

Chlorine 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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J.K. Fawell, Water Research Centre, United Kingdom
(inorganic constituents)
U. Lund, Water Quality Institute, Denmark
(organic constituents and pesticides)
B. Mintz, Environmental Protection Agency, USA
(disinfectants and disinfectant by-products)

The WHO coordinators were as follows:

Headquarters:

H. Galal-Gorchev, International Programme on Chemical Safety
R. Helmer, Division of Environmental Health

Regional Office for Europe:

X. Bonnefoy, Environment and Health
O. Espinoza, Environment and Health

Ms Marla Sheffer of Ottawa, Canada, was responsible for the scientific editing of the document.

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GENERAL DESCRIPTION

Identity

<i>Element or compound</i>	<i>CAS no.</i>	<i>Molecular formula</i>
Chlorine	7782-50-5	Cl ₂
Hypochlorous acid	7790-92-3	HOCl
Sodium hypochlorite	7681-52-9	NaOCl

Physicochemical properties of chlorine (1,2) [Conversion factor in air: 1 ppm = 2.9 mg/m³]

<i>Property</i>	<i>Value</i>
Boiling point	-34.6 °C
Melting point	-101 °C
Density	3.214 g/litre at 0 °C and 101.3 kPa
Vapour pressure	480 Pa at 0 °C
Water solubility	14.6 g/litre at 0 °C

Organoleptic properties

The taste and odour thresholds for chlorine in distilled water are 5 and 2 mg/litre, respectively. In air, chlorine has a pungent and disagreeable odour (2).

Major uses

Large amounts of chlorine are produced for use as disinfectants and bleach for both domestic and industrial purposes, and it is also widely used to disinfect drinking-water and swimming-pool water and to control bacteria and odours in the food industry (3,4).

Environmental fate

In water, chlorine reacts to form hypochlorous acid and hypochlorites. All three species exist in equilibrium with each other, the relative amounts varying with the pH. In dilute solutions and at pH levels above 4.0, very little molecular chlorine exists in solution. The concentrations of hypochlorous acid and the hypochlorite ion are approximately equal at pH 7.5 and 25 °C. Chlorine can react with ammonia or amines in water to form chloramines (4,5).

ANALYTICAL METHODS

A colorimetric method can be used to determine free chlorine in water at concentrations of 0.1–10 mg/litre. Other methods allow for the determination of free chlorine, chloramines, other chlorine species, and total available chlorine, and are suitable for total chlorine concentrations up to 5 mg/litre. The minimum detectable concentration of chlorine is about 0.02 mg/litre (6).

ENVIRONMENTAL LEVELS AND HUMAN EXPOSURE

Air

A mean ambient air level of 1 mg/m³ was reported for chlorine (7).

Water

Chlorine is present in most disinfected drinking-water at concentrations of 0.2–1 mg/litre (3).

Food

Cake flour bleached with chlorine contains chloride at levels in the range 1.3–1.9 g/kg. Unbleached flour may contain small amounts of chlorite (400–500 mg/kg) (8).

Estimated total exposure and relative contribution of drinking-water

The major routes of exposure to chlorine are through drinking-water, food, and contact with items either bleached or disinfected with it.

KINETICS AND METABOLISM IN LABORATORY ANIMALS AND HUMANS

Most studies on the pharmacokinetics of chlorine, hypochlorous acid, or hypochlorites employ reactive ^{36}Cl -labelled compounds and probably reflect the fate of the chloride ion or other reaction products generated from the parent molecules. In rats, hypochlorous acid was readily absorbed through the gastrointestinal tract, distribution being highest in the plasma; smaller amounts were found in bone marrow, kidney, testes, lung, skin, duodenum, spleen, liver, and bone (9,10). *In vivo*, sodium hypochlorite was metabolized to trichloroethanoic acid, dichloroethanoic acid, chloroform, and dichloroacetonitrile (11). Hypochlorous acid administered to rats was excreted primarily in the urine and faeces, mostly in the form of chloride ion (10). None was excreted in expired air (9).

EFFECTS ON LABORATORY ANIMALS AND *IN VITRO* TEST SYSTEMS

Acute exposure

Calcium hypochlorite has an oral LD_{50} in the rat of 850 mg/kg of body weight (2).

