



**Substance name: Cobalt (II) sulphate**  
**EC number: 233-334-2**  
**CAS number: 10124-43-3**

**MEMBER STATE COMMITTEE**

**SUPPORT DOCUMENT FOR IDENTIFICATION OF  
COBALT (II) SULPHATE  
AS A SUBSTANCE OF VERY HIGH CONCERN BECAUSE OF  
ITS CMR PROPERTIES**

**Adopted on 2 December 2010**

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**Substance Name:** Cobalt(II)sulphate  
**EC Number:** 233-334-2  
**CAS number:** 10124-43-3

In addition, this support document covers also the hydrated forms of Cobalt(II)sulphate<sup>1</sup>.

- The substance is identified as substance meeting the criteria of Article 57 (a) of Regulation (EC) 1907/2006 (REACH) owing to its classification in the hazard class carcinogenicity category 1B<sup>2</sup> under Annex VI, part 3, Table 3.1 of Regulation (EC) No 1272/2008, as well as its corresponding classification under Annex VI, part 3, Table 3.2 as carcinogen category 2<sup>3</sup>.
- The substance is identified as substance meeting the criteria of Article 57 (c) of Regulation (EC) 1907/2006 (REACH) owing to its classification in the hazard class reproductive toxicity category 1B<sup>2</sup> under Annex VI, part 3, Table 3.1 of Regulation (EC) No 1272/2008 as well as its corresponding classification under Annex VI, part 3, Table 3.2 of Regulation (EC) No 1272/2008 as toxic for reproduction category 2<sup>3</sup>.

### **Summary of how the substance meets the Carcinogen 1B and Reprotox 1B criteria**

Prior to 1 December 2010 Articles 57 (a) and (c) of REACH required that substances may be included in Annex XIV if they meet the criteria for classification as (a) carcinogenic category 1 or 2 and (c) toxic for reproduction category 1 or 2, in accordance with Directive 67/548/EEC.

As of 1 December 2010 Articles 57(a) and (c) of REACH have been amended by Regulation (EC) No 1272/2008 in so far as they provide that substances may be included in Annex XIV where the substances meet the criteria for classification in (a) the hazard class carcinogenicity category 1A or 1B in accordance with section 3.6 of Annex I to Regulation (EC) no. 1272/2008 and (c) the hazard class reproductive toxicity category 1A or 1B, adverse effects on sexual function and fertility or on development in accordance with section 3.7 of Annex I to Regulation (EC) No 1272/2008.

The original Annex XV dossier of the Netherlands for Cobalt(II)sulphate was submitted before 1 December 2010 and therefore proposed that the substance is identified as meeting the criteria under Article 57(a) and (c) of the version of REACH existing at that time, i.e., the substance meets the criteria for classification as carcinogen category 2 and toxic for reproduction category 2 set out under Directive 67/548/EEC.

However, as the agreement of the Member State Committee in relation to the identification has been taken after 1 December 2010, this agreement is based on the criteria set out in the amended Article 57. It should however be noted that the amendment of Article 57 was not sufficient to reopen the

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<sup>1</sup> According to the rules applied when establishing EINECS (Manual of Decisions, Criteria for reporting substances for EINECS, [http://ecb.jrc.ec.europa.eu/documents/New-Chemicals/Manual\\_of\\_decisions.pdf](http://ecb.jrc.ec.europa.eu/documents/New-Chemicals/Manual_of_decisions.pdf)): "The anhydrous form can be reported and will, by implication, represent all hydrated forms."

<sup>2</sup> Classification in accordance with Regulation (EC) No 1272/2008 Annex VI, part 3, Table 3.1 List of harmonised classification and labelling of hazardous substances as amended and adapted to technical and scientific progress by Commission Regulation (EC) No 790/2009, OJ No L 235, p. 1, 5.9.2009

<sup>3</sup> Classification in accordance with Regulation (EC) No 1272/2008 Annex VI, part 3, Table 3.2 List of harmonised classification and labelling of hazardous substances (from Annex I to Council Directive 67/548/EEC) as amended and adapted to technical and scientific progress by Commission Regulation (EC) No 790/2009, OJ No L 235, p. 1, 5.9.2009

public consultation on the identification of this substance given that the harmonised classification criteria correspond to the criteria for classifying and labelling substances under Directive 67/548/EEC.

Pursuant to Regulation (EC) No 1272/2008 as amended and adapted to technical and scientific progress by Regulation (EC) No 790/2009, as of 1 December 2010, Cobalt(II)sulphate, is listed under index number 027-005-00-0 in Annex VI, part 3, Table 3.1 (the list of harmonised classification and labelling of hazardous substances) of Regulation (EC) No 1272/2008 as carcinogen category 1B. Its corresponding classification in Annex VI, part 3, Table 3.2 (the list of harmonised and classification and labelling of hazardous substances from Annex I to Directive 67/548/EEC) of Regulation (EC) No 1272/2008 is carcinogen category 2. The hydrous forms of Cobalt(II)sulphate are also considered as carcinogens category 1B (corresponding to carcinogen category 2) according to Annex VI, part 1.1.1.5, of Regulation (EC) No 1272/2008. According to part 1.1.1.5 (Entries of group of substance) entries in part 3 for salts (under any denomination) cover both anhydrous and hydrous forms, unless specified otherwise.

Therefore, this classification of the substance(s) in Regulation (EC) No 1272/2008 shows that the substance meets the criteria for classification as carcinogen in accordance with Article 57 (a) of REACH.

Pursuant to Regulation (EC) No 1272/2008 as amended and adapted to technical and scientific progress by Regulation (EC) No 790/2009, as of 1 December 2010, Cobalt(II)sulphate is listed under index number 027-005-00-0 in Annex VI, part 3, Table 3.1 (the list of harmonised classification and labelling of hazardous substances) of Regulation (EC) No 1272/2008 as toxic for reproduction category 1B<sup>2</sup>. Its corresponding classification in Annex VI, part 3, Table 3.2 (the list of harmonised and classification and labelling of hazardous substances from Annex I to Directive 67/548/EEC) of Regulation (EC) No 1272/2008 is toxic for reproduction category 2<sup>3</sup>. All hydrous forms of cobalt(II) sulphate are also considered as toxic for reproduction category 1B (corresponding to toxic for reproduction category 2) according to Annex VI, part 1.1.1.5, of Regulation (EC) No 1272/2008. According to part 1.1.1.5 (Entries of group of substance) entries in part 3 for salts (under any denomination) cover both anhydrous and hydrous forms, unless specified otherwise.

Therefore, this classification of the substance in Regulation (EC) No 1272/2008 shows that the substance meets the criteria for classification as toxic for reproduction in accordance with Article 57 (c) of REACH.

## JUSTIFICATION

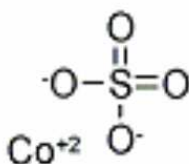
### 1 IDENTITY OF THE SUBSTANCE AND PHYSICAL AND CHEMICAL PROPERTIES

#### 1.1 Name and other identifiers of the substance

**Table 1: Substance identity**

<b>EC number:</b>	233-334-2
<b>EC name:</b>	Cobalt sulphate
<b>CAS number:</b>	10124-43-3
<b>CAS name:</b>	Sulfuric acid, cobalt(2+) salt (1:1)
<b>Index number in Annex VI of the CLP Regulation</b>	027-005-00-0
<b>Molecular formula:</b>	Co.H <sub>2</sub> O <sub>4</sub> S
<b>Molecular weight range:</b>	154.99

#### Structural formula:



This support document covers also the hydrated forms of cobalt(II) sulphate. According to the rules applied when establishing EINECS<sup>4</sup>: “The anhydrous form can be reported and will, by implication, represent all hydrated forms.”

#### 1.2 Composition of the substance

Information on concentration range and on any impurities is not known.

