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Chromium in Drinking-water

Background document for development of
WHO *Guidelines for Drinking-water Quality*

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Preface

One of the primary goals of WHO and its member states is that "all people, whatever their stage of development and their social and economic conditions, have the right to have access to an adequate supply of safe drinking water." A major WHO function to achieve such goals is the responsibility "to propose regulations, and to make recommendations with respect to international health matters ...."

The first WHO document dealing specifically with public drinking-water quality was published in 1958 as International Standards for Drinking-Water. It was subsequently revised in 1963 and in 1971 under the same title. In 1984–1985, the first edition of the WHO Guidelines for drinking-water quality (GDWQ) was published in three volumes: Volume 1, Recommendations; Volume 2, Health criteria and other supporting information; and Volume 3, Surveillance and control of community supplies. Second editions of these volumes were published in 1993, 1996 and 1997, respectively. Addenda to Volumes 1 and 2 of the second edition were published in 1998, addressing selected chemicals. An addendum on microbiological aspects reviewing selected microorganisms was published in 2002.

The GDWQ are subject to a rolling revision process. Through this process, microbial, chemical and radiological aspects of drinking-water are subject to periodic review, and documentation related to aspects of protection and control of public drinking-water quality is accordingly prepared/updated.

Since the first edition of the GDWQ, WHO has published information on health criteria and other supporting information to the GDWQ, describing the approaches used in deriving guideline values and presenting critical reviews and evaluations of the effects on human health of the substances or contaminants examined in drinking-water.

For each chemical contaminant or substance considered, a lead institution prepared a health criteria document evaluating the risks for human health from exposure to the particular chemical in drinking-water. Institutions from Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Poland, Sweden, United Kingdom and United States of America prepared the requested health criteria documents.

Under the responsibility of the coordinators for a group of chemicals considered in the guidelines, the draft health criteria documents were submitted to a number of scientific institutions and selected experts for peer review. Comments were taken into consideration by the coordinators and authors before the documents were submitted for final evaluation by the experts meetings. A "final task force" meeting reviewed the health risk assessments and public and peer review comments and, where appropriate, decided upon guideline values. During preparation of the third edition of the GDWQ, it was decided to include a public review via the world wide web in the process of development of the health criteria documents.

During the preparation of health criteria documents and at experts meetings, careful consideration was given to information available in previous risk assessments carried out by the International Programme on Chemical Safety, in its Environmental Health

Criteria monographs and Concise International Chemical Assessment Documents, the International Agency for Research on Cancer, the joint FAO/WHO Meetings on Pesticide Residues, and the joint FAO/WHO Expert Committee on Food Additives (which evaluates contaminants such as lead, cadmium, nitrate and nitrite in addition to food additives).

Further up-to-date information on the GDWQ and the process of their development is available on the WHO internet site and in the current edition of the GDWQ.

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GENERAL DESCRIPTION

Identity

Chromium is widely distributed in the earth's crust. It can exist in oxidation states of +2 to +6. Soils and rocks may contain small amounts of chromium, almost always in the trivalent state.

Physicochemical properties (1–4)

Property	*Cr*	$CrCl_3$	K_2CrO_4	Cr_2O_3	CrO_3
Melting point (ºC)	1857	1152	968.3	2266	196
Boiling point (ºC)	2672	-	-	4000	
Solubility (g/litre)	Insoluble	Slightly soluble	790	Insoluble	624
Density (g/cm3)	7.14	2.76	2.73	5.21	2.70

Major uses

Chromium and its salts are used in the leather tanning industry, the manufacture of catalysts, pigments and paints, fungicides, the ceramic and glass industry, and in photography, and for chrome alloy and chromium metal production, chrome plating, and corrosion control (1,3,4).