Short-term exposure

No consistent effects on organ weights or histopathology of tissues were noted in Sprague-Dawley rats (10 per sex per dose) given chlorine in drinking-water at 0, 25, 50, 100, 175, or 200 mg/litre (males: 0, 2, 7.5, 12.8, or 16.7 mg/kg of body weight per day; females: 0, 3.5, 12.6, 19.5, or 24.9 mg/kg of body weight per day) for 90 days (12) or in rats fed flour containing 1257 or 2506 mg of chlorine per kg (62.5 or 125 mg/kg of body weight per day) for 28 days (13).

Enhanced weight gain was observed in all male rats (10 per dose) given drinking-water containing chlorine at 0, 20, 40, or 80 mg/litre (0, 4.1, 8.1, or 15.7 mg/kg of body weight per day) for 6 weeks (14). The results of a 4-week study in which female C57BL/6N mice were given hyperchlorinated tapwater (4.8–5.8 mg/kg of body weight per day) suggested an adverse effect on the macrophage defence mechanisms of mice. The LOAEL in this study was 4.8 mg/kg of body weight per day (15).

In a study in which male CR-1:CD-1 mice (30 per dose) received chlorinated drinking-water (0.02, 0.2, 2.9, or 5.8 mg/kg of body weight per day) for 120 days, none of the mice showed evidence of a statistically significant change in humoral or cell-mediated immune response. A NOAEL of 5.8 mg/kg of body weight per day was identified (16).

Long-term exposure

F344 rats (50 per sex per dose) were administered sodium hypochlorite in drinking-water (males: 0.05% or 0.1%, 75 or 150 mg/kg of body weight per day; females: 0.1% or 0.2%, 150 or 300 mg/kg of body weight per day) for 2 years. Effects included a dose-related depression in body weight gain in all groups, depressed liver, brain, and heart weights in males given a 0.05% dose, decreased salivary gland weights in both female groups, and decreased kidney weights in females given 0.2% (17).

In a 2-year bioassay, F344 rats and B6C3F₁ mice were given chlorine in drinking-water at levels of up to 275 mg/litre (up to 24 mg/kg of body weight per day for male rats and male mice, 15 mg/kg of body weight per day for female rats, and 22 mg/kg of body weight per day for female mice). There was a dose-related decrease in water consumption for both mice and rats. No effects on body weight or survival were observed in any of the treated animals (18).

Wistar rats were fed cake prepared from flour treated with 1250 or 2500 mg of chlorine per kg (males: 12.8 or 25.3 mg/kg of body weight per day; females: 17.0 or 35.0 mg/kg of body weight per day) for 104 weeks. A dose-related reduction in spleen weight was seen in females, and dose-related haematological effects were observed in both sexes. A LOAEL of 12.8 mg/kg of body weight per day was identified in this study (19).

Reproductive effects, embryotoxicity, and teratogenicity

C3H/HeJ and C57BL/6J mice administered drinking-water containing 10 mg of residual chlorine per litre (1.9 mg/kg of body weight per day) for 6 months showed no adverse reproductive effects (20). In a seven-generation study in which rats were given drinking-water chlorinated at 100 mg/litre (10 mg/kg of body weight per day), no treatment-related effects on fertility were found (21).

Oral administration of hypochlorite ion or hypochlorous acid at 100, 200, or 400 mg of chlorine per litre (1.6, 4.0, or 8.0 mg/kg of body weight per day) resulted, in the case of hypochlorite, in dose-related increases in the amount of sperm-head abnormalities in male B6C3F₁ mice. A NOAEL of 8.0 mg/kg of body weight per day was identified for hypochlorous acid and a LOAEL of 1.6 mg/kg of body weight per day for hypochlorite ion (22).

Mutagenicity and related end-points

Sodium hypochlorite has been found to be mutagenic in *Salmonella typhimurium* TA1530 and TA100 but not TA1538 (23,24). Calcium and sodium hypochlorite both produced chromosomal aberrations in Chinese hamster fibroblast cells without metabolic activation (24). Hypochlorite ion and hypochlorous acid were negative in the *in vivo* erythrocyte micronucleus assay and in bone marrow aberration studies (22).