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<sup>4</sup> Manual of Decisions, Criteria for reporting substances for EINECS, [http://ecb.jrc.ec.europa.eu/documents/New-Chemicals/Manual\\_of\\_decisions.pdf](http://ecb.jrc.ec.europa.eu/documents/New-Chemicals/Manual_of_decisions.pdf)

### 1.3 Physico-chemical properties

**Table 2: Overview of physicochemical properties**

Property	Value	Remarks
Physical state at 20°C and 101.3 kPa	Dark-bluish crystals	U.S., Department of Health and Human Services
Melting/freezing point	735°C	U.S., Department of Health and Human Services
Water solubility	soluble 362 g/L at 20°C 830 g/L at 100°C	U.S., Department of Health and Human Services
Partition coefficient n-octanol/water (log value)	Not relevant	

## 2 HARMONISED CLASSIFICATION AND LABELLING

### 2.1 Classification according to Directive 67/548/EEC

Pursuant to the Regulation (EC) No 1272/2008 as amended and adapted to technical and scientific progress by Regulation (EC) No 790/2009 as of 1 December 2010, Cobalt(II) sulphate is listed under index number 027-005-00-0<sup>5</sup> in Annex VI, part 3, Table 3.2 of Regulation (EC) No 1272/2008 with the following classification:

Carc.Cat. 2; R49	May cause cancer by inhalation
Repr.Cat. 2; R60	May impair fertility
Xn; R22	Harmful if swallowed
R42/43:	May cause sensitization by inhalation and skin contact
Muta.Cat. 3; R68	Possible risk of irreversible effects
N; R50/53:	Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment

Specific concentration limits:

Classification	Concentration
Carc. Cat. 2 R49	$C \geq 0.01\%$
N; R50-53	$C \geq 2.5\%$
N; R51-53	$0.25\% \leq C < 2.5\%$
R52-53	$0.025\% \leq C < 0.25\%$

Notes:

Note E: Substances with specific effects on human health (see Chapter 4 of Annex VI to Directive 67/548/EEC) that are classified as carcinogenic, mutagenic and/or toxic for reproduction in categories 1 or 2 are ascribed Note E if they are also classified as very toxic (T+), toxic (T) or harmful (Xn). For these substances, the risk phrases R20, R21, R22, R23, R24, R25, R26, R27, R28, R39, R68 (harmful), R48 and R65 and all combinations of these risk phrases shall be preceded by the word 'Also'.

Note 1: The concentration stated or, in the absence of such concentrations, the generic concentrations of this Regulation (Table 3.1) or the generic concentrations of Directive 1999/45/EC (Table 3.2) are the percentages by weight of the metallic element calculated with reference to the total weight of the mixture.

### 2.2 Classification according to Regulation EC 1272/2008

Pursuant to Regulation (EC) No 1272/2008 as amended and adapted to technical and scientific progress by Regulation (EC) No 790/2009 as of 1 December 2010, Cobalt(II) sulphate is listed in

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<sup>5</sup> International Chemical Identification: cobalt sulphate



Annex VI, part 3, Table 3.1 of Regulation (EC) No. 1272/2008 (list of harmonised classification and labelling of hazardous substances) with the following classification:

Carc. 1B, H350i	May cause cancer by inhalation
Muta. 2, H341	Suspected of causing genetic defects
Repr. 1B, H360F*** <sup>6</sup>	May damage fertility
Acute Tox. 4* <sup>7</sup> , H302	Harmful if swallowed
Resp.Sens. 1 H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled
Skin Sens.1 H317	May cause an allergic skin reaction
Aquatic Acute 1 H400	Very toxic to aquatic life
Aquatic Chronic 1 H410	Very toxic to aquatic life with long lasting effects

Specific concentration limits:

Classification	Concentration
Carc. 1B H350i	C ≥ 0.01%

M-factor: 10

Notes:

Note 1: The concentration stated or, in the absence of such concentrations, the generic concentrations of this Regulation (Table 3.1) or the generic concentrations of Directive 1999/45/EC (Table 3.2) are the percentages by weight of the metallic element calculated with reference to the total weight of the mixture.

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<sup>6</sup> According to Annex VI (Part 1, entry 1.2.3): H360 and H361 indicate a general concern for effects on both fertility and development: 'May damage/Suspected fertility or the unborn child'. According to the criteria, the general hazard statement can be replaced by the hazard statement indicating only the property of concern, where either fertility or developmental effects are proven to be not relevant. In order not to lose information from the harmonised classifications for fertility and developmental effects under Directive 67/548/EEC, the classifications have been translated only for those effects classified under that Directive. These hazards statements are indicated by reference \*\*\* in Table 3.1.

<sup>7</sup> The reference (\*) indicates minimum classification.

### **3 ENVIRONMENTAL FATE PROPERTIES**

Not relevant for this type of dossier.

### **4 HUMAN HEALTH HAZARD ASSESSMENT**

Information on the hazard properties of cobalt(II)sulphate and its hydrates is provided for information purposes only as the classification has already been concluded by TC-C&L and included in Annex VI. Please refer to Annex I of this report.

### **5 ENVIRONMENTAL HAZARD ASSESSMENT**

Not relevant for this type of dossier.

## **6 CONCLUSIONS ON THE SVHC PROPERTIES**

### **6.1 PBT, vPvB assessment**

Not relevant for this type of dossier.

### **6.2 CMR assessment**

The classification of Cobalt(II)sulphate (anhydrous and hydrous forms) in Regulation (EC) No 1272/2008 as amended and adapted to technical and scientific progress by Regulation (EC) No 790/2009 (Carc. 1B; H350i: “May cause cancer by inhalation” that corresponds to classification Carc.Cat. 2; R49: “May cause cancer by inhalation”) shows that the substance meets the criteria for classification as carcinogen in accordance with Article 57 (a) of REACH.

Furthermore, the classification of Cobalt(II)sulphate (anhydrous and hydrous forms) in Regulation (EC) No 1272/2008 as amended and adapted to technical and scientific progress by Regulation (EC) No 790/2009 (Repr. 1B; H360F\*\*\*: “May damage fertility” that corresponds to classification Repr.Cat. 2; R60: “May impair fertility”) shows that the substance meets the criteria for classification as toxic for reproduction in accordance with Article 57 (c) of REACH.

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## **ANNEXES**

## 1 ANNEX I: HUMAN HEALTH HAZARD ASSESSMENT

Information on the hazard properties of cobalt(II) sulphate is provided for information purposes only as the classification has already been concluded by TC-C&L and included in Annex VI. However, the C&L proposal and the data used for this are no longer available at the ECB website. The provided information is limited to the endpoints relevant for identification as SVHC and is based on available summaries.

The summaries used in this report are mainly copied from the ASTDR toxicological profile for cobalt (published in 2004); the IARC monographs on the evaluation of carcinogenic risk to humans for cobalt and cobalt compounds (Volume 52, published in 1991) and cobalt in hard metals and cobalt sulphate (Volume 86, published in 2006); and the Report on Carcinogens (RoC) background document for cobalt sulphate (published in 2002). The references are available in the ASTDR, IARC and RoC.

Cobalt(II) sulphate is an inorganic salt of divalent cobalt. The behaviour of the anhydrous and hydrated forms in solution is the same, as dissolution of either results in a system containing hydrated ions and water. Many studies have investigated the carcinogenic, mutagenic and reproductive toxicological effects of cobalt and cobalt compounds as a class including both anhydrous and hydrate forms of cobalt(II) sulphate. These include a number of insoluble and soluble cobalt compounds. The data from soluble cobalt(II) salts compounds can be used to read across to cobalt(II) sulphate as relevant information concerning its CMR effects because these properties are mediated by the ionic form of cobalt(II).

### 1.1 Toxicokinetics (absorption, metabolism, distribution and elimination)

#### 1.1.1 Non-human information

#### 1.1.2 Human information

*The following summary on the toxicokinetics of cobalt and cobalt compounds was taken from the RoC Background Document for Cobalt Sulphate, published in 2002. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

Cobalt is absorbed from the gastrointestinal tract, lungs, and skin. Normal levels in blood and urine in the general population are 0.2 to 2 µg/L, but concentrations greater than 200 µg/L have been reported in the urine of workers occupationally exposed to cobalt (IARC 1991, NTP 1998). Gastrointestinal tract absorption is highly variable depending on the compound, concentration, and other factors, but is estimated to range from 5% to 45% (Lauwerys and Lison 1994) and may be higher in females than in males (Christensen and Poulsen 1994). There is evidence that iron and cobalt share the same transport mechanism in the duodenum (Léonard and Lauwerys 1990). The degree of respiratory absorption in humans is unknown but varies with concentration. Some studies have shown a good correlation between concentrations in air and concentrations in urine of workers (Christensen and Poulsen 1994). Respiratory absorption of cobalt inhaled as cobalt oxide was about 30% (Lauwerys and Lison 1994). Scansetti *et al.* (1994) demonstrated substantial absorption of cobalt through the skin.

