



WORLD HEALTH ORGANIZATION  
INTERNATIONAL AGENCY FOR RESEARCH ON CANCER

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**Volume 49**  
**Chromium, Nickel and Welding**  
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# NICKEL AND NICKEL COMPOUNDS

## Nickel compounds (Group 1)

### Metallic nickel (Group 2B)

For definition of Groups, see [Preamble Evaluation](#).

**VOL.:** 49 (1990) (p. 257)

#### **Nickel**

**CAS No.:** 7440-02-0

#### **Ferronickel**

**CAS No.:** 11133-76-9

#### **Nickel aluminium alloys**

**CAS Nos:** 61431-86-5; 37187-84-1

#### **Nickel-containing steels**

**CAS No.:** 12681-83-3

#### **High nickel alloys**

**CAS Nos.:** 12605-70-8; 11121-96-3; 12675-92-2; 11105-19-4

#### **Nickel hydroxide**

**CAS Nos:** 12054-48-7; 11113-74-9 (amorphous)

#### **Nickel monoxide**

**CAS Nos:** 1313-99-1; 11099-02-8; 34492-97-2

#### **Nickel trioxide**

**CAS No.:** 1314-06-3

#### **Nickel disulfide**

**CAS Nos:** 12035-51-7; 12035-50-6

#### **Nickel sulfide**

**CAS Nos:** 16812-54-7; 11113-75-0 (amorphous); 1314-04-1

#### **Nickel subsulfide**

**CAS Nos:** 12035-72-2; 12035-71-1

#### **Pentlandite**

**CAS Nos:** 53809-86-2; 12174-14-0

#### **Nickel carbonate**

**CAS No.:** 3333-67-3

#### **Basic nickel carbonates**

**CAS Nos:** 12607-70-4; 12122-15-5

**Nickel acetate**  
**CAS No.:** 373-02-4

**Nickel acetate tetrahydrate**  
**CAS No.:** 6018-89-9

**Nickel ammonium sulfates**  
**CAS No.:** 15699-18-0

**Nickel ammonium sulfate hexahydrate**  
**CAS Nos:** 25749-08-0; 7785-20-8

**Nickel chromate**  
**CAS No.:** 14721-18-7

**Nickel chloride**  
**CAS No.:** 7718-54-9

**Nickel chloride hexahydrate**  
**CAS No.:** 7791-20-0

**Nickel nitrate hexahydrate**  
**CAS No.:** 13478-00-7

**Nickel sulfate**  
**CAS No.:** 7786-81-4

**Nickel sulfate hexahydrate**  
**CAS No.:** 10101-97-0

**Nickel sulfate heptahydrate**  
**CAS No.:** 10101-98-1

**Nickel carbonyl**  
**CAS No.:** 13463-39-3

**Nickel antimonide**  
**CAS No.:** 12035-52-8

**Nickel arsenides**  
**CAS Nos:** 27016-75-7; 1303-13-5; 12256-33-6; 12044-65-4; 12255-80-0

**Nickel selenide**  
**CAS Nos:** 1314-05-2; 12201-85-3

**Nickel subselenide**  
**CAS No.:** 12137-13-2

**Nickel sulfarsenide**  
**CAS Nos:** 12255-10-6; 12255-11-7

**Nickel telluride**

CAS Nos: 12142-88-0; 24270-51-7

**Nickel titanate**

CAS No.: 12035-39-1

**Chrome iron nickel black spinel**

CAS No.: 71631-15-7

**Nickel ferrite brown spinel**

CAS No.: 68187-10-0

**Nickelocene**

CAS No.: 1271-28-9

## 5. Summary of Data Reported and Evaluation

### 5.1 Exposure data

Nickel, in the form of various alloys and compounds, has been in widespread commercial use for over 100 years. Several million workers worldwide are exposed to airborne fumes, dusts and mists containing nickel and its compounds. Exposures by inhalation, ingestion or skin contact occur in nickel and nickel alloy production plants as well as in welding, electroplating, grinding and cutting operations. Airborne nickel levels in excess of 1 mg/m<sup>3</sup> have been found in nickel refining, in the production of nickel alloys and nickel salts, and in grinding and cutting of stainless-steel. In these industries, modern control technologies have markedly reduced exposures in recent years. Few data are available to estimate the levels of past exposures to total airborne nickel, and the concentrations of individual nickel compounds were not measured.

Occupational exposure has been shown to give rise to elevated levels of nickel in blood, urine and body tissues, with inhalation as the main route of uptake. Nonoccupational sources of nickel exposure include food, air and water, but the levels found are usually several orders of magnitude lower than those typically found in occupational situations.

### 5.2 Experimental carcinogenicity data

#### **Metallic nickel and nickel alloys**

*Metallic nickel* was tested by inhalation exposure in mice, rats and guinea-pigs, by intratracheal instillation in rats, by intramuscular injection in rats and hamsters, and by intrapleural, subcutaneous, intraperitoneal and intrarenal injection in rats. The studies by inhalation exposure were inadequate for assessment of carcinogenicity. After intratracheal instillation, it produced significant numbers of squamous-cell carcinomas and adenocarcinomas of the lung. Intrapleural injections induced sarcomas. Subcutaneous administration of metallic nickel pellets induced sarcomas in rats, intramuscular injection of nickel powder induced sarcomas in rats and hamsters, and intraperitoneal injections induced carcinomas and sarcomas. No significant increase in the incidence of local kidney tumours was seen following intrarenal injection.

*Nickel alloys* were tested by intramuscular, intraperitoneal and intrarenal injection and by subcutaneous implantation of pellets in rats. A ferronickel alloy did not induce local tumours after intramuscular or intrarenal injection. Two powdered nickel alloys induced malignant tumours following intraperitoneal injection, and one nickel alloy induced sarcomas following subcutaneous implantation in pellets.

#### **Nickel oxides and hydroxides**

*Nickel monoxide* was tested by inhalation exposure in rats and hamsters, by intratracheal instillation in rats, by intramuscular administration in two strains of mice and two strains of rats, and by intrapleural, intraperitoneal and intrarenal injection in rats. The two studies by inhalation exposure in rats were inadequate for an assessment of carcinogenicity; lung tumours were not induced in the study in hamsters. Intratracheal instillation resulted in a significant incidence of lung carcinomas. Local sarcomas were induced at high incidence after intrapleural, intramuscular and intraperitoneal injection. No renal tumour was seen following intrarenal injection.

Two studies in rats in which *nickel trioxide* was injected intramuscularly or intracerebrally were inadequate for evaluation.

In a study in which *nickel hydroxide* was tested in three physical states by intramuscular injection in rats, local sarcomas were induced by dry gel and crystalline forms. Local sarcomas were induced in one study in which nickel hydroxide was tested by intramuscular injection in rats.

### **Nickel sulfides**

*Nickel subsulfide* was tested by inhalation exposure and intratracheal instillation in rats, by subcutaneous injection to mice and rats, by intramuscular administration to mice, rats, hamsters and rabbits, by intrapleural, intraperitoneal, intrarenal, intratesticular, intraocular and intra-articular administration in rats, by injection into retroperitoneal fat in rats, by implantation into rat heterotopic tracheal transplants and by administration to pregnant rats.

After exposure by inhalation, rats showed a significant increase in the incidence of benign and malignant lung tumours. Multiple intratracheal instillations resulted in malignant lung tumours (adenocarcinomas, squamous-cell carcinomas and mixed tumours).

A high incidence of local sarcomas was observed in rats after intrapleural administration. Subcutaneous injection induced sarcomas in mice and rhabdomyosarcomas and fibrous histiocytomas in rats. Nickel subsulfide has been shown consistently to induce local sarcomas following intramuscular administration, and dose-response relationships were demonstrated in rats and hamsters. The majority of the sarcomas induced were of myogenic origin, and the incidences of metastases were generally high. In rats, strain differences in tumour incidence and local tissue responses were seen. After intramuscular implantation of millipore diffusion chambers containing nickel subsulfide, a high incidence of local sarcomas was induced.

Mesotheliomas were included among the malignancies induced by intraperitoneal administration. Intrarenal injections resulted in a dose-related increase in the incidence of renal-cell neoplasms. A high incidence of sarcomas (including some rhabdomyosarcomas) was seen after intratesticular injection, and a high incidence of eye neoplasms (including retinoblastomas, melanomas and gliomas) after intraocular injection. Intra-articular injection induced sarcomas (including rhabdomyosarcomas and fibrous histiocytomas), and injection into retroperitoneal fat induced mainly fibrous histiocytomas. Implantation of pellets containing nickel subsulfide into rat heterotopic tracheal transplants induced both carcinomas and sarcomas; in the group given the highest dose, sarcomas predominated. The study in which pregnant rats were injected with nickel subsulfide early in gestation was inadequate for evaluation.