Carcinogenicity

F344 rats (50 per sex per dose) were given sodium hypochlorite in drinking-water (males: 0.05% or 0.1%, 75 or 150 mg/kg of body weight per day; females: 0.1% or 0.2%, 150 or 300 mg/kg of body weight per day) for 2 years. Experimental groups did not differ from controls with respect to the total tumour incidences or mean survival times, and most of the tumours found were of types that commonly occur spontaneously in F344 rats. The authors concluded that sodium hypochlorite was not carcinogenic in rats (17).

In a seven-generation toxicity study, the incidence of malignant tumours in rats consuming drinking-water with a free chlorine level of 100 mg/litre (10 mg/kg of body weight per day)

did not differ from that in controls (21). The incidence of tumours in treated animals was not significantly elevated in F344 rats and B6C3F₁ mice (50 per sex per dose) given solutions of sodium hypochlorite (70 or 140 mg/kg of body weight per day for male rats, 95 or 190 mg/kg of body weight per day for female rats, 84 or 140 mg/kg of body weight per day for male and female mice) in their drinking-water for 103–104 weeks (25).

In a 2-year bioassay, F344 rats and B6C3F₁ mice were given chlorine in drinking-water at levels of 0, 70, 140, or 275 mg/litre (8, 13, or 24 mg/kg of body weight per day for male rats; 5, 7, or 15 mg/kg of body weight per day for female rats; 8, 15, or 24 mg/kg of body weight per day for male mice; and 1, 13, or 22 mg/kg of body weight per day for female mice). Although there was a marginal increase in mononuclear-cell leukaemia in the groups of female rats given 140 and 275 mg/litre, it was considered to be equivocal evidence of carcinogenic activity because the incidence was significantly elevated compared with controls only for the middle dose and the incidence of leukaemia in the concurrent controls was lower than the mean in historical controls (18).

EFFECTS ON HUMANS

Exposure to chlorine, hypochlorous acid, and hypochlorite ion through ingestion of household bleach occurs most commonly in children. Intake of a small quantity of bleach generally results in irritation of the oesophagus, a burning sensation in the mouth and throat, and spontaneous vomiting. In these cases, it is not clear whether it is the sodium hypochlorite or the extremely caustic nature of the bleach that causes the tissue injury.

The effects of heavily chlorinated water on human populations exposed for varying periods were summarized in a report that was essentially anecdotal in character and did not describe in detail the health effects observed (26). In a study on the effects of progressively increasing chlorine doses (0, 0.001, 0.014, 0.071, 0.14, 0.26, or 0.34 mg/kg of body weight) on healthy male volunteers (10 per dose), there was an absence of adverse, physiologically significant toxicological effects in all of the study groups (27). It has been reported that asthma can be triggered by exposure to chlorinated water (28). Episodes of dermatitis have also been associated with exposure to chlorine and hypochlorite (29,30).

In a study of 46 communities in central Wisconsin where chlorine levels in water ranged from 0.2 to 1 mg/litre, serum cholesterol and low-density lipoprotein levels were higher in communities using chlorinated water. Levels of high-density lipoprotein (HDL) and the cholesterol/HDL ratio were significantly elevated in relation to the level of calcium in the drinking-water, but only in communities using chlorinated water. The authors speculated that chlorine and calcium in drinking-water may interact in some way that affects lipid levels (31).

An increased risk of bladder cancer appeared to be associated with the consumption of chlorinated tapwater in a population-based, case-control study of adults consuming chlorinated or non-chlorinated water for half of their lifetimes (32).

GUIDELINE VALUE

In humans and animals exposed to chlorine in drinking-water, specific adverse treatment-related effects have not been observed. IARC has concluded that hypochlorites are not classifiable as to their carcinogenicity to humans (Group 3) (17).

The guideline value for free chlorine in drinking-water is derived from a NOAEL of 15 mg/kg of body weight per day, based on the absence of toxicity in rodents that received chlorine as hypochlorite in drinking-water for up to 2 years (18). Application of an uncertainty factor of 100 (for inter- and intraspecies variation) to this NOAEL gives a TDI of 150 µg/kg of body weight. With an allocation of 100% of the TDI to drinking-water, the guideline value is 5

mg/litre (rounded figure). It should be noted, however, that this value is conservative, as no adverse effect level was identified in this study. Most individuals are able to taste chlorine or its by-products (e.g. chloramines) at concentrations below 5 mg/litre, and some at levels as low as 0.3 mg/litre.

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