Once absorbed, cobalt is preferentially distributed to the liver, kidney, and heart (Léonard and Lauwerys 1990, Christensen and Poulsen 1994). Without occupational exposure, the cobalt content in the adult human body is about 1 to 2 mg. The cobalt content of bone and muscle account for 14% and 13%, respectively, of the total body burden, with the rest occurring in soft tissues (Léonard and Lauwerys 1990, IARC 1991). The highest cobalt concentrations are in the liver, because vitamin B12 is stored there; IARC (1991) reported that the cobalt concentration in the liver at autopsy ranged from 6 to 151 µg/kg, with a median value of 30 µg/kg. Patients dying of cardiomyopathy from excessive intake of cobalt-fortified beer had 10 times the normal amount of cobalt in the heart (IARC 1991).

Concentrations of arsenic and cobalt were evaluated in tissue and plasma of patients with laryngeal carcinoma (Collecchi *et al.* 1986). Plasma and histologically nonmalignant and malignant laryngeal tissues were obtained from each of 15 male patients with no known exposure to toxic amounts of cobalt. The cobalt concentrations in malignant laryngeal tissue ( $68.7 \pm 7.3$  ng/g dry weight, mean  $\pm$  SD) were significantly higher ( $P < 0.01$ , paired t-test and Wilcoxon's test) than those in nonmalignant laryngeal tissue ( $39.6 \pm 7.0$ ). The plasma cobalt concentrations were 25-fold higher in the 15 patients with laryngeal carcinoma than in 11 apparently normal male individuals ( $18.27 \pm 2.10$  and  $0.73 \pm 0.10$  ng/mL, respectively;  $P < 0.001$ , Student's t-test and Mann-Whitney U-test). Similar significant differences were reported for plasma and tissue arsenic levels. The authors reported that further studies were in progress to ascertain the clinical significance of the changes in tissue and plasma cobalt and arsenic concentrations; however, no additional publications on this subject were identified in a search of the literature since 1986.

Cobalt is excreted in the urine and, to a lesser degree, in the feces. In experimental animals, 70% or more is eliminated in the urine (IARC 1991). In humans, 28% to 56% of radiolabelled cobalt chloride was eliminated in the urine and 2% to 12% in the feces within eight days after parental administration. Between 9% and 16% of the administered dose was eliminated very slowly, with a biological half-life of about two years (Smith *et al.* 1972). Thus, cobalt excretion has two distinct phases: a rapid initial phase, with a half-life of a few days, followed by a slow second phase, with a half-life of a year or more (Léonard and Lauwerys 1990, Lauwerys and Lison 1994). Cobalt concentrations in the urine of workers in the Italian hard-metal industry were 10 to 100 µg/L at the beginning of the work shift, increasing to 16 to 210 µg/L at the end of the shift (Sabbioni *et al.* 1994). Clearance from the lungs has not been studied but is expected to be rapid for soluble cobalt salts (NTP 1998).

### **1.1.3 Summary and discussion on toxicokinetics**

#### **1.2 Acute toxicity**

Not relevant for this type of dossier.

#### **1.3 Irritation**

Not relevant for this type of dossier.

#### **1.4 Corrosivity**

Not relevant for this type of dossier.



## 1.5 Sensitisation

Not relevant for this type of dossier.

## 1.6 Repeated dose toxicity

Not relevant for this type of dossier

## 1.7 Mutagenicity

### 1.7.1 Non-human information

#### 1.7.1.1 In vitro data

*The following summary was taken from the IARC monograph for Cobalt in hard-metals and cobalt sulphate, published in 2006. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

Cobalt sulphate has been shown to induce chromosomal aberrations and aneuploidy in plant cells (Komczynski *et al.*, 1963; Herich, R. 1965; Gori *et al.* 1957), chemical changes in bases in purified calf thymus DNA and in isolated human chromatin in the presence of hydrogen peroxide, and cytoskeletal perturbation of microtubules and microfilaments and p53 protein in mouse fibroblasts treated *in vitro*. Cell transformation of Syrian hamster embryo cells has been induced by cobalt sulphate *in vitro*.

A number of mammalian genes (metallothionein MT-IIA, heat-shock proteins hsp70, c-fos) are transcriptionally regulated by a *cis*-acting DNA element located in their upstream regions. This DNA element responds to various heavy metals, including cobalt, to stimulate the expression of these genes (Murata *et al.*, 1999). *MT-IIA* and *hps70* but not *c-fos* RNA transcripts were increased in HeLa S<sub>3</sub> cells exposed to high concentrations of cobalt sulphate (> 10 µM). Metal response element (MRE)-DNA binding activity was not inhibited by cobalt sulphate in Hela cells *in vitro* while the results for heat shock element (HSE)-DNA binding activity were inconclusive. It is unknown whether MT-IIA and hps70 induction plays a role in the pathophysiological processes involved in cobalt carcinogenesis.

#### 1.7.1.2 In vivo data

Molecular analysis of lung neoplasms of B6C3F1 mice exposed to cobalt sulphate heptahydrate showed the presence of *K-ras* mutations with a much higher frequency (55%) of G > T transversion at codon 12 than in controls (0%). This provides suggestive evidence that cobalt sulphate heptahydrate may indirectly damage DNA by oxidative stress (NTP, 1998).

## 1.7.2 Human data

No studies are available specifically to cobalt(II) sulphate and its hydrates.

### 1.7.3 Other relevant information

#### 1.7.3.1 In vitro and in vivo data

Several other cobalt(II) salts have been investigated in different short term tests for mutagenic effects. The most studied is the water soluble cobalt(II) chloride. Few results are available for other cobalt salts.

##### Mutagenicity effects for cobalt(II) chloride

*The following summary was taken from the IARC monograph for Cobalt in hard-metals and cobalt sulphate, published in 2006. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

##### a) In Vitro

Cobalt(II) chloride was found to be inactive in the  $\lambda$  prophage induction assay, and gave conflicting results in the *Bacillus subtilis* rec<sup>+/-</sup> growth inhibition assay; when a cold preincubation procedure was used, positive results were observed (Kanematsu *et al.*, 1980). Lysogenic induction and phage reactivation was found in *Escherichia coli* in the absence of magnesium. Also in *E. coli*, reduction of fidelity of DNA replication by substitution of magnesium and inhibition of protein synthesis were observed. Cobalt(II) chloride was inactive in all but two bacterial mutagenicity tests. One study gave positive results in the absence, but not in the presence, of an exogenous metabolic system, and in the second study, a preincubation procedure was used.

In bacteria, cobalt(II) chloride has been reported to reduce the incidence of spontaneous mutations and to inhibit mutations induced by *N*-methyl-*N'*-nitrosoguanidine and 3-amino-1,4-dimethyl-5*H*-pyrido[4,3-*b*]indole. It was found to be comutagenic with several heteroaromatic compounds such as benzo(a)pyrene and naphthylamine. In *Saccharomyces cerevisiae*, cobalt(II) chloride induced gene conversion and petite  $\rho$ -mutation in mitochondrial DNA but not other types of mutation.

In mammalian cells cultured *in vitro*, positive results were obtained for induction of DNA-protein cross-linkage, DNA strand breakage and sister chromatid exchange in most studies. Cobalt(II) chloride induced mutations at the *Hprt* locus in Chinese hamster V79 cells, but not at the *8AG* and the *Gpt* loci. At the same *Gpt* locus in a transgenic Chinese hamster V79 G12 cell line, lower concentrations of cobalt(II) chloride did induce gene mutations. In a single study, at the *Tk* locus in mouse lymphoma L5178Y cells, the results were negative. In most studies, in cultured human cells *in vitro*, positive results were obtained for inhibition of protein-DNA binding activities, inhibition of p53 binding to DNA and for induction of gene expression, induction of DNA strand breakage and sister chromatid exchange. Chromosomal aberrations were not observed in cultured human cells (IARC, 1991). Cobalt(II) chloride induced aneuploidy in cultured human lymphocytes.

