risk estimate. Scand J Work Environ Health 24:1-51.

Järup L, Hellström L, Alfvén T, Carlsson MD, Grubb A, Persson B, Pettersson C, Spång G, Schütz A and Elinder CG (2000) Low level exposure to cadmium and early kidney damage: The OSCAR study. Occup Environ Med 57(10):668-672.

Jin T, Nordberg M, Frech W, Dumont X, Bernard A, Ye TT, Kong Q, Wang Z, Li P, Lundström NG, Li Y and Nordberg GF (2002) Cadmium biomonitoring and renal dysfunction among a population environmentally exposed to cadmium from smelting in China. Biometals 15:397-410.

Jin T, Wu X, Tang Y, Nordberg M, Bernard A, Ye T, Kong Q, Lundström NG and Nordberg GF (2004a) Environmental epidemiological study and estimation of benchmark dose for renal dysfunction in a cadmium-polluted area in China. Biometals 17(5):525-530.

Jin T, Nordberg G, Ye T, Bo M, Wang H, Zhu G, Kong Q and Bernard A (2004b) Osteoporosis and renal dysfunction in a general population exposed to cadmium in China. Environ Res 96(3):353-359.

JRC (2007) European Union Risk Assessment Report: cadmium metal Part II - human health. Vol 74. Joint Research Centre (JRC).

Kašuba V, Rozgaj R, Sarić MM and Blanuša M (2002) Evaluation of genotoxic damage of cadmium chloride in peripheral blood of suckling Wistar rats. J Appl Toxicol 22: 271-277.

Kawada T, Koyama H and Suzuki S (1989) Cadmium, NAG activity, and B2-microglobulin in the urine of cadmium pigment workers. Br J Ind Med 46:52-55.

Kazantzis G (1979) Renal tubular dysfunction and abnormalities of calcium metabolism in cadmium workers. Environ Health Perspect 28:155-159.

Klimisch HJ (1993) Lung deposition, lung clearance and renal accumulation of inhaled cadmium chloride and cadmium sulphide in rats. Toxicology 84: 103-124.

Mailhes JB, Preston RJ, Yuan ZP and Payne HS (1988) Analysis of mouse metaphase II oocytes as an assay for chemically induced aneuploidy. Mutat Res 198: 145-152.

Mason HJ, Davison AG, Wright AL, Guthrie CJG, Fayers PM, Venables KM, Smith NJ, Chettle DR, Franklin DM, Scott MC, Holden H, Gompertz D and Newman-Taylor AJ (1988). Relations between liver cadmium, cumulative exposure, and renal function in cadmium alloy workers. Br J Ind Med 45:793-802.

Miller BM and Adler ID (1992) Aneuploidy induction in mouse spermatocytes. Mutagenesis 7: 69-76.

Mukherjee A, Giri AK, Sharma A and Talukder G (1988) Relative efficacy of short-term tests in detecting genotoxic effects of cadmium chloride in mice in vivo. Mutat Res 206: 285-295.

NICNAS (National Industrial Chemicals Notification and Assessment Scheme) (2013) Inventory multi-tiered assessment and prioritisation (IMAP). Human health tier II assessment for cadmium oxide (CDO). Australian Government Department of Health.

Nogawa K, Honda R, Kido T, Tsuritani I, Yamada Y, Ishizaki M and Yamaya H (1989) A dose-response analysis of cadmium in the general environment with special reference to total cadmium intake limit. Environ Res 48:7-16.

Noonan CW, Sarasua SM, Campagna D, Kathman SJ, Lybarger JA and Mueller PW (2002) Effects of exposure to low levels of environmental cadmium on renal biomarkers. Environ Health Perspect 110(2):151-155.

Nordberg G, Jin T, Bernard A, Fierens S, Buchet JP, Ye T, Kong Q and Wang H (2002) Low bone density and renal dysfunction following environmental cadmium exposure in China. Ambio 31(6):478-481.

Oo YK, Kobayashi E, Nogawa K, Okubo Y, Suwazono Y, Kido T and Nakagawa H (2000) Renal effects of cadmium intake of a Japanese general population in two areas unpolluted by cadmium. Arch Environ Health 55(2):98-103.

Park JD, Cherrington RJ and Klaassen CD (2002) Intestinal absorption of cadmium is associated with divalent metal transporter 1 in rats. Toxicol Sci 68: 288-294.

Piscator M (1984) Long-term observations on tubular and glomerula function in cadmium-exposed persons. Environ Health Perspect 54:175-179.

Roels HA, Lauwerys RR, Buchet JP, Bernard AM, Vos A and Oversteyns M (1989) Health significance of cadmium induced renal dysfunction: a five year follow-up. Br J Ind Med 46:755-764.

Roels HA, Lauwerys RR, Bernard AM, Buchet JP, Vos A and Oversteyns M (1991) Assessment of the filtration reserve capacity of the kidney in workers exposed to cadmium. Br J Ind Med 48:365-374.

Roels H, Bernard AM, Cardenas A, et al. (1993) Markers of early renal changes induced by industrial pollutants. III. Application to workers exposed to cadmium. Brit J Ind Med 50:37-48.

Schutte R, Nawrot TS, Richart T, Thijs L, Vanderschueren D, Kuznetsova T, Van Hecke E, Roels HA and Staessen JA (2008) Bone resorption and environmental exposure to cadmium in women: A population study. Environ Health Perspect 116:777-783.

Scott R, Haywood JK, Boddy K, Williams ED, Harvey I and Paterson PJ (1980) Whole body calcium deficit in cadmium-exposed workers with hypercalciuria. Urology 15:356-359.