*Nickel disulfide* was tested by intramuscular and intrarenal injection in rats. High incidences of local tumours were induced.

*Nickel monosulfide* was tested by intramuscular and intrarenal injection in rats. The crystalline form induced local tumours, but the amorphous form did not.

*Nickel ferrosulfide* matte induced local sarcomas after administration by intramuscular injection in rats.

### **Nickel salts**

*Nickel sulfate* was tested for carcinogenicity by intramuscular and intraperitoneal injection in rats. Repeated intramuscular injections did not induce local tumours; however, intraperitoneal injections induced malignant tumours in the peritoneal cavity.

*Nickel chloride* was tested by repeated intraperitoneal injections in rats, inducing malignant tumours in the peritoneal cavity.

*Nickel acetate* was tested by intraperitoneal injection in mice and rats. After repeated intraperitoneal injections in rats, malignant tumours were induced in the peritoneal cavity. In strain A mice, lung adenocarcinomas were induced in one study and an increased incidence of pulmonary adenomas in two studies.

Studies in rats in which *nickel carbonate* was tested for carcinogenicity by intraperitoneal administration and *nickel fluoride* and *nickel chromate* by intramuscular injection could not be evaluated.

### **Other forms of nickel**

*Nickel carbonyl* was tested for carcinogenicity by inhalation exposure and intravenous injection in rats. After inhalation exposure, a few lung carcinomas were observed two years after the initial treatment. Intravenous injection induced an increase in the overall incidence of neoplasms, which were located in several organs.

*Nickelocene* induced some local tumours in rats and hamsters following intramuscular injection.

One sample of *dust collected in nickel refineries*, containing nickel subsulfide and various proportions of nickel monoxide and nickel sulfate, induced sarcomas in mice and rats following intramuscular injection. Intraperitoneal administration of two samples of dust, containing unspecified nickel sulfides and various proportions of nickel oxide, soluble nickel and metallic nickel, induced sarcomas in rats. In a study in which hamsters were given prolonged exposure to a *nickel-enriched fly ash* by inhalation, the incidence of tumours was not increased.

Intramuscular administration to rats of *nickel sulfarsenide*, two *nickel arsenides*, *nickel antimonide*, *nickel telluride* and two *nickel selenides* induced significant increases in the incidence of local sarcomas, whereas administration of *nickel monoarsenide* and *nickel titanate* did not. None of these compounds increased the incidence of renal-cell tumours in rats after intrarenal injection.

### **5.3 Human carcinogenicity data**

Increased risks for lung and nasal cancers were found to be associated with exposures during high-temperature oxidation of nickel matte and nickel-copper matte (roasting, sintering, calcining) in cohort studies in Canada, Norway (Kristiansand) and the UK (Clydach), with exposures in electrolytic refining in a study in Norway, and with exposures during leaching of nickel-copper oxides in acidic solution (copper plant) and extraction of nickel salts from concentrated solution (hydrometallurgy) in the UK (see Table 26).

The substantial excess risk for lung and nasal cancer among Clydach hydrometallurgy workers seems likely to be due, at least partly, to their exposure to 'soluble nickel'. Their estimated exposures to other types of nickel (metallic, sulfidic and oxidic) were up to an order of magnitude lower than those in several other areas of the refinery, including some where cancer risks were similar to those observed in hydrometallurgy. Similarly, high risks for lung and nasal cancers were observed among electrolysis workers at Kristiansand. These men were exposed to high estimated levels of soluble nickel and to lower levels of other forms of nickel. Nickel sulfate was the only or predominant soluble nickel species present in these areas.

The highest risks for lung and nasal cancers were observed among calcining workers, who were heavily exposed to both sulfidic and oxidic nickel. A high lung cancer rate was also seen among nickel plant cleaners at Clydach, who were heavily exposed to these insoluble compounds, with little or no exposure to soluble

nickel. The separate effects of oxides and sulfides cannot be estimated, however, as high exposure was always either to both, or to oxides together with soluble nickel. Workers in calcining furnaces and nickel plant cleaners were also exposed to high levels of metallic nickel.

Among hard-rock sulfide nickel ore miners in Canada, there was some increase in lung cancer risk, but exposure to other substances could not be excluded. In studies of open-cast miners of silicate-oxide nickel ores in the USA and in New Caledonia, no significant increase in risk was seen, but the numbers of persons studied were small and the levels of exposure were reported to be low.

No significant excess of respiratory tract cancer was observed in three studies of workers in high-nickel alloy manufacture or in a small study of users of metallic nickel powder. No increase in risk for lung cancer was observed in one small group of nickel electroplaters in the UK with no exposure to chromium.

In a case-control study, an elevated risk for lung cancer was found among persons exposed to nickel together with chromium-containing materials.

The results of epidemiological studies of stainless-steel welders are consistent with the finding of excess mortality from lung cancer among other workers exposed to nickel compounds, but they do not contribute independently to the evaluation of nickel since welders are also exposed to other compounds. (See also the monograph on welding.)

#### **5.4 Other relevant data**

Nickel and nickel compounds are absorbed from the respiratory tract, and to a smaller extent from the gastrointestinal tract, depending on dissolution and cellular uptake. Absorbed nickel is excreted predominantly in the urine. Nickel tends to persist in the lungs of humans and of experimental animals, and increased concentrations are seen notably in workers after inhalation of nickel. The nasal mucosa may retain nickel for many years.

Nickel carbonyl is the most acutely toxic nickel compound and causes severe damage to the respiratory system in experimental animals and in humans. Nickel causes contact dermatitis in humans. In experimental animals, adverse effects have also been documented in the respiratory system and in the kidney.

In four studies, the frequency of sister chromatid exchange did not appear to be increased in peripheral blood lymphocytes of nickel workers exposed during various processes. Enhanced frequencies of chromosomal gaps and/or anomalies were observed in single studies in peripheral blood lymphocytes of employees engaged in: (i) crushing, roasting and smelting (exposure mainly to nickel oxide and nickel subsulfide); (ii) electrolysis (exposure mainly to nickel chloride and nickel sulfate); and (iii) electroplating (exposure to nickel and chromium compounds). Enhanced frequencies were also seen in lymphocytes from retired workers who had previously been exposed in crushing, roasting and smelting and/or electrolysis.

Some nickel compounds have adverse effects on reproduction and prenatal development in rodents. Decreased fertility, reduction in the number of pups per litter and birth weight per pup, and a pattern of anomalies, including eye malformations, cystic lungs, hydronephrosis, cleft palate and skeletal deformities, have been demonstrated.

In one study, metallic nickel did not induce chromosomal aberrations in cultured human cells, but it transformed animal cells *in vitro*. Nickel oxides induced anchorage-independent growth in human cells *in vitro* and transformed cultured rodent cells; they did not induce chromosomal aberrations in cultured human cells in one study.

Crystalline nickel subsulfide induced anchorage-independent growth and increased the frequency of sister chromatid exchange but did not cause gene mutation in human cells *in vitro*. Crystalline nickel sulfide and subsulfide induced cell transformation, gene mutation and DNA damage in cultured mammalian cells; the

sulfide also induced chromosomal aberrations and sister chromatid exchange. Amorphous nickel sulfide did not transform or produce DNA damage in cultured mammalian cells. In one study, crystalline nickel sulfide and crystalline nickel subsulfide produced DNA damage in *Paramoecium*.

Nickel chloride and nickel nitrate were inactive in assays *in vivo* for induction of dominant lethal mutation and micronuclei, and nickel sulfate did not induce chromosomal aberrations in bone-marrow cells; however, nickel chloride induced chromosomal aberrations in Chinese hamster and mouse bone-marrow cells.

Soluble nickel compounds were generally active in the assays of human and animal cells *in vitro* in which they were tested.

Nickel sulfate and nickel acetate induced anchorage-independent growth in human cells *in vitro*. Nickel sulfate increased the frequency of chromosomal aberrations in human cells, and nickel sulfate and nickel chloride increased the frequency of sister chromatid exchange. Nickel sulfate did not induce single-strand DNA breaks in human cells. Nickel sulfate and nickel chloride transformed cultured mammalian cells. Chromosomal aberrations were induced in mammalian cells by nickel chloride, nickel sulfate and nickel acetate, and sister chromatid exchange was induced by nickel chloride and nickel sulfate. Nickel chloride and nickel sulfate also induced gene mutation, and nickel chloride caused DNA damage in mammalian cells. In one study, nickel sulfate inhibited intercellular communication in cultured mammalian cells.