##### b) In Vivo

*In vivo*, cobalt(II) chloride administered by intraperitoneal injection induced aneuploidy (pseudodiploidy and hyperploidy) in bone marrow and testes of Syrian hamsters, micronuclei in bone marrow in male BALB/c mice, and enhanced the micronuclei frequencies induced by the three other mutagens tested. A gene expression mechanism is involved in several tissue and cellular responses induced by soluble cobalt (generally cobalt chloride) mimicking the pathophysiological response to hypoxia, a response which involves various genes including those coding for erythropoiesis and for growth factors for angiogenesis (Gleadle *et al.*, 1995; Steinbrech *et al.*, 2000; Beyersmann, 2002). Up-regulation of erythropoietin gene expression was observed *in vivo* after a

single intraperitoneal injection of cobalt chloride (60 mg/kg bw) into rats (Göpfert *et al.*, 1995) and might be of relevance in explaining the polyglobulia noted in humans treated with high doses of cobalt (Curtis *et al.*, 1976). In Chinese hamster ovary cells, cobalt also up-regulated the expression of haeme oxygenase-1, a potent antioxidant and anti-inflammatory mediator which helps to maintain cellular homeostasis in response to stress and injury (Gong *et al.*, 2001). In studies designed to explore the molecular mechanisms of gene response to hypoxia, cobalt (12 and 60 mg/kg bw as cobalt chloride) was found to up-regulate the expression of the *PDGF-B* gene in lungs and kidneys of male Sprague-Dawley rats (Bucher *et al.*, 1996). Since PDGF is an important growth factor which modulates cell proliferation and the expression of several proto-oncogenes mainly in mesenchymal cells, this effect of cobalt might explain how it may exert fibrogenic and/or carcinogenic properties, but this remains to be documented.

#### Mutagenicity effects for other cobalt compounds

*The following summary was taken from the IARC monograph for Cobalt in hard-metals and cobalt sulphate, published in 2006. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

Cobalt sulphide particles were found to induce DNA strand breaks and alkali-labile sites in Chinese hamster ovary cells. Data on the induction of gene mutations in Chinese hamster cells by cobalt sulphide particles are conflicting. Cobalt sulphide was shown to induce morphological transformation in Syrian hamster embryo cells; the crystalline form of cobalt sulphide being more active than the amorphous form.

Cobalt(III) nitrate induced gene mutations in *Pisum abyssinicum* chlorophyll. Eight of 15 cobalt(III) complexes with aromatic ligands were found to be positive in a DNA repair assay and four among the eight were also mutagenic to *Salmonella typhimurium*. Cobalt(III) complexes with desferal-induced scission of double-stranded DNA, and a cobalt(III) Schiff-base complex induced inhibition of zinc-finger transcription factors.

#### **1.7.3.2 Human Data**

Five studies have been conducted to date on the possible cytogenetic effects induced by cobalt compounds in lymphocytes (or leukocytes) of individuals exposed to metals.

*The following summary was taken from the IARC monograph for Cobalt in hard-metals and cobalt sulphate, published in 2006. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

##### a) Sister chromatid exchange

Results of sister chromatid exchange have been obtained in two studies in which exposure was to a mixture of metals. Occupational exposure to metals was studied by Gennart *et al.* (1993) who determined sister chromatid exchange in 26 male workers exposed to cobalt, chromium, nickel and iron dust in a factory producing metal powder and in 25 controls, who were clerical workers, matched for age, smoking habits and alcohol consumption. Slight exposure to nickel or chromium oxides could not be excluded, since, at one stage of the production process, the metals are melted in an oven. The differences in the concentrations of cobalt in the urine in exposed persons (cobalt geometric mean, 23.6 µg/g creatinine; range, 6.4–173.1) and controls (cobalt geometric mean, .1 µg/g creatinine; range, 0.2–3.2) were statistically significant. Analysis of variance revealed that both exposure status (exposed versus controls) and smoking habits (smokers and former smokers

versus never smokers) had statistically-significant effects on the sister chromatid exchange or high-frequency cell (HFC) rank values. These effects may not be attributable to cobalt alone.

Stea *et al.* (2000) compared sister chromatid exchange in patients who had chrome–cobalt alloy prostheses and in those with other metal alloys. The study population consisted of 30 patients with joint prostheses and 17 control subjects matched for age, sex, and exposure to occupational and environmental risk factors such as chemicals, antineoplastic drugs and traffic smog. The mean sister chromatid exchange rate in subjects with prostheses ( $5.2 \pm 1.5$ ) was not statistically different from that in subjects without prostheses ( $4.4 \pm 1.3$ ). Subjects with titanium–aluminium–vanadium alloy prostheses had a significantly higher sister chromatid exchange frequency ( $6.3 \pm 2.3$ ) than the controls ( $4.4 \pm 1.3$ ) whereas subjects with prostheses made of chrome–cobalt alloys or mixed prostheses had a higher, but not significantly, sister chromatid exchange frequency ( $4.7 \pm 1.1$  and  $5.0 \pm 2.1$ , respectively) than the controls. The number of sister chromatid exchanges was not affected by the presence of bone-cement used in prosthesis fixation nor by duration of the implant. There was no difference in the incidence of sister chromatid exchange between the two populations (those with prostheses and controls) considered globally and the considered risk factors, including smoking. The HFC values ( $> 9$  exchanges per cell) were also recorded. Among the cases studied, three patients with implants (one with a prosthesis made of chrome–cobalt alloy and two with mixed prostheses) showed markedly elevated percentages of HFCs ( $> 10\%$ ). It was concluded that the indication of possible cytogenetic damage in the patient populations should be considered with caution, since the sample population was small.

#### b) Micronuclei and DNA damage

Burgaz *et al.* (2002) applied the micronucleus test to assess the effect of occupational exposure to metal alloys in both exfoliated nasal cells, and *in vitro* in lymphocytes. The groups studied consisted of 27 male dental laboratory technicians exposed to metal alloys (35–65% cobalt, 20–30% chromium, 0–30% nickel) in dental laboratories during the production of skeletal prostheses, and 15 male controls from the faculty of pharmacy. In the exposed group, a significant correlation was found between urinary cobalt concentrations and frequencies of micronuclei in nasal cells, but not in lymphocytes. The results of multifactorial variance analysis revealed that occupational exposure was the only factor that significantly influenced the induction of micronuclei.

The possible genotoxic effects of occupational exposure to cobalt alone or to hard-metal dust was explored in a study using the in-vitro cytochalasin-B micronucleus test in lymphocytes as end-point for mutations (De Boeck *et al.*, 2000). The authors concluded that workers exposed solely to cobalt-containing dust at TLV/TWA ( $20\mu\text{g}$  cobalt/g creatinine in urine, equivalent to TWA exposure to  $20\mu\text{g}/\text{m}^3$ ) did not show increased genotoxic effects but that workers who smoked and were exposed to hard-metal dusts form a specific occupational group which needs closer medical surveillance.

Hengstler *et al.* (2003) concluded from a study of workers co-exposed to cadmium, cobalt, lead and other heavy metals, that such mixed exposure may have genotoxic effects. The authors determined DNA single-strand break induction by the alkaline elution method in cryopreserved mononuclear blood cells of 78 individuals co-exposed to cadmium (range of concentrations in air,  $0.05\text{--}138\mu\text{g}/\text{m}^3$ ), cobalt (range,  $0\text{--}10\mu\text{g}/\text{m}^3$ ) and lead (range,  $0\text{--}125\mu\text{g}/\text{m}^3$ ) and of 22 subjects without occupational exposure to heavy metals (control group). Some concerns about the study were addressed by Kirsch-Volders and Lison (2003) who concluded that it did not provide convincing evidence to support the alarming conclusion of Hengstler *et al.* (2003).

### 1.7.4 Summary and discussion of mutagenicity

The results of genotoxicity assays for cobalt(II) sulphate along with a variety of cobalt(II) salts demonstrate the mutagenic potential of these salts both in vitro and in vivo. Cobalt, in salts with a valence state of +2, was mostly negative in mutagenicity tests conducted in *Salmonella typhimurium*, *Escherichia coli*, and yeast, but weakly positive in *Bacillus subtilis*. In mammalian test systems, many cobalt compounds and metals are genotoxic. Cobalt compounds and cobalt metals have been reported to cause clastogenic effects in mammalian cells such as human lymphocytes, transformation in hamster cells, sister chromatid exchanges in human lymphocytes, and micronucleus formation in mouse bone marrow cells and human lymphocytes. It has also been demonstrated to induce micronuclei in vivo (bone marrow in mice).