Environmental fate

The distribution of compounds containing chromium(III) and chromium(VI) depends on the redox potential, the pH, the presence of oxidizing or reducing compounds, the kinetics of the redox reactions, the formation of chromium(III) complexes or insoluble chromium(III) salts, and the total chromium concentration. In the environment, chromium(VI) occurs mostly as CrO42- or HcrO4- and chromium(III) as Cr(OH)n(3-n)+. In soil, chromium(III) predominates. Chromium(VI) can easily be reduced to chromium(III) by organic matter, for example, and its occurrence in soil is often the result of human activities. In water, chromium(III) is a positive ion that forms hydroxides and complexes, and is adsorbed at relatively high pH values. In surface waters, the ratio of chromium(III) to chromium(VI) varies widely, and relatively high concentrations of the latter can be found locally. In general, chromium(VI) salts are more soluble than those of chromium(III), making chromium(VI) relatively mobile.

In air, chromium is present in the form of aerosols. It can be removed from the atmosphere by wet and dry deposition. Both trivalent and hexavalent chromium are released into the air. Because of analytical difficulties, data on chromium speciation in ambient air are rarely available, but the proportion present as chromium(VI) has been estimated as 0.01–30%, based on one study (4).

ANALYTICAL METHODS

Methods for the determination of chromium in biological and environmental samples are developing rapidly, and all early results (especially for the lower chromium levels) should be interpreted with caution.

Many techniques can be used for the determination of total chromium, including atomic absorption spectroscopy, emission spectroscopy, X-ray fluorescence, and neutron activation analysis. Detection limits for atomic absorption spectroscopy are in the range 0.05–0.2 □ g/litre (5).

For determining chelated chromium or the hexavalent or trivalent form only, such methods as gas chromatography (with various detection techniques), polarography, and spectrophotometry can be used (30.2 µg/litre (5).

For determining chelated chromium or the hexavalent or trivalent form only, such methods as gas chromatography (with various detection techniques), polarography, and spectrophotometry can be used (3–5). The determination of chromium species is currently a very sophisticated procedure, and few analytical data are available (4).

ENVIRONMENTAL LEVELS AND HUMAN EXPOSURE

Air

In arctic air, chromium concentrations of 5–70 pg/m3 have been measured. Ambient air at most stations in the USA contained very little chromium; mean levels were generally below 300 ng/m3, and median levels less than 20 ng/m3 (6). In non-industrialized areas, concentrations above 10 ng/m3 are uncommon (7). Concentrations in urban areas are 2–4 times higher than regional background concentrations (8). The mean concentration of total chromium in air in the Netherlands varied from 2 to 5 ng/m3 (4).

As a result of smoking, indoor air concentrations can be 10–400 times greater than outdoor concentrations (approximately 1000 ng/m3).

Water

The average concentration of chromium in rainwater is in the range 0.2–1 □g/litre (4,9–11). Natural chromium concentrations in seawater of 0.04–0.5 µg/litre have been measured (3). In the North Sea, a concentration of 0.7 µg/litre was found (4).

The natural total chromium content of surface waters is approximately 0.5–2 µg/litre and the dissolved chromium content 0.02–0.3 µg/litre (4,10,12). Chromium concentrations in antarctic lakes increase with depth from <0.6 to 30 µg/litre (13). Most surface waters contain between 1 and 10 µg of chromium per litre. In general, the chromium content of surface waters reflects the extent of industrial activity. In surface waters in the USA, levels up to 84 µg/litre have been found (1); in central Canada, surface water concentrations ranged from 0.2 to 44 µg/litre [data from the National Water Quality Data Bank (NAQUADAT), Inland Waters Directorate, Environment Canada, 1985]. In the Rhine, chromium levels are below 10 µg/litre (14), and in 50% of the natural stream waters in India the concentration is below 2 µg/litre (9).