Nickel sulfate induced aneuploidy and gene mutation in a single study in *Drosophila*; nickel chloride and nickel nitrate did not. Nickel chloride induced gene mutation and recombination in yeast.

In single studies, nickel acetate produced DNA damage in bacteria, while nickel nitrate did not; the results obtained with nickel chloride were inconclusive. In bacteria, neither nickel acetate, sulfate, chloride nor nitrate induced gene mutation.

Nickel carbonate induced DNA damage in rat kidney *in vivo*. Crystalline nickel subselenide transformed cultured mammalian cells, and nickel potassium cyanide increased the frequency of chromosomal aberrations. Nickelocene did not induce bacterial gene mutation. DNA damage was induced in calf thymus nucleohistone by nickel[III]-tetraglycine complexes.

## 5.5 Evaluation

There is *sufficient evidence* in humans for the carcinogenicity of nickel sulfate, and of the combinations of nickel sulfides and oxides encountered in the nickel refining industry.

There is *inadequate evidence* in humans for the carcinogenicity of metallic nickel and nickel alloys.

There is *sufficient evidence* in experimental animals for the carcinogenicity of metallic nickel, nickel monoxides, nickel hydroxides and crystalline nickel sulfides.

There is *limited evidence* in experimental animals for the carcinogenicity of nickel alloys, nickelocene, nickel carbonyl, nickel salts, nickel arsenides, nickel antimonide, nickel selenides and nickel telluride.

There is *inadequate evidence* in experimental animals for the carcinogenicity of nickel trioxide, amorphous nickel sulfide and nickel titanate.

The Working Group made the overall evaluation on nickel compounds as a group on the basis of the combined results of epidemiological studies, carcinogenicity studies in experimental animals, and several types of other relevant data supported by the underlying concept that nickel compounds can generate nickel ions at critical sites in their target cells.

## Overall evaluation

Nickel compounds are *carcinogenic to humans (Group 1)*.

Metallic nickel is *possibly carcinogenic to humans (Group 2B)*.

For definition of the italicized terms, see [Preamble Evaluation](#)

**Previous evaluations:** Vol.: 2 (1973) (p. 126); Vol. 11 (1976) (p. 75); Suppl. 7 (1987) (p. 264)

## Synonyms for Nickel and Nickel Compounds

### Synonyms for Nickel

- Ni 233
- Ni 270
- Nickel 270
- Nickel element
- NP 2
- N1

### Synonyms for Ferronickel

- Iron alloy [base] [Fe, Ni]
- Nickel alloy [nonbase] [Fe, Ni]

### Synonyms for Nickel aluminium alloys

- Raney alloy
- Raney nickel

### Synonyms for Nickel-containing steels

- Alloy 21-6-9
- AMS 5656C
- Armco 21-6-9
- 21-6-9 Austenitic steel
- Iron alloy [base]
- Nitronic 40
- Nitronic 40 stainless steel
- Pyromet 538
- Stainless steel 21-6-9
- Steel 21-6-9
- 21-6-9 Stainless steel
- 21-6-9 Steel

### Synonyms for High nickel alloys

CAS No. 12605-70-8:

- Chromel C
- 06Kh15N60

- Kh15N60N
- Nichrome
- NiCr 60/15
- PNKh
- Tophet C

CAS No. 11121-96-3:

- AFNOR ZFeNC45-36
- AISI 332
- Alloy 800
- Incoloy alloy 800
- JIS NCF 800
- NCF Steel
- NCF 800 HTB
- Pyromet 800
- Sanicro 31
- Thermax 4876
- TIG N800

CAS No. 126-75-92-2:

- Haynes alloy No. 188

CAS No. 11105-19-4:

- Alloy 400
- H3261
- Monel alloy 400
- Monel (NiCu30Fe)

### **Synonyms for Nickel hydroxide**

- Nickel dihydroxide
- Nickel hydroxide [Ni(OH)<sub>2</sub>]
- Nickel(2+) hydroxide
- Nickel[II] hydroxide
- Nickelous hydroxide

### **Synonyms for Nickel monoxide**

CAS Nos 1313-99-1; 11099-02-8:

- Black nickel oxide
- Green nickel oxide
- Mononickel oxide
- Nickel monoxide
- Nickel oxide [NiO]
- Nickel(2+) oxide
- Nickel[II] oxide
- Nickelous oxide

CAS No. 34492-97-2:

- Bunsenite (NiO)

### **Synonyms for Nickel trioxide**

- Black nickel oxide
- Dinickel trioxide
- Nickelic oxide
- Nickel oxide
- Nickel oxide [Ni<sub>2</sub>O<sub>3</sub>]
- Nickel[III] oxide
- Nickel peroxide
- Nickel sesquioxide

### **Synonym for Nickel disulfide**

CAS No. 12035-51-7:

- Nickel sulfide [NiS<sub>2</sub>]

CAS No. 12035-50-6:

Vaesite [NiS<sub>2</sub>]

### **Synonyms for Nickel sulfide**

CAS Nos 16812-54-7; 11113-75-0 (amorphous):

- Mononickel monosulfide
- Nickel monosulfide
- Nickel monosulfide [NiS]
- Nickel sulfide [NiS]
- Nickel(2+) sulfide
- Nickel[II] sulfide
- Nickelous sulfide

CAS No. 1314-04-1:

- Millerite [NiS]

### **Synonyms for Nickel subsulfide**

CAS No. 12035-72-2:

- Nickel sesquisulfide
- Nickel subsulfide [Ni<sub>3</sub>S<sub>2</sub>]
- Nickel sulfide [Ni<sub>3</sub>S<sub>2</sub>]
- Trinickel disulfide

CAS No. 12035-71-1:

- Heazlewoodite [Ni<sub>3</sub>S<sub>2</sub>]
- Khizlevudite

### **Synonym for Pentlandite**

CAS No. 53809-86-2:

- Pentlandite [Fe<sub>9</sub>Ni<sub>9</sub>S<sub>16</sub>]

CAS No. 12174-14-0:

- Pentlandite

### **Synonyms for Nickel carbonate**

- Carbonic acid, nickel(2+) salt (1:1)
- Nickel carbonate (1:1)
- Nickel carbonate [NiCO<sub>3</sub>]
- Nickel(2+) carbonate
- Nickel(2+) carbonate [NiCO<sub>3</sub>]
- Nickel[II] carbonate
- Nickel monocarbonate
- Nickelous carbonate

### **Synonyms for Basic nickel carbonates**

CAS No. 12607-70-4:

- Carbonic acid, nickel salt, basic
- Nickel carbonate hydroxide [Ni<sub>3</sub>(CO<sub>3</sub>)(OH<sub>4</sub>)]
- Nickel, (carbonato(2-)) tetrahydroxytri-

CAS No.: 12122-15-5:

- Nickel, bis(carbonato(2-))hexahydropenta-
- Nickel hydroxycarbonate

### **Synonyms for Nickel acetate**

- Acetic acid, nickel(2+) salt
- Nickel(2+) acetate
- Nickel[II] acetate
- Nickel diacetate
- Nickelous acetate

### **Synonyms for Nickel acetate tetrahydrate**

- Acetic acid, nickel(2+) salt, tetrahydrate

### **Synonyms for Nickel ammonium sulfates**

- Ammonium nickel sulfate  $[\text{NH}_4)_2\text{Ni}(\text{SO}_4)_2]$
- Nickel ammonium sulfate  $[\text{Ni}(\text{NH}_4)_2(\text{SO}_4)_2]$
- Sulfuric acid, ammonium nickel(2+) salt (2:2:1)

### Synonyms for Nickel ammonium sulfate hexahydrate

CAS No. 25749-08-0:

- Ammonium nickel sulfate  $[\text{NH}_4)_2\text{Ni}(\text{SO}_4)_3]$
- Sulfuric acid, ammonium nickel(2+) salt (3:2:2)

CAS No. 7785-20-8:

- Ammonium nickel(2+) sulfate hexahydrate
- Ammonium nickel sulfate  $[(\text{NH}_4)_2\text{Ni}(\text{SO}_4)_2]$
- Diammonium nickel disulfate hexahydrate
- Diammonium nickel(2+) disulfate hexahydrate
- Diammonium nickel[II] disulfate hexahydrate
- Nickel ammonium sulfate  $[\text{Ni}(\text{NH}_4)_2(\text{SO}_4)_2]$  hexahydrate
- Nickel diammonium disulfate hexahydrate
- Sulfuric acid, ammonium nickel(2+) salt (2:2:1), hexahydrate