TC-C&L concluded on the then available data after discussions in November 2003, May 2004 and September 2004 that cobalt(II) sulphate and cobalt(II) sulphate heptahydrate should be classified with R68 (summary record ECBI/139/04 rev.2).

## 1.8 Carcinogenicity

### 1.8.1 Non-human information

#### 1.8.1.1 Carcinogenicity: oral

No carcinogenicity studies were available using the oral route of exposure.

#### 1.8.1.2 Carcinogenicity: inhalation

The NTP (1998) conducted a two year inhalation carcinogenicity study of cobalt sulphate heptahydrate (a soluble cobalt salt) with mice and rats. The hydrated and non-hydrated forms of a solute will behave similarly when dissolved in water, forming both a solution of hydrated ions and water (RoC, 2004). These studies and results are summarized below.

*The following information was taken from the RoC Background Document for Cobalt Sulphate, for Cobalt, published in 2002. Information on the references cited in this section (in parenthesis) and Annex II can be found in the cited summary document.*

#### NTP carcinogenicity bioassay in mice

Groups of six-week-old B6C3F1 mice (50 of each sex) were administered cobalt sulphate heptahydrate aerosols by inhalation at target concentrations of 0, 0.3, 1.0, or 3.0 mg/m<sup>3</sup>, 6 h/day, 3 days/week, for 105 weeks (NTP 1998, Bucher *et al.* 1999<sup>8</sup>). The corresponding concentrations expressed as elemental cobalt were 0, 0.063 mg/m<sup>3</sup>, 0.210 mg/m<sup>3</sup>, and 0.628 mg/m<sup>3</sup>. Exposure concentrations were based on previous subacute and subchronic studies (Bucher *et al.* 1990, NTP 1991). Cobalt sulphate heptahydrate was generated and delivered from an aqueous solution via a compressed-air-driven nebulizer, an aerosol charge neutralizer, and an aerosol distribution system. The aerosol was dried and mixed with humidified air before delivery to the inhalation chambers,

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<sup>8</sup> It should be noted that the article referring to, Bucher *et al.* 1999, reports the test substance to be cobalt sulphate hexahydrate.

thus allowing partial rehydration of the aerosol particles. The mass median aerosol particle diameter was 1 to 3  $\mu\text{m}$ , and the aerosol consisted of 1 mole of cobalt, 1 mole of sulphate, and 5.9 moles of water per mole of aerosolized cobalt sulphate (Bucher *et al.* 1999). The overall chemical purity of the study material was reported to be 99%. Survival was not significantly affected by exposure. Mean body weights were slightly higher in exposed females than in controls, and mean body weights were lower in the high-dose males than in controls from week 96 to the end of the study.

The incidences of alveolar/bronchiolar adenoma, alveolar/bronchiolar carcinoma, and alveolar/bronchiolar adenoma or carcinoma (combined) showed a positive exposure response trend in all groups. The incidences of these neoplasms were significantly higher in all the high-dose groups than in the controls, as was the incidence of adenoma or carcinoma (combined) in mid-dose female mice. The NTP (1998) concluded that there was clear evidence of carcinogenic activity in both male and female mice, based on increased incidences of lung tumors. Although the incidence of hemangiosarcoma was significantly increased in male mice in the mid-dose group, *Helicobacter hepaticus* infection was present in these mice, making interpretation of this finding difficult. Liver sections from several male mice were positive for bacteria, and the spectrum of liver lesions in these mice was consistent with *H. hepaticus* infection.

In addition to the neoplastic lesions, exposure to cobalt sulphate induced a spectrum of inflammatory, fibrotic, and proliferative lesions in other portions of the respiratory tract that were consistent with results observed in the shorter-term studies. These included hyperplasia of the olfactory epithelium (high-dose groups), squamous metaplasia of the larynx (all exposed groups), cytoplasmic vacuolization of the bronchi (all exposed groups), diffuse histiocytic cell infiltration (high-dose males), and focal histiocytic cell infiltration of the lung (high-dose females). Histiocytic infiltration was observed most often in lungs with alveolar/bronchiolar neoplasms and was attributed to the neoplasms, rather than to a direct effect of cobalt sulphate.

#### NTP carcinogenicity bioassay in rats

Groups of six-week-old F344/N rats (50 of each sex) were administered cobalt sulphate heptahydrate aerosols by inhalation at target concentrations of 0, 0.3, 1.0, or 3.0  $\text{mg}/\text{m}^3$ , 6 h/day, 5 days/week, for 105 weeks (NTP 1998, Bucher *et al.* 1999). Exposure concentrations were based on previous subacute and subchronic studies (Bucher *et al.* 1990, NTP 1991). Survival of exposed rats did not differ significantly from that of controls. Among males, survival was 34%, 30%, 42%, and 30% in the control, low exposure, mid-exposure, and high-exposure groups, respectively. Overall, survival was higher in females than in males, at 56%, 51%, 52%, and 60% in the control, low exposure, mid-exposure, and high-exposure groups, respectively. Mean body weights in all exposed groups did not differ significantly from those of controls throughout the study). The incidence of alveolar/bronchiolar adenoma or carcinoma (combined) showed a significant positive exposure-related trend in male rats and was significantly higher in the high-dose group than in the control group. A significant positive exposure-related trend for alveolar adenoma, carcinoma, and adenoma or carcinoma (combined) was observed in female rats, and incidences were significantly higher in the mid-dose and high-dose groups than in the controls. In addition, squamous-cell carcinoma of the lung was observed in two female rats (one each in the mid-dose and high-dose groups). The incidence of benign adrenal pheochromocytoma was increased in high-dose females, and the incidence of benign, complex, or malignant pheochromocytoma (combined) was increased in mid-dose males and high-dose females. The increased incidences in the high-dose females were considered to be exposure related. The NTP (1998) concluded that there was some evidence of carcinogenicity in male rats, based on increased incidences of alveolar/bronchiolar neoplasms. Marginal increases in adrenal medullary tumors in male rats may have been related to exposure to cobalt sulphate heptahydrate. There was clear evidence of carcinogenicity in female rats, based on

increased incidences of alveolar/bronchiolar neoplasms and pheochromocytoma of the adrenal medulla.

Nonneoplastic lesions of the respiratory tract generally were more severe in rats than in mice. Significantly increased incidences of inflammatory, fibrotic, and proliferative lesions were observed in all dose groups in the lung (hyperplasia and metaplasia of the alveolar epithelium, granulomatous inflammation, interstitial fibrosis, and proteinosis), nose (lateral wall hyperplasia and olfactory epithelium atrophy), and larynx (squamous metaplasia of the epiglottis). The NTP characterized all fibroproliferative lesions as atypical hyperplasia. Several animals had malignant neoplasms with a very prominent fibrous component, some of which presumably had progressed from atypical hyperplasia. The NTP (1998) concluded that it was clear that all the morphologic variants of proliferative lesions represented a response to cobalt sulphate heptahydrate.

#### *Summary of NTP carcinogenicity in mice and rats*

Under the conditions of these 2-year inhalation studies there was some evidence of carcinogenicity of cobalt sulphate in male F344/N rats based on increase incidences of alveolar/bronchiolar neoplasms. Marginal increase of pheochromocytomas of the adrenal medulla may have been related to exposure to cobalt sulphate heptahydrate. There was clear evidence of the carcinogenic activity in female F344/N rats based on incidences of alveolar/bronchiolar neoplasms and pheochromocytomas of the adrenal medulla in groups exposed to cobalt sulphate heptahydrate. There was clear evidence of carcinogenic activity of cobalt sulphate heptahydrate in male and female B6C3f1 mice base on increase incidences of alveolar/bronchiolar neoplasms.

### **1.8.1.3 Carcinogenicity: dermal**

No carcinogenic studies were available using the dermal route of exposure.

### **1.8.2 Human information**

No studies are available specifically to cobalt(II) sulphate and its hydrates in humans.

### **1.8.3 Other relevant information**

#### **1.8.3.1 In vivo data**

##### Other cobalt compounds

Syrian golden hamsters (51 per group) exposed by inhalation (as cobalt oxide) at 10.0 mg/m<sup>3</sup> for 7h/day, 5 days/week, for a lifetime developed emphysema, but the incidence of pulmonary tumors was not different from controls. While tobacco smoke exposure induced pulmonary tumors in 14/51 animals, the incidence in animals exposed to both tobacco smoke and cobalt oxide was 11/51 (Wehner *et al.*, 1977).