In general, the chromium concentration in groundwater is low (<1 µg/litre). In the Netherlands, a mean concentration of 0.7 µg/litre has been measured, with a maximum of 5 µg/litre (4). In India, 50% of 1473 water samples from dug wells contained less than 2 µg/litre (9). In groundwater in the USA, levels up to 50 µg/litre have been reported; in shallow groundwater, median levels of 2–10 µg/litre have been found (1,15). Most supplies in the USA contain less than 5 µg/litre. In 1986, levels in 17 groundwater supplies and one surface water supply exceeded 50 µg/litre (1)

Approximately 18% of the population of the USA are exposed to drinking-water levels between 2 and 60 µg/litre and <0.1% to levels between 60 and 120 µg/litre (1). In the Netherlands, the chromium concentration of 76% of the supplies was below 1 µg/litre and of 98% below 2 µg/litre (16). A survey of Canadian drinking-water supplies gave an overall median level of 2 µg of chromium per litre, with maxima of 14 µg/litre (raw water) and 9 µg/litre (treated water) (17).

Food

Food contains chromium at concentrations ranging from <10 to 1300 µg/kg (4,18,19). Highest concentrations have been found in meat, fish, fruit, and vegetables (18). Utensils used in the preparation of food may contribute to chromium levels.

Estimated total exposure and relative contribution of drinking-water

Mean chromium intakes from food and water range from 52 to 943 µg/day (3). The estimated total intake of chromium from air, water, and food by the general population in the United Kingdom is in the range 78–106 µg/day. Food contributed 93–98% of the total intake and water 1.9–7%. The contribution from air was negligible (18). In the Netherlands, the estimated mean daily chromium intake is 100 µg, with a range of 50–200 µg (4).

In general, food appears to be the major source of intake. Drinking-water intake can, however, contribute substantially when total chromium levels are above 25 µg/litre.

Kinetics and metabolism in laboratory animals and humans

Oral exposure studies in animals found the <0.5–6% of chromium compounds were absorbed; in human studies, the corresponding figure could be as much as 10%. Absorption depends on chromium speciation; chromium(VI) appears to be absorbed from the gastrointestinal tract to a greater extent than chromium(III). Tissue chromium levels of rats exposed to chromium(VI) (as potassium chromate) in drinking-water were 4–15 times higher than those of rats exposed to chromium(III) (as the trichloride). The absorption of chromium(VI) is lowered by partial intragastric reduction to chromium(III) (20). Mean fractional absorption values of 5% and 25% have been estimated for the gastrointestinal absorption of chromium(III) and chromium(VI) species and of organic chromium in food ("biologically incorporated"), respectively (21). A fractional absorption value of 5% is considered to be a good estimate for the gastrointestinal absorption of soluble inorganic chromium compounds, but 0.5% is more appropriate for that of insoluble inorganic chromium compounds such as chromic trioxide pigment (20).

Once absorbed, the fate of chromium will depend on the oxidation state. Chromium(VI) readily penetrates cell membranes, and chromium(III) does not. Chromium is therefore found in both erythrocytes and plasma after gastrointestinal absorption of chromium(VI) but exclusively in the plasma after that of chromium(III). Once transported through the cell membrane, chromium(VI) is rapidly reduced to chromium(III), which subsequently binds to macromolecules. In animal studies, chromium was found to accumulate mainly in liver, kidneys, spleen, and bone marrow after both oral and parenteral administration of different compounds, the distribution depending on the speciation. In humans, the highest concentrations are found in hilar lymph nodes and lungs, followed by spleen, liver, and kidneys (20), and tissue chromium levels decline with age. In both laboratory animals and humans, water-soluble compounds can be converted to insoluble compounds with long residence times.

After oral exposure to chromium compounds, especially those of chromium(III), chromium is recovered almost entirely in the faeces because of the poor absorption rate. Animal studies show that urine is the major route of elimination of absorbed chromium. In a 1-year balance study in which two humans had mean daily dietary intakes of 200 and 290 µg of chromium, 60% and 40% of the total amount excreted were recovered in the urine and faeces, respectively (20).

EFFECTS ON LABORATORY ANIMALS AND IN VITRO TEST SYSTEMS

Acute exposure

Oral LD50 values in rats were in the range 20–250 mg of chromium(VI) per kg of body weight and 185–615 mg of chromium(III) per kg of body weight, based on tests with dichromates and chromic compounds, respectively (20).