### Synonyms for Nickel chromate

- Chromium nickel oxide  $[\text{NiCrO}_4]$
- Nickel chromate  $[\text{NiCrO}_4]$
- Nickel chromium oxide  $[\text{NiCrO}_4]$

### Synonyms for Nickel chloride

- Nickel chloride  $[\text{NiCl}_2]$
- Nickel(2+) chloride
- Nickel[II] chloride
- Nickel dichloride
- Nickel dichloride  $[\text{NiCl}_2]$
- Nickelous chloride

### Synonym for Nickel chloride hexahydrate

- Nickel chloride  $[\text{NiCl}_2]$  hexahydrate

### Synonyms for Nickel nitrate hexahydrate

- Nickel(2+) bis(nitrate)hexahydrate
- Nickel dinitrate hexahydrate
- Nickel[II] nitrate hexahydrate
- Nickel nitrate  $[\text{Ni}(\text{NO}_3)_2]$  hexahydrate
- Nickelous nitrate hexahydrate
- Nitric acid, nickel(2+) salt, hexahydrate

### Synonyms for Nickel sulfate

- Nickel monosulfate
- Nickel sulfate (1:1)
- Nickel sulfate [NiSO<sub>4</sub>]
- Nickel(2+) sulfate
- Nickel(2+) sulfate (1:1)
- Nickel[II] sulfate
- Nickelous sulfate
- Sulfuric acid, nickel(2+) salt (1:1)

#### **Synonym for Nickel sulfate hexahydrate**

- Sulfuric acid, nickel(2+) salt (1:1), hexahydrate

#### **Synonym for Nickel sulfate heptahydrate**

- Sulfuric acid, nickel(2+) salt (1:1), heptahydrate

#### **Synonyms for Nickel carbonyl**

- Nickel carbonyl [Ni(CO)<sub>4</sub>], [T-4]-
- Nickel tetracarbonyl
- Tetracarbonylnickel
- Tetracarbonylnickel (0)

#### **Synonyms for Nickel antimonide**

CAS No. 12035-52-8:

- Antimony compound with nickel (1:1)
- Nickel antimonide [NiSb]
- Nickel compound with antimony (1:1)
- Nickel monoantimonide

CAS No. 12125-61-0:

- Breithauptite (SbNi)

#### **Synonyms for Nickel arsenides**

CAS No. 27016-75-7:

- Nickel arsenide (NiAs)

CAS No. 1303-13-5:

- Nickeline
- Nickeline (NiAs)
- Nicolite

CAS No. 12256-33-6:

- Nickel arsenide ( $\text{Ni}_{11}\text{As}_8$ )
- Nickel arsenide tetragonal

CAS No. 12044-65-4:

- Maucherite [ $\text{Ni}_{11}\text{As}_8$ ]
- Placodine
- Temiskamite

CAS No. 12255-80-0:

- Nickel arsenide [ $\text{Ni}_5\text{As}_2$ ]
- Nickel arsenide hexagonal

### **Synonyms for Nickel selenide**

CAS No. 1314-05-2:

- Nickel monoselenide
- Nickel selenide [ $\text{NiSe}$ ]

CAS No. 12201-85-3:

- Maekinenite
- Makinenite ( $\text{NiSe}$ )

### **Synonym for Nickel subselenide**

- Nickel selenide [ $\text{Ni}_3\text{Se}_2$ ]

### **Synonym for Nickel sulfarsenide**

CAS No. 12255-10-6:

- Nickel arsenide sulfide [ $\text{NiAsS}$ ]

CAS No. 12255-11-7:

- Gersdorffite ( $\text{NiAsS}$ )

### **Synonyms for Nickel telluride**

CAS No. 12142-88-0:

- Nickel monotelluride
- Nickel telluride [ $\text{NiTe}$ ]

CAS No. 24270-51-7

- Imgreite (NiTe)

### **Nickel titanate**

- Nickel titanate[IV]
- Nickel titanate [NiTiO<sub>3</sub>]
- Nickel titanium oxide [NiTiO<sub>3</sub>]
- Nickel titanium trioxide

### **Chrome iron nickel black spinel**

- C.I. Pigment Black 20
- DCMA-13-50-9
- Nickel iron chromite black spinel

### **Nickel ferrite brown spinel**

- C.I. Pigment Brown 34
- DCMA-13-35-7

### **Synonyms for Nickelocene**

- Bis( $\eta^5$ -2,4-cyclopentadien-1-yl)nickel
- Di- $\pi$ -cyclopentadienyl-nickel
- Dicyclopentadienylnickel
- Nickel, bis( $\eta^5$ -2,4-cyclopentadien-1-yl)
- Nickel, di- $\pi$ -cyclopentadienyl-

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Last updated: 12 November 1997

**CHROMIUM AND CHROMIUM COMPOUNDS**  
**Chromium[VI] (Group 1)**  
**Metallic chromium and chromium[III] compounds (Group 3)**

For definition of Groups, see [Preamble Evaluation](#).

**VOL.:** 49 (1990) (p. 49)

**Chromium**

**CAS No.:** 7440-47-3

**Cobalt-chromium alloy**

**CAS No.:** 11114-92-4

**Cobalt-chromium-molybdenum alloy**

**CAS No.:** 12629-02-6

**Chromium-containing stainless steels**

**CAS No.:** 71631-40-8

**Ferrochrome**

**CAS No.:** 11114-46-8

**Iron-nickel-chromium alloy**

**CAS No.:** 11121-96-3

**Nickel-chromium alloy**

**CAS No.:** 12605-70-8

**Basic chromic sulfate**

**CAS Nos:** 12336-95-7; 64093-79-4

**Chromic acetate**

**CAS No.:** 1066-30-4

**Chromic chloride**

**CAS No.:** 10025-73-7

**Chromic hydroxide**

**CAS No.:** 1308-14-1

**Chromic nitrate**

**CAS No.:** 13548-38-4

**Chromic oxide**

**CAS No.:** 1308-38-9

**Chromic perchlorate**

**CAS No.:** 13537-21-8

**Chromic phosphate**  
CAS No.: 7789-04-0

**Chromic sulfate**  
CAS No.: 10101-53-8

**Chromite ore**  
CAS No.: 1308-31-2

**Nickel chromate**  
CAS No.: 12018-18-7

**Potassium chromic sulfate**  
CAS No.: 10141-00-1

**Ammonium chromate**  
CAS No.: 7788-98-9

**Ammonium dichromate**  
CAS No.: 7789-09-5

**Barium chromate**  
CAS No.: 10294-40-3

**Basic lead chromate**  
CAS No.: 1344-38-3

**Calcium chromate**  
CAS No.: 13765-19-0

**Chromium[VI] chloride**  
CAS No.: 14986-48-2

**Chromium trioxide**  
CAS No.: 1333-82-0

**Chromyl chloride**  
CAS No.: 14977-61-8

**Lead chromate**  
CAS No.: 7758-97-6

**Molybdenum Orange**  
CAS No.: 12656-85-8

**Potassium chromate**  
CAS No.: 7789-00-6

**Potassium dichromate**  
CAS No.: 7778-50-9

**Sodium chromate**  
**CAS No.:** 7775-11-3

**Sodium dichromate**  
**CAS No.:** 10588-01-9

**Strontium chromate**  
**CAS No.:** 7789-06-2

**Zinc chromate**  
**CAS No.:** 13530-65-9

**Zinc chromate hydroxides**  
**CAS No.:** 15930-94-6

**Zinc potassium chromates [hydroxides]**  
**CAS No.:** 11103-86-9

**Zinc Yellow**  
**CAS No.:** 37300-23-5

**Chromium carbonyl**  
**CAS No.:** 13007-92-6

**Chromic chromate**  
**CAS No.:** 24613-89-6

**Chromium[II] chloride**  
**CAS No.:** 10049-05-5

**Chromium[IV] dioxide**  
**CAS No.:** 12018-01-8

## **5. Summary of Data Reported and Evaluation**

### **5.1 Exposure data**

Chromium in the form of various alloys and compounds has been in widespread commercial use for over 100 years. Early applications included chrome pigments and tanning liquors. In recent decades, chromium has also been widely used in chromium alloys and chrome plating.