Different forms of cobalt (pieces, powder, alloy particles, soluble and insoluble salts) have been investigated for possible carcinogenic effects in long-term animal experiments with rabbits, rats, mice, hamster and guinea-pigs. Several routes of administration of the compound have been used,

but mainly intramuscular injections (Jensen A.A, & Tüchsen, F., 1990). See Annex II for a summary of the results.

### 1.8.3.2 Human data

Several epidemiological studies addressing cancer risk in the hard-metal and cobalt production industry have been reported.

*The following information was taken from the RoC Background Document for Cobalt Sulphate, for Cobalt, published in 2002. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

#### Hard-metal industry

Four mortality studies of the hard-metal industry have been conducted in Sweden and France. Most of these studies investigated the effects of occupational exposure to hard metals (cobalt and tungsten) or metallic cobalt (Hogstedt *et al.* 2000, Lasfargues *et al.* 1994, Moulin *et al.* 1998, Wild *et al.* 2000; reported in IARC 2006). These studies have reported increases in lung cancer from occupational inhalation exposure to hard metal.

Hogstedt & Alexandersson (1990) reported on 3163 male workers, each with at least 1 year of occupational exposure at hard metal manufacturing plants in Sweden during 1940–1982 and followed from 1951 to 1982. Exposures included a number of other substances used in the production of hard metal, such as tungsten carbide. The lung cancer SMR was 1.34 (95% CI = 0.77–2.13); the all-cause mortality SMR was slightly less than unity. Among workers with more than 10 years of employment and more than 20 years since first exposure, a significant excess of lung cancer mortality was observed (SMR = 2.78, 95% CI = 1.11–5.72). Smoking habits among hard metal workers were reported to be similar to those of the male Swedish population.

Lasfargues *et al.* (1994) conducted a cohort mortality study of 709 male workers employed for  $\geq 1$  year at a hard metal manufacturing plant (including two workshops) in central France. Follow-up was from 1956 to 1989. Categories of exposure were defined based on dust and urinary measurements of cobalt taken in 1983. Workers who had been employed in jobs with different degrees of exposure were categorized according to their highest exposure. Job histories were obtained from company records; before 1970, however, the records were often missing. The overall mortality did not differ from expected (SMR = 1.05, 95% CI = 0.82–1.31). Mortality due to lung cancer was in excess (SMR = 2.13, 95% CI = 1.02–3.93), and the excess was highest among workers in the areas with highest exposures to cobalt (SMR = 5.03, 95% CI = 1.85–10.95).

An industry-wide cohort mortality study of the French hard metal industry was conducted by Moulin *et al.* (1998) to further evaluate the potential association of lung cancer risk with occupational exposure to cobalt and tungsten carbide. The cohort included 5777 men and 1682 women (total = 7459 workers) from 10 factories (most of which were in eastern France), including the factory studied by Lasfargues *et al.* (1994). The all-cause mortality SMR was 0.93; the lung cancer SMR was 1.30 (95% CI = 1.00–1.66). Sixty-one of the 63 lung cancer deaths in the cohort were included in a nested case–control study. Three controls that were alive on the date the case died were matched to each case based on gender and age. Occupational exposure of the cases and controls was evaluated based on a job–exposure matrix involving 320 job periods and exposure intensity scores from 0 to 9. Data on smoking were available for 80% of the cases and controls. The odds ratio for workers exposed to cobalt and tungsten carbide was 1.93 (95% CI = 1.03–3.62) for exposure levels 2–9 versus levels 0–1. The odds ratio for cobalt with tungsten carbide increased



with duration of exposure and cumulative dose, but less so for level of exposure. Adjustments for exposure to known or suspected carcinogens and smoking did not change the results.

A study of the largest plant in the multicentre cohort of Moulin *et al.* (1998) was conducted by Wild *et al.* (2000). The authors used the same job–exposure matrix of Moulin *et al.* (1998) but made use of the more detailed job histories available. Follow-up was from 1968 to 1992. The SMR for the all-cause mortality was 1.02 (95% CI = 0.92–1.13). The SMR for lung cancer among men was increased (SMR = 1.70, 95% CI = 1.24–2.26). The lung cancer SMR for exposure to hard metal dust at an intensity score of  $\geq 2$  was 2.02 (95% CI = 1.32–2.96). In a Poisson regression model including terms for smoking and other occupational carcinogens, the risk for lung cancer increased with duration of exposure to cobalt with tungsten before sintering; there was no evidence of risk from exposure to sintered hard metal dust.

#### Cobalt production industry

Moulin *et al.* (1993) studied the mortality of a cohort of 1148 workers in a cobalt electrochemical plant in France that produced cobalt and sodium by electrochemistry, extending the follow-up of an earlier study by Mur *et al.* (1987; reported in IARC 1991). The cohort included all men who had worked at the plant for a minimum of 1 year between 1950 and 1980. Follow-up was to the end of 1988 and was obtained for 99% of French-born workers. Because of difficulty in follow-up of non-French workers, results were presented only for the 870 French-born (i.e. a loss to follow-up of 24%). The SMR for all causes of death was 0.95 (95% CI = 0.78–1.26). The SMR for lung cancer was 1.16 (95% CI = 0.24–3.40) among workers exclusively employed in cobalt production and 1.18 (95% CI = 0.32–3.03) for workers ever employed in cobalt production.

#### Other cobalt compounds

Tüchsen *et al.* (1996) did not find evidence of an increased risk of lung cancer among a cohort of 874 women occupationally exposed to poorly soluble cobalt–aluminate spinel in two porcelain production factories in Denmark compared with that expected based on national rates for Danish women.

#### *Summary on human data*

Available studies of the carcinogenic effects of cobalt in occupationally-exposed humans have reported mixed results, with both positive and negative results. Several studies of hard metals (cobalt and tungsten carbide) exposure to humans (Lasfargues *et al.* 1994; Moulin *et al.* 1998; Wild *et al.* 2000) have reported increases in lung cancer from occupational inhalation exposure to hard metal (ASTDR, 2004). Even though these studies consistently reported an increased risk of lung cancer among workers exposed to cobalt, the workers were also exposed to other agents (e.g., tungsten carbide) and probably were not exposed to soluble cobalt (Report on Carcinogens, 2004). Thus, it is difficult to ascertain whether the increased incidence of lung cancer is attributable to cobalt. Only one study investigated the effects of exposure to cobalt salts. The initial study reported an increased risk of lung cancer among cobalt production workers, but a follow-up study of the same workers found no increased risk of cancer (Mur *et al.* 1987, Moulin *et al.* 1993). Interpretation of this finding is limited by the small number of exposed workers who developed cancer.

The IARC in volume 52 (1991) reviewed the carcinogenic risk to humans of cobalt and cobalt compounds and concluded the evidence of carcinogenicity was *inadequate*.

### **1.8.3.3 IARC assessments**

The IARC has classified cobalt and cobalt compounds as possibly carcinogenic to humans (Group 2B) based on sufficient evidence that cobalt metal powder and cobaltous oxide are carcinogenic in

animals (IARC, 1991). The IARC recently (2006) classified cobalt metal with tungsten carbide as probably carcinogenic to humans (Group 2A). Cobalt metal without tungsten carbide and cobalt sulphate and soluble cobalt(II) salts were classified as possibly carcinogenic to humans (Group 2B) (IARC, 2006). This was based on sufficient evidence in experimental animals for the carcinogenicity of cobalt sulphate and cobalt metal powder

#### **1.8.4 Summary and discussion of carcinogenicity**

Lifetime inhalation of cobalt(II)sulphate resulted in increased tumor incidences in both rats and mice; NTP reported that there was some evidence of carcinogenicity in male Fischer 344 (F344) strain rats, and clear evidence of carcinogenicity in female F344 strain rats and male and female B6C3F1 strain mice following inhalation exposure. Oral and dermal data on the carcinogenic effects of cobalt and cobalt compounds are not available.

TC-C&L concluded on the then available data after discussions in November 2003, May 2004 and September 2004 that cobalt(II) sulphate and cobalt(II) sulphate heptahydrate should be classified with R49 (summary record ECBI/139/04 rev.2).