Shaikh ZA, Tohyama C and Noland CV (1987) Occupational exposure to cadmium: Effect on metallothionein and other biological indices of exposure and renal function. Arch Toxicol 59:360-364.

Shin M, Paek D, Yoon C. 2011. The relationship between the bone mineral density and urinary cadmium concentration of residents in an industrial complex. Environ Res 111(1):101-109.

Staessen JA, Roels HA, Emelianov D, Kuznetsova T, Thijs L, Vangronsveld J and Fagard R (1999) Environmental exposure to cadmium, forearm bone density, and risk of fractures: Prospective population study. Lancet 353(9159):1140-1144.

Suter KE (1975) Studies on the dominant-lethal and fertility effects of the heavy metal compounds methylmercuric hydroxide, mercuric chloride, and cadmium chloride in male and female mice. Mutat Res 30: 365-374.

Sutou S, Yamamoto K, Sendota H, Tomomatsu K, Shimizu Y and Sugiyama M (1980a) Toxicity, fertility, teratogenicity, and dominant lethal tests in rats administered cadmium subchronically. I. Toxicity studies. Ecotoxicol Environ Saf 4: 39-50.

Sutou S, Yamamoto K, Sendota H and Sugiyama M (1980b) Toxicity, fertility, teratogenicity, and dominant lethal tests in rats administered cadmium subchronically. II. Fertility, teratogenicity, and dominant lethal tests. Ecotoxicol Environ Saf 4: 51-56.

Suwazono Y, Kobayashi E, Okubo Y, Nogawa K, Kido T and Nakagawa H (2000) Renal effects of cadmium exposure in cadmium nonpolluted areas in Japan. Environ Res 84:44-55.

Takenaka S, Oldiges H, König H, Hochrainer D and Oberdörster D (1983) Carcinogenicity of cadmium chloride aerosols in W rats. JNCI 70: 367-373.

Tallkvist J, Bowlus CL and Lönnerdal B (2001) DMT1 gene expression and cadmium absorption in human absorptive enterocytes. Toxicol Lett 122: 171-177.

Thun MJ, Osorio AM, Schober S, Hannon WH, Lewis B and Halperin W (1989) Nephropathy in cadmium workers: Assessment of risk from airborne occupational exposure to cadmium. Br J Ind Med 46:689-697.

Toffoletto F, Apostoli P, Ghezzi I, et al. (1992) Ten-year follow-up of biological monitoring of cadmium-exposed workers. In: Nordgerg GF, Herber RFM, Alessio L, eds. Cadmium in the human environment: Toxicity and carcinogenicity. Geneva: International Agency for Research on Cancer, 107-111.

Trzcinka-Ochocka M, Jakubowski M, Szymczak W, Janasik B and Brodzka R (2010) The effects of low environmental cadmium exposure on bone density. Environ Res 110(3):286-293.

Tsuchiya K (1969a) Causation of Ouch-Ouch disease (Itai-Itai Byō) – An introductory review – Part I. Nature of the disease. Keio J Med 18: 181-194.

Tsuchiya K (1969b) Causation of Ouch-Ouch disease (Itai-Itai Byō) – An introductory review – Part II. Epidemiology and Evaluation. Keio J Med 18: 195-211.

Valverde M, Fortoul TI, Diaz-Barriga F, Mejia J and del Castillo ER (2000) Induction of genotoxicity by cadmium chloride inhalation in several organs of CD-1 mice. Mutagenesis 15: 109-114.

Verschoor M, Herber R, van Hemmen, Wibowo A and Zielhuis R (1987) Renal function of workers with low-level cadmium exposure. Scand J Work Environ Health 13:232-238.

Wada O, Iijima M, Ono T and Toyokawa K (1972) Solubility of cadmium compounds into gastric and intestinal juices. Ind Health 10: 122-124.

Waalkes MP and Rehm S (1992) Carcinogenicity of oral cadmium in the male Wistar (WF/NCr) rat: effect of chronic dietary zinc deficiency. Fundam Appl Toxicol 19: 512-520.

Waalkes MP and Rehm S (1994) Chronic toxic and carcinogenic effects of cadmium chloride in male DBA/2NCr and NFS/NCr mice: strain-dependent association with tumors of the hematopoietic system, injection site, liver, and lung. Fundam Appl Toxicol 23:21-31.

Waalkes MP, Rehm S, Riggs CW, Bare RM, Devor DE, Poirier LA, Wenk ML, Henneman JR and Balaschak MS (1988) Cadmium carcinogenesis in male Wistar [Crl:(WI)BR] rats: dose-response analysis of tumor induction in the prostate and testes and at the injection site. Cancer Res 48: 4656-4663.

Wang H, Zhu G, Shi Y, Weng S, Jin T, Kong Q and Nordberg GF (2003) Influence of environmental cadmium exposure on forearm bone density. J Bone Miner Res 18(3):553-560.

Watanabe T and Endo A (1982) Chromosome analysis of preimplantation embryos after cadmium treatment of oocytes at meiosis I. Environ Mutagen 4: 563-567.

Watanabe T, Shimada T and Endo A (1979) Mutagenic effects on cadmium on mammalian oocyte chromosomes. Mutat Res 67: 349-356.

Wu Q, Magnus JH and Hentz JG (2010) Urinary cadmium, osteopenia, and osteoporosis in the US population. Osteoporos Int 21(8):1449-1454.

Yamanaka O, Kobayashi E, Nogawa K, Suwazono Y, Sakurada I and Kido T (1998) Association between renal effects and cadmium exposure in cadmium-nonpolluted area in Japan. Environ Res 77:1-8.

Zhu G, Wang H, Shi Y, Weng S, Jin T, Kong Q and Nordberg GF (2004) Environmental cadmium exposure and forearm bone density. Biometals 17:499-503.