Several million workers worldwide are exposed to airborne fumes, mists and dust containing chromium or its compounds. Of the occupational situations in which exposure to chromium occurs, highest exposures to chromium[VI] may occur during chromate production, welding, chrome pigment manufacture, chrome plating and spray painting; highest exposures to other forms of chromium occur during mining, ferrochromium and steel production, welding and cutting and grinding of chromium alloys.

Data on exposure levels are available for several specific industries and job categories covering several decades. In the past, exposures to chromium[VI] in excess of 1 mg/m<sup>3</sup> were found repeatedly in some processes, including chromium plating, chromate production and certain welding operations; exposures to total chromium have been even higher. Modern control technologies have markedly reduced exposures in some processes, such as electroplating, in recent years.

Occupational exposure has been shown to give rise to elevated levels of chromium in blood, urine and some body tissues, inhalation being the main route.

Nonoccupational sources of exposure to chromium include food, air and water, but the levels are usually several orders of magnitude lower than those typically encountered in occupational situations.

## 5.2 Experimental carcinogenicity data

### Chromium[O]

Studies in rats by intratracheal, intramuscular and intrafemoral administration, in mice and rats by intrapleural and intraperitoneal administration and in mice, rats and rabbits by intravenous injections were inadequate to evaluate the carcinogenicity of *chromium metal* as a powder.

### Chromium[III]

In studies in which *chromic acetate* was administered by the oral route to mice and rats and by intrapleural and intramuscular administration to rats, the incidence of tumours was not increased. In studies in which rats were administered *chromic oxide* by intrabronchial or oral routes, no increase in the incidence of tumours was observed. In experiments by intrabronchial implantation of *chromic chloride* or *chrome tan* (a basic chromic sulfate) in rats and by intraperitoneal administration of *chromic sulfate* in mice, the incidence of tumours was not increased. Many of these studies suffered from certain limitations. *Chromite ore* has been extensively tested in rats by intrabronchial, intrapleural and intrafemoral administration; no increase in the incidence of tumours was seen.

### Chromium[VI]

*Calcium chromate* has been tested by inhalation in mice, by intratracheal administration in rats and hamsters, by intrabronchial administration in rats, by intrapleural administration in rats, by subcutaneous administration in mice and by intramuscular administration in rats and mice. In the one study by inhalation in mice, there was an increase in the incidence of lung adenomas which was of borderline significance; in the single study by intratracheal administration and in the three studies by intrabronchial administration in rats, lung tumours were induced. No lung tumour was seen in hamsters after intratracheal instillation. Local tumours were produced in rats by intrapleural and in rats and mice by intramuscular administration of calcium chromate. *Chromium trioxide* (chromic acid) has been tested as a mist by inhalation at two dose levels in mice and as a solid by intrabronchial implantation in three studies in rats. In mice, a low incidence of lung adenocarcinomas was observed at the higher dose and of nasal papillomas at the lower dose; perforation of the nasal septum was observed at both dose levels. A few lung tumours were seen in two of the studies by intrabronchial administration in rats. *Sodium dichromate* has been tested in rats by inhalation, intratracheal, intrabronchial, intrapleural and intramuscular administration. Lung tumours, benign and malignant, were observed in the studies by inhalation and by intratracheal administration. No increase in the occurrence of local tumours was seen after intrabronchial, intrapleural or intramuscular administration. *Barium chromate* has been tested in rats by intrabronchial, intrapleural and intramuscular implantation. No increase in the occurrence of tumours was seen following intrabronchial implantation; the other studies were inadequate to allow an evaluation of the carcinogenicity of this compound. *Lead chromate* and derived pigments have been tested by intrabronchial implantation in rats without producing a significant increase in the incidence of tumours. Lead chromate and derived pigments have also been tested in rats by subcutaneous and intramuscular injection, producing malignant tumours at the site of injection and, in one study, renal carcinomas. A study by intrapleural administration to rats could not be evaluated. No increase in tumour incidence was observed when lead chromate was administered intramuscularly to mice. A single subcutaneous injection of *basic lead chromate* produced a high incidence of local sarcomas in rats. *Zinc chromates* have been tested in rats by intrabronchial implantation, producing bronchial carcinomas, by intrapleural administration, producing local tumours, and by subcutaneous and intramuscular injection, producing local sarcomas. Two samples of *strontium chromate* were tested in rats by intrabronchial implantation, producing a high incidence of bronchial carcinomas;

intrapleural and intramuscular injection of strontium chromate produced local sarcomas.

## Other forms of chromium

A range of *roasted chromite ores* (Cr[III/VI]), often described as mixed chromium dust, and other residue materials encountered in the early stages of bichromate production have been tested extensively in rats, mice, guinea-pigs and rabbits by inhalation and by intratracheal, intrabronchial, intrapleural and intramuscular administration. The results of these tests were generally negative, although a low incidence of local tumours was observed in rats following intrapleural or intramuscular implantation of roasted chromite ore. The studies were considered to suffer from certain inadequacies. *Chromium[IV] dioxide* was tested by inhalation in rats, producing a few lung lesions of questionable nature; the study had a number of limitations.

### 5.3 Human carcinogenicity data

Epidemiological studies carried out in the Federal Republic of Germany, Italy, Japan, the UK and the USA of workers in the chromate production industry have consistently shown excess risks for lung cancer. The workers in this industry may be exposed to a variety of forms of chromium, including chromium[VI] and [III] compounds.

Similarly, studies carried out in the Federal Republic of Germany, France, the Netherlands, Norway, the UK and the USA of workers in the production of chromate pigments have also consistently shown excess risks for lung cancer. Workers in this industry are exposed to chromates, not only in the pigments themselves but also from soluble chromium[VI] compounds in the raw materials used in their production. Excess risk for lung cancer has been clearly established in facilities where zinc chromate was produced, although other chromium pigments were also generally made in these plants. A small study in the UK of workers producing lead chromate pigments showed no overall excess risk for lung cancer, but a nonsignificant excess risk for lung cancer was seen in a subgroup of workers with lead poisoning. No data were available on risk associated with exposure to strontium chromate or to other specific chromate pigments.

In two limited reports from the UK and in a small Italian study, excesses of lung cancer were reported in workers in the chromium plating industry. In a group of persons working in die-casting and plating in USA, similar results were seen. These findings were confirmed in a large study of chromium platers in the UK, which demonstrated an excess risk for lung cancer in platers, particularly among those with at least ten years of employment at chrome baths. Workers in this industry have been exposed to soluble chromium[VI] compounds and possibly also to nickel.

In three reports, from Norway, Sweden and the USSR, in which ferrochromium workers were studied, the overall results with regard to lung cancer were inconclusive. The major exposure in this industry is to chromium[III] compounds and to metallic chromium, although exposure to chromium[VI] may also occur.

Cases of sinonasal cancer were reported in epidemiological studies of primary chromate production workers in Japan, the UK and the USA, of chromate pigment production workers in Norway and of chromium platers in the UK, indicating a pattern of excess risk for these rare tumours.

For cancers other than of the lung and sinonasal cavity, no consistent pattern of cancer risk has been shown among workers exposed to chromium compounds.

The results of epidemiological studies of stainless-steel welders are consistent with the finding of excess mortality from lung cancer among other workers exposed to chromium[VI], but they do not contribute independently to the evaluation of chromium since welders are also exposed to other compounds. (See also the monograph on welding.)

No epidemiological study addressed the risk of cancer from exposure to metallic chromium alone.

## 5.4 Other relevant data

Inhaled chromium[VI] from welding and chrome-plating aerosols is readily absorbed from the respiratory tract. The degree of absorption depends on the extent of reduction of the hexavalent form to chromium[III], which is absorbed to a much lesser extent. The same factors apply to absorption from the gastrointestinal tract, although absorption by this route is generally much less than that from the respiratory tract.

Chromium[VI] compounds may cause adverse effects to the skin, the respiratory tract and, to a lesser degree, the kidneys in humans, while chromium[III] is less toxic.

Elevated levels of sister chromatid exchange were observed in workers exposed to chromium[VI] compounds in electroplating factories in four out of six studies. Chromosomal aberrations were found in all three studies of exposed workers; an increase frequency of aneuploidy was reported in one study. The two available studies on chromium[III] were inadequate to evaluate its cytogenetic effect in humans.

Chromates enter cells more readily than chromium[III] compounds and are reduced ultimately to chromium[III]. The reduction process and the subsequent intracellular activity of reduced chromium species are important for the mechanism of toxicity and carcinogenicity of chromium[VI]. Particulate chromium[III] compounds can also enter cells by phagocytosis.