### **1.9 Toxicity for reproduction**

#### **1.9.1 Effects on fertility**

##### **1.9.1.1 Non-human information**

*The following information was taken from the ASTDR Toxicological profile for cobalt, published in 2004. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

In animals, long-term exposure to cobalt-containing aerosols has resulted in effects on reproductive end points (see section 5.8.2). Testicular atrophy was reported in rats, but not in mice, exposed to 19 mg cobalt/m<sup>3</sup> as cobalt sulphate over 16 days (Bucher *et al.* 1990; NTP 1991). Following exposure of mice to cobalt (as cobalt sulphate) for 13 weeks, a decrease in sperm motility was found at 1.14 mg cobalt/m<sup>3</sup>, and testicular atrophy was found at 11.4 mg cobalt/m<sup>3</sup>. A significant increase in the length of the estrous cycle was reported in female mice exposed to 11.4 mg cobalt/m<sup>3</sup> for 13 weeks (Bucher *et al.* 1990; NTP 1991). No effects on the male or female reproductive systems were observed in rats similarly treated for 13 weeks (Bucher *et al.* 1990; NTP 1991), or in mice or rats exposed to up to 1.14 mg cobalt/m<sup>3</sup> for 104 weeks (Bucher *et al.* 1999; NTP 1998).

##### **1.9.1.2 Human information**

No human studies were available specifically to cobalt(II) sulphate and its hydrates regarding fertility and developmental effects in humans. There is some information available however of human exposure to cobalt (as cobalt chloride) see section 1.9.3.2.

## 1.9.2 Other relevant information

### 1.9.2.1 Effects on fertility

Several studies have been conducted with soluble cobalt compounds to explore their potential effect on fertility.

*The following information was taken from the ASTDR Toxicological profile for cobalt, published in 2004. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

Testicular degeneration and atrophy have been reported in rats exposed to 13.3–58.9 mg cobalt/kg/day as cobalt chloride for 2–3 months in the diet or drinking water (Corrier *et al.* 1985; Domingo *et al.* 1984; Mollenhauer *et al.* 1985; Nation *et al.* 1983; Pedigo and Vernon 1993; Pedigo *et al.* 1988), or in mice exposed to 43.4 mg cobalt/kg/day as cobalt chloride for 13 weeks in the drinking water (Anderson *et al.* 1992, 1993). Pedigo and Vernon (1993) reported that cobalt dichloride (400 ppm in drinking water for 10 weeks) increased pre-implantation losses per pregnant female in the dominant lethal assay by compromising the fertility of treated male mice.

#### *Other publications*

In an abstract reported by Elbetieha *et al.* (2004), sexually mature male mice exposed to cobalt(II) chloride at 200, 400, or 800 mg/l in their drinking-water for 12 weeks were assessed for effects on fertility by breeding these exposed males to unexposed females. Fertility, as measured by successful matings, was reduced in mice exposed to cobalt chloride at 400 and 800 mg/l (internal doses of  $46.91 \pm 4.78$  and  $93.01 \pm 6.76$  mg/kg body weight per day, respectively). The number of implantation sites was significantly reduced in females mated with exposed males at 400 and 800 mg/l. The number of viable fetuses was decreased in females mated with males at all three exposure levels. In the 800 mg/l males, absolute epididymal weight was significantly decreased, whereas relative and absolute testes weights were decreased in males exposed to both 400 and 800 mg/l. Epididymal sperm count was decreased in males of all three exposure levels. At 400 and 800 mg/l, males also exhibited reduced testicular sperm counts and daily sperm production. The testes displayed severe abnormalities, including hypertrophy of the interstitial Leydig cells, congested blood vessels, degeneration of the spermatogonial cells, and necrosis of seminiferous tubules and interstitial tissue.

## 1.9.3 Developmental toxicity

### 1.9.3.1 Non-human information

*The following information was taken from the ASTDR Toxicological profile for cobalt, published in 2004. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

Szakmary *et al.* (2001) reported that exposure of pregnant rats to 0–38 mg Co/kg-day as cobalt sulphate did not result in changes in fetal death rates, maternal body weight gain, average litter size, or average fetal or placental weights; however, a dose-related trend was seen for the percent of fetuses with retarded body weights. In contrast, no effects on fetal growth or survival were found following exposure of rats to 24.8 mg cobalt/kg/day as cobalt chloride during gestation days 6–15 (Paternian *et al.* 1988). In mice, exposure to 81.7 mg cobalt/kg/day as cobalt chloride during

gestation days 8–12 was reported to have no effect on fetal growth or mortality in mice (Seidenberg *et al.* 1986). In a later mouse study that exposed pregnant mice to 19 mg Co/kg-day as cobalt sulphate, no changes in litter size, postimplantation loss, or average fetal or placental weights were seen; the only difference seen was an increase in the percent of fetuses with retarded body weights (Szakmary *et al.* 2001). The same study reported that rabbits exposed to  $\geq 38$  mg Co/kg-day, as cobalt sulphate, showed nearly complete maternal lethality, and complete fetal loss. Rabbits exposed to 7.6 mg Co/kg, as cobalt sulphate, showed significant increases in mortality and fetal resorption, as well as an increase in fetuses with retarded body weight (Szakmary *et al.* 2001)

### **1.9.3.2 Human information**

No developmental effects on human fetuses were observed following treatment of pregnant women with cobalt chloride to raise hematocrit and hemoglobin levels that are often depressed during pregnancy. Dosages up to 0.6 mg cobalt/kg/day for 90 days were given (Holly 1955). Examination of the fetuses, however, was limited to the reporting of obvious birth defects, and exposure only occurred in the final trimester (ASTDR, 2004)

## **1.9.4 Other relevant information**

### **1.9.4.1 Developmental toxicity**

Several studies have been conducted with soluble cobalt compounds to explore their potential effect on development.

*The following information was taken from the ASTDR Toxicological profile for cobalt, published in 2004. Information on the references cited in this section (in parenthesis) can be found in the cited summary document.*

Oral exposure of female rats to cobalt chloride at 5.4 or 21.8 mg cobalt/kg/day from gestation day 14 through lactation day 21 has been shown to result in stunted growth and decreased survival, respectively, of newborn pups (Domingo *et al.* 1985b). The effects on the offspring occurred at levels that also caused maternal toxicity (reduced body weight and food consumption, and altered hematological measurements) and might therefore have been an indirect effect of maternal toxicity rather than a direct effect of cobalt on the fetus (Domingo *et al.* 1985b). Teratogenic effects were not observed.

#### *Other publications*

Wide (1984) reported that a single intravenous injection of cobalt chloride hexahydrate into pregnant NMRI mice (5 mM per animal in the tail vein; [120  $\mu$ g/animal]) on day 8 of gestation significantly affected fetal development (71% of skeletal malformations versus 30% in controls); in animals injected at day 3 of gestation, no interference with implantation was noted. In the same experiment but replacing cobalt chloride by tungstate (25 mM of W per animal; [460  $\mu$ g/animal]) a significant increase in the number of resorptions was observed (19% versus 7% in controls), but no skeletal malformations (RoC, 2006).

Paksy *et al.* (1999) found that in-vitro incubation of postblastocyst mouse embryos with cobalt(II) ions (as cobalt sulphate) adversely affected the development stages at a concentration of 100  $\mu$ M and decreased the trophoblast area (at a concentration of 10  $\mu$ M) (ASDTR, 2004).

### **1.9.5 Summary and discussion of reproductive toxicity**

Effects on male and female sexual function were observed after repeated inhalatory exposure of rats and mice. Mice and rats exposed to high oral doses of cobalt dichloride for 2-3 months experience testicular degeneration and atrophy and reduced fertility. Stunted growth and decreased survival were observed among newborn rats at dose levels that also caused maternal toxicity in one study. Similar doses did not produce such effects in another study of rats or in a study of mice. Rabbits exposed at high doses were found to have increased mortality, fetal resorption, and number of fetuses with decreased body weight. No teratogenic effects were reported in any of the studies.

TC-C&L concluded on the then available data after discussions in November 2003, May 2004 and September 2004 that cobalt(II) sulphate and cobalt(II) sulphate heptahydrate should be classified with R60 (summary record ECBI/139/04 rev.2).

### **1.10 Other effects**

Not relevant for this type of dossier.