Short-term exposure

Three-month-old inbred BD rats (5–14 per sex per dose) were exposed for 90 days, 5 days per week, to 0, 2%, or 5% of insoluble, nonhydrated chromium(III) oxide (Cr_2O_3) pigment in feed (22). The dose levels are equivalent to 0, 480, and 1210 mg of chromium(III) per kg of body weight per day (20). Survival, feed intake, body and organ weights, blood analysis, and the macroscopic and microscopic appearance of major organs were not affected. The only effect observed was a dose-related decrease in liver and spleen weights, ranging from 15% to 35% (22).

Long-term exposure

Chromium(III)

In a 1-year study, 5-week-old Sprague-Dawley albino rats (9 males and 12 females) were exposed to 25 mg of chromium(III) per litre (as chromium trichloride, $CrCl_3$) in drinking-water, equivalent to 2.5 mg of chromium(III) per kg of body weight per day. Feed consumption, body weight gain, and the gross and microscopic appearance of tissues were not affected. The only effect observed was some accumulation of chromium in various tissues (23).

Chromium(VI)

In a 1-year study, 5-week-old albino Sprague-Dawley rats (8–12 per sex per dose) were exposed to dose levels up to 25 mg of chromium(VI) per litre (as potassium chromate) in drinking-water. The highest dose is equivalent to 2.5 mg of chromium(VI) per kg of body weight per day. Feed consumption, body weight gain, blood parameters, and the gross and microscopic appearance of organs were not affected. The only effects observed were decreased water consumption (20%) and accumulation of chromium in various tissues (23).

In a limited lifetime toxicity study in which Swiss mice of the Charles River CD strain (54 per sex) were exposed from weaning until death to 5 mg of chromium(VI) per litre (as potassium chromate) in drinking-water, survival parameters and body weight were not affected (24). Exposure of NMRI mice in a 29-month three-generation study to 135 mg of chromium(VI) per litre (as potassium chromate) in drinking-water did not affect survival or growth (25).

Reproductive toxicity, embryotoxicity, and teratogenicity

In a 90-day study with limited numbers of 3-month-old inbred BD rats, exposure of male and female animals for 60 days prior to mating and through gestation to dose levels of 0, 2%, or

5% insoluble, nonhydrated chromium(III) oxide pigment in feed did not result in embryotoxicity or fetotoxicity or teratogenicity (22). In studies with hamsters and mice, parenteral administration of chromium(III) or chromium(VI) during gestation did result in embryotoxicity or fetotoxicity and teratogenicity. These effects appear to be associated with maternal toxicity, but definitive conclusions cannot be reached (20).

Mutagenicity and related end-points

Chromium(VI) compounds cause mutations and allied effects such as chromosomal aberrations in a wide range of prokaryotic and eukaryotic test systems, both in vitro and in vivo. Chromium(III) compounds are not active in similar systems, or only at high, cytotoxic concentrations. It has therefore been concluded that chromium(VI) is mutagenic, whereas chromium(III) is not.

The mutagenic activity of chromium(VI) is decreased or abolished by reducing agents such as human gastric juice and rat liver microsomal fraction. Inactive chromium(III) compounds are not converted to mutagens by biological systems, but only by treatment with strong oxidizing agents. The difference between the mutagenic action of chromium(VI) and chromium(III) can be explained by differences in physicochemical properties. Although chromium(VI), which readily penetrates cell membranes, is the causative agent, there are strong indications that chromium(III) or intermediates such as chromium(V) formed during the intracellular reduction of chromium(VI) are the genetically active agents that form ligands with macromolecules such as DNA (20).

Carcinogenicity

In a lifetime carcinogenicity study in which 3-month-old inbred male and female BD rats (60 per dose) were exposed, 5 days per week for 600 days, to 0, 2%, or 5% of insoluble, nonhydrated chromium(III) oxide pigment in feed, tumour incidence was not affected (22). The highest dose is equivalent to 1210 mg of chromium(III) per kg of body weight per day (20).