Chromium[VI] compounds cross the placental barrier in greater amounts than chromium[III] compounds. Chromium trioxide increased fetal death rate, caused growth retardation and increased the frequency of skeletal deformities and of cleft palate in rodents. Developmental effects have also been reported in mice exposed to chromic chloride.

Chromium[VI] compounds of various solubilities in water were consistently active in numerous studies covering a wide range of tests for genetic and related effects. In particular, potassium dichromate, sodium dichromate, ammonium dichromate, potassium chromate, sodium chromate, ammonium chromate, chromium trioxide, calcium chromate, strontium chromate and zinc yellow induced a variety of effects (including DNA damage, gene mutation, sister chromatid exchange, chromosomal aberrations, cell transformation and dominant lethal mutation) in a number of targets, including animal cells *in vivo* and animal and human cells *in vitro*. Potassium chromate induced aneuploidy in insects, while chromium trioxide did not; various compounds induced gene mutation in insects. Potassium dichromate produced recombination, gene mutation and aneuploidy in fungi. All of these chromium[VI] compounds induced DNA damage and gene mutation in bacteria. Similar patterns were observed with zinc chromate, barium chromate, lead chromate and the derived pigments chromium orange, chromium yellow and molybdenum orange, which, however, often required preliminary dissolution in alkali or acids. A liquid chromium[VI] compound (chromyl chloride) and its vapours induced gene mutation in bacteria.

Although chromium[III] compounds were generally even more reactive than chromium[VI] compounds with purified DNA and isolated nuclei, 12 compounds of various solubilities (chromic chloride, chromic acetate, chromic nitrate, chromic sulfate, chromic potassium sulfate, chromium alum, neochromium, chromic hydroxide, chromic phosphate, chromic oxide, chromite ore and cupric chromite) gave positive results in only a minority of studies using cellular test systems, often under particular treatment conditions or at very high concentrations, which were generally orders of magnitude higher than those needed to obtain the same effects with chromium[VI] compounds. Some of the positive results could be ascribed to contamination with traces of chromium[VI] compounds. In particular, no DNA damage was observed in cells of animals treated *in vivo* with chromic chloride, and no micronuclei were seen in cells of animals given chromic nitrate. The chromium[III] compounds tested generally did not produce DNA damage, gene mutation, sister chromatid exchange or cell transformation in cultured animal and human cells. Chromosomal aberrations were often observed with high concentrations of chromium[III] compounds. Weak effects on gene mutation and mitotic gene conversion were observed in fungi. Negative results were obtained in the large majority of tests for DNA damage and gene mutation in bacteria. Certain complexes of chromium[III] with organic ligands, which favour the penetration of chromium[III] into cells, were reported to induce DNA damage and gene mutation in bacteria and in cultured mammalian cells.

A chromium[II] compound (chromous chloride) gave negative results in in-vitro tests with animal cells (DNA

damage, chromosomal aberrations and aneuploidy). A water-insoluble chromium[0] compound (chromium carbonyl) did not induce DNA damage in bacteria.

No relevant study on the genetic and related effects of metallic chromium was available to the Working Group.

## 5.5 Evaluation

There is *sufficient evidence* in humans for the carcinogenicity of chromium[VI] compounds as encountered in the chromate production, chromate pigment production and chromium plating industries.

There is *inadequate evidence* in humans for the carcinogenicity of metallic chromium and of chromium[III] compounds.

There is *sufficient evidence* in experimental animals for the carcinogenicity of calcium chromate, zinc chromates, strontium chromate and lead chromates.

There is *limited evidence* in experimental animals for the carcinogenicity of chromium trioxide (chromic acid) and sodium dichromate.

There is *inadequate evidence* in experimental animals for the carcinogenicity of metallic chromium, barium chromate and chromium[III] compounds.

The Working Group made the overall evaluation on chromium[VI] compounds on the basis of the combined results of epidemiological studies, carcinogenicity studies in experimental animals, and several types of other relevant data which support the underlying concept that chromium[VI] ions generated at critical sites in the target cells are responsible for the carcinogenic action observed.

### Overall evaluation

Chromium[VI] is *carcinogenic to humans (Group 1)*.

Metallic chromium and chromium[III] compounds are *not classifiable as to their carcinogenicity to humans (Group 3)*.

For definition of the italicized terms, see [Preamble Evaluation](#)

**Previous evaluations:** Vol. 2 (1973) (p. 100); Vol. 23 (1980) (p. 205); Suppl. 7 (1987) (p. 165)

### Synonyms for Chromium and Chromium Compounds

#### Synonym for Chromium

- Chrome

#### Synonym for Chromium [trivalent]

- Chromium[III] compounds

#### Synonym for Chromium [hexavalent]

- Chromium[VI] compounds

### **Synonyms for Cobalt-chromium alloy**

- Cobalt alloy [nonbase], Co, Cr
- Cobalt alloy, Co, Cr

### **Synonyms for Cobalt-chromium-molybdenum alloy**

- Akrit CoMo35
- AMS 5385D
- Celsit 290
- Cobalt alloy [base], [Co 56-68; Cr 25-29, Mo 5-6, Ni 1.8-3.8, Fe 0-3, Mn0-1, Si 0-1, C 0.2-0.3]
- F 75
- HS 21
- Protasul-2
- Vinertia
- Vitallium
- Zimalloy

### **Synonyms for Chromium-containing stainless steels**

- AF 22
- AF 22-130
- AISI 318L
- Alloy 2205
- Arosta 4462
- AST 2205
- Avesta 2205
- Avesta 223FAL
- CR22
- DIN 1.4462
- ES 2205
- FAL 223
- Iron alloy [base] [Fe 64-72, Cr 21-23, Ni 4.5-6.5, Mo 2.5-3.5, Mn 0-2, Si 0-1, N 0.1-0.2]
- Mann AF-22
- Nirosta 4462
- NKK-Cr22
- Novonox FALC 223
- NU 744 LN
- NU stainless 744 LN
- Remanit 4462
- SAF 2205
- Sandvik SAF 2205
- SS 2377
- Stainless steel 2205
- Uddeholm Nu 744 LN
- UHB 744LN
- UNS S31803
- Uranus 45N
- UR45N
- Vallourec VS22
- VEW A903
- VLX 562
- VS 22
- X2CrNiMoN2253
- Z2CND22.5AZ

- 744LN

### **Synonyms for Ferrochrome**

- Carbon ferrochromium
- Chrome ferroalloy
- Chromium alloy [base], [Cr, C, Fe, N, Si]
- Chromium ferroalloy
- Ferrochrome
- Ferrochromium

### **Synonyms for Iron-nickel-chromium alloy**

- AFNOR ZFeNC45-36
- AISI 332
- Alloy 800
- Alloy 800 NG
- DIN 1.4876
- IN 800
- Incoloy 800
- Iron alloy [base], [Fe 39-47, Ni 30-35, Cr 19-23, Mn 0-1.5, Si 0-1, Cu 0-0.8, Al 0-0.6, Ti 0-0.6, C 0-0.1]
- JIS NCF800
- N 800
- NCF 800
- NCF 800 HTB
- NCF steel
- Nickel 800
- Nicrofer 3220
- POLDI AKR 17
- Pyromet 800
- Sanicro 31
- Thermax 4876
- TIG N800

### **Synonyms for Nickel-chromium alloy**

- Chromel C
- Kh15N60N
- Nichrome
- Nickel alloy [base] [Ni 57-62, Fe 22-28, Cr 14-18, Si 0.8-1.6, Mn 0-1, C 0-0.2]
- PNKh
- Tophet C

### **Synonyms for Basic chromic sulfate**

CAS No. 12336-95-7:

- Basic chromium sulfate
- Chromedol
- Chrometan
- Chrome tan
- Chromium hydroxide sulfate [Cr(OH)(SO<sub>4</sub>)]
- Chromium sulfate
- Monobasic chromium sulfate
- Peachrome

- Sulfuric acid, chromium salt, basic

CAS No. 64093-794

- Neochromium

### **Synonyms for Chromic acetate**

- Acetic acid, chromium [3+] salt
- Chromium acetate
- Chromium[III] acetate
- Chromium triacetate

### **Synonyms for Chromic chloride**

- Chromium chloride [CrCl<sub>3</sub>]
- Chromium[III] chloride
- Chromium trichloride
- Trichlorochromium

### **Synonyms for Chromic hydroxide**

- Chromic acid [H<sub>3</sub>CrO<sub>3</sub>]
- Chromium hydroxide [Cr(OH)<sub>3</sub>]
- Chromium[III] hydroxide
- Chromium(3+) hydroxide
- Chromium trihydroxide