## 2 ANNEX II: ANIMAL CARCINOGENICITY AND RELATED EFFECTS DATA OF OTHER COBALT COMPOUNDS.

Reference	Species/ Strain	Sex	Dose Schedule	Experimental parameter/observation	Group				Comments
					0	1	2	3	
<b>Cobalt metal powder</b>									
Heath (1954a, 1956)	Rat Hooded	M	i.m. single inj. fowl serum	Dose (mg)	0	28			
				Survival (122 weeks)	Not given				
		F		Dose (mg)	0	28	28		
				Survival (122 weeks)	Not given	5/10	8/10		
				Local sarcoma	0/10				
Health & Daniel (1962)	Rat Hooded	F	intrathoracic in serum	Dose (mg)	0	28			
				Survival (3 days)		12/20			
				Thoracic tumour		4/12			
Jasmin & Riopelle (1976)	Rat Sprague-Dawley	F	intrarenal	Dose (mg)	0	5			Inadequate
				Survival (12 months)	Not given	0/18			
				Kidney tumour	0/16				
<b>Cobalt alloys</b>									
Heath <i>et al.</i> (1971); Swanson <i>et al.</i> (1973)	Rat Hooded	F	i.m. single inj., wear particles from Co/Cr/Mo in horse serum	Dose (mg)	0	28			
				Survival (29 months)	Not given	23/80			
				Local sarcoma					
Gaechter <i>et al.</i> (1977)	Rat Sprague-Dawley	M+F	i.m. impl. Co/Cr/W/Ni/C/Mn/Si/Fe (1.6 x 8 mm)	Dose (polished rod)	0 <sup>a</sup>	0 <sup>a</sup>	1		Not significant difference in distant tumours
				Survival (2 years)	Not given	0/30	0/90		
				Local tumour	0/30				
Memoli <i>et al.</i> (1986)	Rat Sprague-Dawley	M+F	Intraoss. impl., Co/Cr/Ni/Mo/W/Zr	Dose (powder, wire, rod)	0 <sup>a</sup>	0 <sup>a</sup>	1		
				Survival (30 months)	Not given	0/26	7/76 <sup>b</sup>		
				Local sarcoma	0/51				
Memoli <i>et al.</i> (1960)	Rat Wister	M+F	s.c. impl. Co/Cr/Mo/Ni	Dose (pellets-2mm diam)					
				Survival (27 months)	Not given	0/10			
				Local sarcoma					
<b>Cobalt alloys (contd)</b>									

Reference	Species/ Strain	Sex	Dose Schedule	Experimental parameter/observation	Group				Comments
					0	1	2	3	
Meachim <i>et al.</i> (1982)	Rat Wistar and hooded	F	i.m. impl. Co/Cr/Mo fine and coarse particles	Dose (mg) Survival (2 years) Local tumour	0 5/50 0	28 11/51 0	28 7/61 0	28 0/53 0	
Steinhoff & Mohr (1991)	Rat Sprague- Dawley	M+F	3 i.p. inj., Co/Al/Cr spinel powder	Dose (mg/kg bw) Survival (2 years) Local tumour	0 Not given 1/20	200 2/20			
Steinhoff & Mohr (1991)	Rat Sprague- Dawley	M+F	Intratracheal inst. 1 x 2 weeks Co/Al/Cr spinel 2 years	Dose (mg/kg bw) Survival (2 years) Squamous-cell tumour of the lung	0 Not given 0/200	10 3/100			
Meachim <i>et al.</i> (1982)	Guinea-pig	F	i.m. impl. Co/Cr/Mo powder	Dose (mg) Survival (3 years) Local tumour Local fibroblastic hyperplasia		28 12/46 0/46 8/46			
<b>Cobalt[II] oxide</b>									
Gilman & Ruckerbauer (1962)	Mouse Swiss	F	i.m. inj., in each thigh	Dose (mg/site) Survival (13 weeks) Local tumour sarcoma	0 48/51 0/48	10 46/75 0/46			
Steinhoff & Mohr (1991)	Rat Sprague- Dawley	M  F	Intratracheal inst. 1 x 2 weeks 2 years	Dose (mg/kg bw) Survival (2 years) Benign squamous pulmonary tumour Bronchiolalveolar adenoma Pulmonary adenocarcinoma Bronchialveolar adenocarcinoma  Dose (mg/kg bw) Survival (2 years) Bronchiolalveolar adenoma Bronchialveolar adenocarcinoma	0 Not given 0/100 0/100 0/100 0/100  0 Not given 0/100 0/100	2 1/50 0/50 2/50 2/50 1/50  2 10 1/50 0/50 1/50	10 0/50 2/50 2/50 1/50		
Gilman & Ruckerbauer (1962)	Rat Wistar	M+F	i.m. inj.	Dose (mg/site) Survival (90 days) Local sarcoma	0 10/10 0/10	30 10/10 5/10			
Gilman (1962)	Rat Wistar	M+F	i.m. inj.	Dose (mg/site) Survival (13 weeks) Local sarcoma		20 24/32 13/29 sites			
<b>Cobalt[II] oxide (contd)</b>									
Steinhoff & Mohr (1991)	Rat	M	s.c. inj.	Dose (mg/kg bw)	0	2	10		

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Reference	Species/ Strain	Sex	Dose Schedule	Experimental parameter/observation	Group				Comments
					0	1	2	3	
	Sprague-Dawley		2 mg/kg bw 5/weeks or 10 mg/kg bw 1/week for 2 years	Survival (2 years) Local malignant tumour	Not given 0/20	5/10	4/10		
Steinhoff & Mohr (1991)	Rat Sprague-Dawley	M+F	3 i.p. inj. at 2-month intervals	Total dose (mg/kg bw) Survival (2 years) Local malignant tumour	0 Not given 1/20	200 14/20			
Wehner <i>et al.</i> (1977)	Hamster ENG:ELA	M	Inhalation 7h/day 5d/week for life	Dose (mg/m <sup>3</sup> ) Survival (18 months) Reticulum-cell sarcoma Carcinoma Lymphosarcoma Leukaemia Plasma cell tumour	0 7/51 0/51 0/51 0/51 0/51 1/51	200 9/51 1/51 1/51 0/51 0/51 0/51			No statistical difference
<b>Cobalt [II] sulphide</b>									
Gilman (1962)	Rat Wistar	M+F	i.m. inj.	Dose (mg/site) Survival (13 weeks) Local sarcoma		20 29/30 35/58 sites			
Jasmin & Riopelle (1976)	Rat Sprague-Dawley	F	intrarenal	Dose (mg) Survival (12 months) Kidney tumour	0 Not given 0/16	5 0/20			Inadequate
<b>Cobalt[II] chloride</b>									
Shabaan <i>et al.</i> (1977)	Rat Wistar	M	s.c. 2 x 5 day, 9-d interval	Dose (mg/kg bw) Survival <sup>c</sup> Subcutaneous sarcoma	0 19/20 0/19	40 11/20 8/11	40 16/20 6/16		$p < 0.001$ (Fisher exact test)
<b>Cobalt naphthenate</b>									
Nowak (1966)	Mouse NS	NS	i.m. inj. NS	Dose (mg) Survival Tumour of the striated muscle	0	0.2 8/30			Inadequate
Nowak (1961)	Rabbit	M	i.m. i.v. i. pleural i. hepatic	Dose unspecified	0	5 1 1 1			Inadequate
<b>Cobalt [III] acetate</b>									
Stoner <i>et al.</i> (1976)	Mouse	M+F	i.p. inj.	Total dose (mg/kg bw)	0	95	237	475	Not significant



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Reference	Species/ Strain	Sex	Dose Schedule	Experimental parameter/observation	Group				Comments
					0	1	2	3	
	Strain A		3/week, 24 doses	Survival (30 weeks) Pulmonary tumour	19/20 7/19	20/20 8/20	20/20 8/20	17/20 10/17	

<sup>a</sup>group 0, untreated; group 1, sham-treated; <sup>b</sup>Powder, 1/18 sarcoma; MP35N, 3/26 sarcomas; compacted wire, 3/32 sarcomas; <sup>c</sup>2 months for groups 0 and 1; at 8 months for group 2; NS, not specified.

i.m., intramuscular; inj, injection; impl., implantation; intraoss, intra-osseous; s.c., subcutaneous; inst., instillation; i.p., intraperitoneally, i.v., intravenous