In a limited lifetime carcinogenicity study, Swiss mice of the Charles River CD strain (54 per sex) were exposed from weaning until death to 5 mg of chromium(VI) per litre (as potassium chromate) in drinking-water. According to the authors (24), the study suggested that chromium(VI) is carcinogenic, but the very limited data reported do not allow evaluation (20).

Exposure of NMRI mice in a 29-month three-generation study to 135 mg of chromium(VI) per litre (as potassium chromate) in drinking-water did not result in carcinogenic activity in the stomach (25).

The carcinogenicity of chromium, especially with regard to lung tumours, has also been investigated in a number of inhalation studies; in other studies, the chromium was administered by implantation or injection. Based on all the available studies, it has been concluded that there is sufficient evidence in experimental animals for the carcinogenicity of calcium, lead, strontium, and zinc chromates (chromium(VI)); limited evidence for the carcinogenicity of chromium trioxide (chromic acid) and sodium dichromate; and inadequate evidence for the carcinogenicity of other chromium(VI) and chromium(IIII) compounds and of metallic chromium (2,26).

EFFECTS ON HUMANS

Requirements

The daily chromium requirement for adults is estimated to be 0.5–2 µg of absorbable chromium(III). If a fractional absorption value of 25% for "biologically incorporated" chromium(III) in food is assumed, this is provided by a daily dietary intake of 2–8 µg of chromium(III), equivalent to 0.03–0.13 µg of chromium(III) per kg of body weight per day for a 60-kg adult (20).

Acute exposure

Ingestion of 1–5 g of "chromate" (not further specified) results in severe acute effects such as gastrointestinal disorders, haemorrhagic diathesis, and convulsions. Death may occur following cardiovascular shock (20).

Mutagenicity

In some occupational studies, increased incidences of genotoxic effects such as chromosomal aberrations and sister chromatid exchanges have been found in workers exposed to chromium(VI) compounds (20).

Carcinogenicity

In epidemiological studies, an association has been found between occupational exposure to chromium(VI) compounds and mortality due to lung cancer. On the basis of these studies, it has been concluded that there is sufficient evidence of respiratory carcinogenicity in humans exposed to chromium(VI) in these occupational settings. Data on lung cancer risk in other chromium-associated occupational settings and for cancer at sites other than the lungs are considered to be insufficient. The epidemiological data do not allow an evaluation of the relative contributions to carcinogenic risk of metallic chromium, chromium(III), and chromium(VI) or of soluble versus insoluble chromium compounds, but it appears that exposure to a mixture of chromium(VI) compounds of different solubilities results in the highest risk to humans (2,26).

IARC has classified chromium(VI) in Group 1 (carcinogenic to humans) and metallic chromium and chromium(III) in Group 3 (not classifiable as to their carcinogenicity to humans) (2,26).

PROVISIONAL GUIDELINE VALUE

In principle, because the health effects are determined largely by the oxidation state, different guideline values for chromium(III) and chromium(VI) should be derived. However, current analytical methods and the variable speciation of chromium in water favour a guideline value for total chromium.
Because of the carcinogenicity of chromium(VI) by the inhalation route and its genotoxicity, the current guideline value of 0.05 mg/litre has been questioned, but the available toxicological data do not support the derivation of a new value. As a practical measure, 0.05 mg/litre, which is considered to be unlikely to give rise to significant risks to health, has been retained as a provisional guideline value until additional information becomes available and chromium can be re-evaluated.