### **Synonyms for Chromic nitrate**

- Chromium nitrate
- Chromium(3+) nitrate
- Chromium[III] nitrate
- Chromium trinitrate
- Nitric acid, chromium(3+) salt

### **Synonyms for Chromic oxide**

- Anadonis green
- Casalis green
- Chrome green
- Chrome ochre
- Chrome oxide
- Chrome oxide green
- Chrome oxide green BX
- Chrome oxide green GN-N
- Chrome oxide pigment
- Chrome oxide X1134
- Chromia
- Chromium oxide [Cr<sub>2</sub>O<sub>3</sub>]
- Chromium oxide green
- Chromium sesquioxide
- Chromium[III] oxide

- Chromium(3+) trioxide
- C.I. Pigment green 17
- Dichromium trioxide
- Green chrome oxide
- Green chromic oxide
- Green chromium oxide
- Green cinnabar
- Green oxide of chromium
- Green oxide of chromium OC-31
- Green rouge
- 11661 Green
- Guignet's green
- Leaf green
- Levanox green GA [hydrated chromic oxide]
- Oil green
- Oxide of chromium
- P-106F10
- Pure chromium oxide green 59
- Ultramarine green

### **Synonyms for chromic perchlorate**

- Chromium perchlorate
- Chromium triperchlorate
- Perchloric acid, chromium(3+) salt

### **Synonyms for Chromic phosphate**

- Arnaudon's green [hemiheptahydrate]
- Chromium orthophosphate
- Chromium monophosphate
- Chromium phosphate
- Phosphoric acid, chromium(3+) salt (1:1)
- Phosphoric acid chromium[III] salt
- Plessy's green [hemiheptahydrate]

### **Synonyms for Chromic sulfate**

- Baychrom A
- Baychrom F
- Chromitan B
- Chromitan MS
- Chromitan NA
- Chromium sulfate (2:3)
- Chromium[III] sulfate
- Cromitan
- Dichromium sulfate
- Dichromium tris(sulfate)
- Dichromium trisulfate
- Koreon
- Sulfuric acid, chromium(3+) salt (3:2)

### **Synonyms for Chromite ore**

- Chrome ore

- Chromite [Cr<sub>2</sub>FeO<sub>4</sub>]
- Chromite mineral
- Iron chromite

### **Synonym for Nickel chromate**

- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], nickel salt (1:1)

### **Synonyms for Potassium chromic sulfate**

- Chrome alum 0% basicity
- Chrome alum
- Chrome potash alum
- Chromic potassium sulfate
- Chromium potassium sulfate
- Crystal chrome alum
- Potassium chromium alum
- Potassium chromium sulfate
- Potassium disulfatochromate[III]
- Sulfuric acid, chromium(3+) potassium salt (2:1:1)

### **Synonyms for Ammonium chromate**

- Chromic acid, ammonium salt
- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], diammonium salt
- Diammonium chromate
- Neutral ammonium chromate

### **Synonyms for Ammonium dichromate**

- Ammonium bichromate
- Ammonium chromate
- Chromic acid [H<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>], diammonium salt
- Diammonium dichromate
- Dichromic acid, diammonium salt

### **Synonyms for Barium chromate**

- Barium chromate [VI]
- Barium chromate (1:1)
- Barium chromate oxide
- Baryta Yellow
- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], barium salt (1:1)
- C.I. Pigment Yellow 31
- Lemon chrome
- Lemon Yellow
- Permanent Yellow
- Steinbuhl Yellow
- Ultramarine Yellow

### **Synonyms for Basic lead chromate**

- Arancio Cromo

- Austrian Cinnabar
- Chinese red
- Chrome Orange
- Chrome Orange 54
- Chrome Orange 56
- Chrome Orange 57
- Chrome Orange 58
- Chrome Orange G
- Chrome Orange R
- Chrome Orange 5R
- Chrome Orange dark
- Chrome Orange light
- Chrome Orange RF
- Chrome Orange NC22
- Chrome Orange XL
- Chrome red
- C.I. Pigment red
- C.I. Pigment Orange 21
- C.P. Chrome Orange dark 2030
- C.P. Chrome Orange extra dark 2040
- C.P. Chrome Orange light 2010
- C.P. Chrome Orange medium 2020
- Dainichi chrome Orange R
- Dainichi chrome Orange 5R
- Genuine acetate Orange chrome
- Genuine Orange chrome
- Indian red
- International Orange 2221
- Irgachrome Orange OS
- Lead chromate oxide
- Light Orange chrome
- No. 156 Orange chrome
- Orange chrome
- Orange nitrate chrome
- Pale Orange chrome
- Persian red
- Pigment Orange 21
- Pure Orange chrome M
- Pure Orange chrome Y
- Red lead chromate
- Vynamon Orange CR

### **Synonyms for Calcium chromate**

- Calcium Chrome Yellow
- Calcium chromium oxide
- Calcium monochromate
- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], calcium salt (1:1)
- C.I. Pigment Yellow 33
- Gelbin
- Yellow ultramarine

### **Synonyms for Chromium[VI] chloride**

- (OC-6-11)-Chromium chloride [CrCl<sub>6</sub>]
- Chromium hexachloride

## Synonyms for Chromium trioxide

- Chromia
- Chromic acid
- Chromic[VI] acid
- Chromic acid, solid
- Chromic anhydride
- Chromic trioxide
- Chromium oxide [CrO<sub>3</sub>]
- Chromium[VI] oxide
- Chromium(6+) trioxide
- Monochromium oxide

## Synonyms for Chromyl chloride

- Chlorochromic anhydride
- Chromium chloride oxide
- Chromium dichloride dioxide
- Chromium, dichlorodioxo-(T-4)
- Chromium dioxide dichloride
- Chromium dioxychloride
- Chromium oxychloride
- Dichlorodioxochromium

## Synonyms for Lead chromate

- Canary chrome yellow 40-2250
- Chrome green
- Chrome green UC61
- Chrome green UC74
- Chrome green UC76
- Chrome lemon
- Chrome Yellow
- Chrome Yellow 5G
- Chrome Yellow GF
- Chrome Yellow LF
- Chrome Yellow light 1066
- Chrome Yellow light 1075
- Chrome Yellow medium 1074
- Chrome Yellow medium 1085
- Chrome Yellow medium 1295
- Chrome Yellow medium 1298
- Chrome Yellow primrose 1010
- Chrome Yellow primrose 1015
- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], lead(2+) salt (1:1)
- C.I. Pigment Yellow 34
- Cologne Yellow
- Crocoite
- Dainichi Chrome Yellow G
- Lead chromium oxide
- LD Chrome Yellow Supra 70 FS
- Leipzig Yellow
- Paris Yellow
- Phoenicochroite
- Pigment green 15
- Plumbous chromate
- Primrose Chrome Yellow

- Pure lemon chrome L3GS

### **Synonyms for Molybdenum Orange**

- Chrome vermillion
- C.I. Pigment red 104
- Krolor Orange RKO 786D
- Lead chromate molybdate sulfate red
- Mineral fire red 5DDS
- Mineral fire red 5GGS
- Mineral fire red 5GS
- Molybdate Orange
- Molybdate Orange Y 786D
- Molybdate Orange YE 421D
- Molybdate Orange YE 698D
- Molybdate red
- Molybdate red AA3
- Molybden red
- Molybdenum red
- Renol molybdate red RGS
- Vynamon scarlet BY
- Vynamon scarlet Y

### **Synonyms for Potassium chromate**

- Chromic acid [ $\text{H}_2\text{CrO}_4$ ], dipotassium salt
- Bipotassium chromate
- Dipotassium chromate
- Dipotassium monochromate
- Neutral potassium chromate
- Potassium chromate[VI]

### **Synonyms for Potassium dichromate**

- Chromic acid [ $\text{H}_2\text{Cr}_2\text{O}_7$ ], dipotassium salt
- Dichromic acid dipotassium salt
- Dipotassium bichromate
- Dipotassium dichromate
- Lopezite
- Potassium bichromate
- Potassium dichromate[VI]

### **Synonyms for Sodium chromate**

- Chromic acid [ $\text{H}_2\text{CrO}_4$ ], disodium salt
- Chromium disodium oxide
- Chromium sodium oxide
- Disodium chromate
- Neutral sodium chromate
- Sodium chromium oxide

### **Synonyms for Sodium dichromate**

- Bichromate of soda

- Chromic acid [H<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>], disodium salt
- Chromium sodium oxide
- Dichromic acid, disodium salt
- Disodium dichromate
- Sodium bichromate
- Sodium chromate
- Sodium dichromate[VI]

### Synonyms for Strontium chromate

- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], strontium salt (1:1)
- C.I. Pigment Yellow 32
- Deep Lemon Yellow
- Strontium chromate[VI]
- Strontium chromate (1:1)
- Strontium chromate 12170
- Strontium chromate A
- Strontium chromate X-2396
- Strontium Yellow
- Sutokuro T

### Synonyms for Zinc chromate

- Buttercup Yellow
- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], zinc salt (1:1)
- Chromium zinc oxide
- Zinc chromium oxide
- Zinc tetraoxochromate
- Zinc tetroxochromate

### Synonyms for Zinc chromate hydroxides

- Basic zinc chromate
- Buttercup Yellow
- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], zinc salt (1:2)
- Chromic acid [H<sub>6</sub>CrO<sub>6</sub>], zinc salt (1:2)
- Chromium zinc hydroxide
- Zinc chromate hydroxide
- Zinc chromate[VI] hydroxide
- Zinc chromate oxide [Zn<sub>2</sub>(CrO<sub>4</sub>)O], monohydrate
- Zinc hydroxochromate
- Zinc tetrahydroxochromate
- Zinc Yellow

### Synonyms for Zinc potassium chromates [hydroxides]

- Basic zinc potassium chromate
- Buttercup Yellow
- Chromic acid [H<sub>6</sub>Cr<sub>2</sub>O<sub>9</sub>], potassium salt (1:1:2)
- Citron Yellow
- Potassium hydroxyoctaoxodizincatedichromate(1-)
- Potassium zinc chromate
- Potassium zinc chromate hydroxide
- Zinc chrome

- Zinc Yellow

### **Synonyms for Chromium carbonyl**

- Chromium carbonyl [Cr(CO)<sub>6</sub>]
- Chromium hexacarbonyl
- Hexacarbonyl chromium

### **Synonyms for Chromic chromate**

- Chromic acid [H<sub>2</sub>CrO<sub>4</sub>], chromium(3+) salt (3:2)
- Chromium chromate

### **Synonyms for Chromium[II] chloride**

- Chromium chloride [CrCl<sub>2</sub>]
- Chromium dichloride
- Chromous chloride

### **Synonyms for Chromium[IV] dioxide**

- Chromium oxide [CrO<sub>2</sub>]
- Chromium dioxide
- Chromium[IV] oxide

# WELDING (Group 2B)

For definition of Groups, see [Preamble Evaluation](#).

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## 5. Summary of Data Reported and Evaluation

### 5.1 Exposure data

Welding has been an important industrial process since the early twentieth century and has become widespread since about 1940. A wide variety of welding techniques is used, although most welding is performed using electric arc processes - manual metal arc, metal inert gas and tungsten inert gas welding - all of which have been used for at least 40 years. Although most welding is on mild steel, about 5% is on stainless-steels; welding on stainless-steels can constitute more than 20% of welding in industrial economies. Welding of aluminium and other metals amounts to only a few per cent of the total.

The number of workers worldwide whose work involves some welding is estimated to be about three million.

Welders are exposed to a range of fumes and gases. Fume particles contain a wide variety of oxides and salts of metals and other compounds, which are produced mainly from electrodes, filler wire and flux materials. Fumes from the welding of stainless-steel and other alloys contain nickel compounds and chromium[VI] and [III]. Ozone is formed during most electric arc welding, and exposures can be high in comparison to the exposure limit, particularly during metal inert gas welding of aluminium. Oxides of nitrogen are found during manual metal arc welding and particularly during gas welding. Welders who weld painted mild steel can also be exposed to a range of organic compounds produced by pyrolysis. Welders, especially in shipyards, may also be exposed to asbestos dust.

### 5.2 Experimental carcinogenicity data

Particulates collected from stainless-steel welding fumes were tested by intratracheal instillation in hamsters and by intrabronchial implantation in rats. No treatment-related tumour was seen in rats, and single lung tumours were seen in groups of hamsters receiving manual metal arc stainless-steel welding fume. No study in which animals were exposed to welding fume by inhalation was available for evaluation.

### 5.3 Human carcinogenicity data

Two cohort studies of lung cancer mortality among persons in various occupations did not show significant increases in risk among welders. A total of three pleural mesotheliomas was reported from one of these studies. One large cohort study conducted in the UK showed an almost two-fold excess risk for lung cancer among shipyard welders, which was not confirmed when comparison was made with a local referent population. A moderately increased incidence of lung cancer was found in a large study of shipyard welders in Finland. Five studies conducted in the USA and Europe indicated an increased risk for lung cancer of about 30%.

A large European cohort study, including three cohorts reported previously, detected statistically significant increases in both the incidence of and mortality from lung cancer but demonstrated no consistent difference in cancer risk among stainless-steel welders as compared to mild-steel welders or to shipyard welders. In addition, five deaths were due to mesothelioma.

Of the 12 case-control studies on the association between lung cancer and exposure or employment as a welder, two detected no excess risk. Of the remaining ten, four showed a moderate excess, which was

statistically significant in the largest study, conducted in the USA. The other six studies, of welders in various occupations, gave risk estimates exceeding a two-fold increase, which in four of the studies were statistically significant.

Four case-control studies conducted on bladder cancer - two in Canada, one in the USA and one in the Federal Republic of Germany - addressed the possible role of exposures during welding. Only one of the two from Canada reported a significantly increased risk.

Two case-control studies of leukaemia from the USA reported an elevated relative risk for myeloid leukaemia. No overall excess risk for either acute or all leukaemia was observed in a pooled analysis of data from several studies of welders.

Of the case-control studies of cancers at other sites, one on nasal cancer carried out in the Nordic countries, one on laryngeal cancer from Denmark and one on pancreatic cancer from Sweden reported elevated relative risks among welders.

#### **5.4 Other relevant data**

Welding fumes are retained in the lungs. Experimental studies have shown that sparingly soluble compounds may be released only slowly from the lungs. Elevated concentrations of chromium and nickel are seen in blood and urine, primarily in manual metal arc stainless-steel welders. Airway irritation and metal fume fever are the commonest acute effects of welding fumes. Studies of different groups of welders have documented an increased prevalence of pulmonary function abnormalities, in particular small airway disease, chronic bronchitis and slight abnormalities on chest X-rays, but only minimal indications of pulmonary fibrosis.

Reduced sperm quality has been reported in welders. Decreased fertility was seen in both male and female rats exposed to welding fumes; and the rate of fetal death was increased in pregnant female rats exposed to welding fumes.

One of three studies showed increased levels of sister chromatid exchange and chromosomal aberrations in peripheral blood lymphocytes of workers exposed during stainless-steel welding. The greater frequencies of sister chromatid exchanges were found in exposed workers who smoked.

In a single study, manual metal arc stainless-steel welding fumes injected intraperitoneally caused a mutagenic response in the mouse spot test. No increase in the frequency of sister chromatid exchange in peripheral blood lymphocytes or of chromosomal aberrations in lymphocytes or bone-marrow cells was observed in one study in rats after inhalation of stainless-steel or mild-steel welding fumes.

Both positive and negative results were obtained in tests for gene mutation in cultured mammalian cells exposed to stainless-steel welding fumes (manual metal arc). Stainless-steel welding fumes (manual metal arc and metal inert gas) induced transformation of mammalian cells *in vitro* in a single study. The frequencies of chromosomal aberrations and of sister chromatid exchange were increased in mammalian cells exposed *in vitro* to stainless-steel welding fumes (manual metal arc or metal inert gas). In a single study, mild-steel welding fumes (manual metal arc) increased the frequency of sister chromatid exchange but not of chromosomal aberrations in the same system. Fumes from the manual metal arc welding of mild steel or cast iron using a nickel electrode increased the frequency of sister chromatid exchange, but not of chromosomal aberrations, in mammalian cells *in vitro*.

Fumes from the manual metal arc or metal arc welding of stainless-steel and from manual metal arc welding of mild steel, but not the fumes from metal inert gas welding on mild steel or from mild steel welding with a nickel electrode, were mutagenic to bacteria.

#### **5.5 Evaluation**

There is *limited evidence* in humans for the carcinogenicity of welding fumes and gases.

There is *inadequate evidence* in experimental animals for the carcinogenicity of welding fumes.

### **Overall evaluation**

Welding fumes are *possibly carcinogenic to humans (Group 2B)*.

For definition of the italicized terms, see [Preamble Evaluation](#)

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Last updated: 5 November 1997