REFERENCES

1. Office of Drinking Water. Health advisory—chromium. Washington, DC, US Environmental Protection Agency, 1987.
2. International Agency for Research on Cancer. Some metals and metallic compounds. Lyon, 1980:205-323 (IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans, Vol. 23).
3. Chromium. Geneva, World Health Organization, 1988 (Environmental Health Criteria No. 61).
4. Slooff W et al. Integrated criteria document chromium. Bilthoven, Netherlands, National Institute of Public Health and Environmental Protection, 1989 (Report no. 758701002).
5. International Organization for Standardization. Water quality—determination of total chromium. Geneva, 1990 (ISO 9174:1990).
6. Environmental Monitoring Systems Laboratory. Frequency distributions by site/year for chromium, the results of samples collected at National Air Surveillance Network sites. Research Triangle Park, NC, US Environmental Protection Agency, 1984.
7. National Academy of Sciences. Drinking water and health, Vol. 3. Washington, DC, National Academy Press, 1980.
8. Nriagu JO, Nieboer E, eds. Chromium in the natural and human environments. New York, NY, John Wiley, 1988.
9. Handa BK. Occurrence and distribution of chromium in natural waters of India. Advances in environmental science and technology, 1988, 20:189 214.
10. Xingzhen Q, Xiuxia L. [Investigation on the natural background values and states of elements in natural water from the upper reaches of the Nenjiang river.] Kexue tongbao, 1987, 32(14):983 987 (in Chinese).
11. Barrie LA et al. On the concentration of trace metals in precipitation. Atmospheric environment, 1987, 21(5):1133 1135.
12. Shiller AM, Boyle EA. Variability of dissolved trace metals in the Mississippi River. Geochimica et cosmochimica acta, 1987, 51(12):3273 3277.
13. Masuda N et al. Trace element distributions in some saline lakes of the Vestfold Hills, Antarctica. Hydrobiologia, 1988, 165:103 114.
14. RIWA. De samenstelling van het Rijnwater in 1986 en 1987. [Composition of the water of the Rhine in 1986 and 1987.] Amsterdam, 1989.
15. Deverel SJ, Millard SP. Distribution and mobility of selenium and other trace elements in shallow ground water of the Western San Joaquin Valley, California. Environmental science and technology, 1988, 22:697 702.
16. Fonds AW, van den Eshof AJ, Smit E. Water quality in the Netherlands. Bilthoven, Netherlands, National Institute of Public Health and Environmental Protection, 1987 (Report no. 218108004).
17. Méranger JC, Subramanian KS, Chalifoux C. A national survey of cadmium, chromium, copper, lead, zinc, calcium and magnesium in Canadian drinking water supplies. Environmental science and technology, 1979, 13:707.
18. Ministry of Agriculture, Fisheries and Food. Survey of aluminium, antimony, chromium, cobalt, indium, nickel, thallium and tin in food. 15. Report of the Steering Group on Food Surveillances; The Working Party on the Monitoring of Foodstuffs for Heavy Metals. London, Her Majesty's Stationery Office, 1985.
19. Agency for Toxic Substances and Disease Registry. Toxicological profile for chromium. Washington, DC, US Public Health Service, 1989 (ATSFDR/TP 88/10).
20. Janus JA, Krajnc EI. Integrated criteria document chromium: effects. Appendix. Bilthoven, Netherlands, National Institute of Public Health and Environmental Protection, 1990.
21. Thorne MC et al. Pharmacodynamic models of selected toxic chemicals in man, Vol. 1. Review of metabolic data. Lancaster, MTP Press, 1986.

22. Ivankovic S, Preussmann R. Absence of toxic and carcinogenic effects after administration of high doses of chromic oxide pigment in subacute and long-term feeding experiments in rats. Food and cosmetics toxicology, 1975, 13:347 351.
23. MacKenzie RD et al. Chronic toxicity studies. II. Hexavalent and trivalent chromium administered in drinking water to rats. Archives of industrial health, 1958, 18:232 234.
24. Schroeder HA, Mitchener M. Scandium, chromium(VI), gallium, yttrium, rhodium, palladium, indium in mice: effects on growth and life span. Journal of nutrition, 1971, 101:1431 1438.
25. Borneff I et al. [Carcinogenic substances in water and soil. XXII. Mouse drinking study with 3,4-benzpyrene and potassium chromate.] Archiv für Hygiene, 1968, 152(68):45 53 (in German).
26. International Agency for Research on Cancer. Chromium, nickel and welding. Lyon, 1990 (IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 49).