

Iron 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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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

Iron is the second most abundant metal in the earth's crust, of which it accounts for about 5%. Elemental iron is rarely found in nature, as the iron ions Fe^{2+} and Fe^{3+} readily combine with oxygen- and sulfur-containing compounds to form oxides, hydroxides, carbonates, and sulfides. Iron is most commonly found in nature in the form of its oxides (1,2).

Physicochemical properties (3)

<i>Property</i>	<i>Value</i>
Melting point	1535 °C
Specific gravity	7.86 at 25 °C

Organoleptic properties

Iron (as Fe^{2+}) concentrations of 40 $\mu\text{g}/\text{litre}$ can be detected by taste in distilled water. In a mineralized spring water with a total dissolved solids content of 500 mg/litre, the taste threshold value was 0.12 mg/litre. In well-water, iron concentrations below 0.3 mg/litre were characterized as unnoticeable, whereas levels of 0.3–3 mg/litre were found acceptable (E. Dahi, personal communication, 1991).

In drinking-water supplies, iron(II) salts are unstable and are precipitated as insoluble iron(III) hydroxide, which settles out as a rust-coloured silt. Anaerobic groundwaters may contain iron(II) at concentrations of up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well, although turbidity and colour may develop in piped systems at iron levels above 0.05–0.1 mg/litre. Staining of laundry and plumbing may occur at concentrations above 0.3 mg/litre (4).

Iron also promotes undesirable bacterial growth ("iron bacteria") within a waterworks and distribution system, resulting in the deposition of a slimy coating on the piping (4).

Major uses

Iron is used as constructional material, *inter alia* for drinking-water pipes. Iron oxides are used as pigments in paints and plastics. Other compounds are used as food colours and for the treatment of iron deficiency in humans. Various iron salts are used as coagulants in water treatment.

Environmental fate

Aeration of iron-containing layers in the soil can affect the quality of both groundwater and surface water if the groundwater table is lowered or nitrate leaching takes place. Dissolution of iron can occur as a result of oxidation and decrease in pH.

ANALYTICAL METHODS

Iron in water can be determined by atomic absorption spectrometry (detection limit 1 $\mu\text{g}/\text{litre}$) or by colorimetric methods (detection limit 5 $\mu\text{g}/\text{litre}$) (5).

ENVIRONMENTAL LEVELS AND HUMAN EXPOSURE

Air

In remote areas, iron levels in air are about 50–90 ng/m³; at urban sites, levels are about 1.3 µg/m³. Concentrations up to 12 µg/m³ have been reported in the vicinity of iron- and steel-producing plants (6).

Water

The median iron concentration in rivers has been reported to be 0.7 mg/litre. In anaerobic groundwater where iron is in the form of iron(II), concentrations will usually be 0.5–10 mg/litre, but concentrations up to 50 mg/litre can sometimes be found (6). Concentrations of iron in drinking-water are normally less than 0.3 mg/litre but may be higher in countries where various iron salts are used as coagulating agents in water-treatment plants and where cast iron, steel, and galvanized iron pipes are used for water distribution.

Food

Iron occurs as a natural constituent in plants and animals. Liver, kidney, fish, and green vegetables contain 20–150 mg/kg, whereas red meats and egg yolks contain 10–20 mg/kg. Rice and many fruits and vegetables have low iron contents (1–10 mg/kg).

Estimated total exposure and relative contribution of drinking-water

Reported daily intakes of iron in food — the major source of exposure — range from 10 to 14 mg (7,8). Drinking-water containing 0.3 mg/litre would contribute about 0.6 mg to the daily intake. Intake of iron from air is about 25 µg/day in urban areas.

KINETICS AND METABOLISM IN HUMANS

Iron is an essential trace element in living organisms. The data in this section are derived from studies in humans only; laboratory animals are not acceptable models because they have much higher intakes than humans and do not absorb iron compounds in the same way (6).

Most iron is absorbed in the duodenum and upper jejunum (9). Absorption depends on the individual's iron status and is regulated so that excessive amounts of iron are not stored in the body (10). Total body iron in adult males and females is usually about 50 and 34–42 mg/kg of body weight, respectively (10). The largest fraction is present as haemoglobin, myoglobin, and haem-containing enzymes. The other major fraction is stored in the body as ferritin and haemosiderin, mainly in the spleen, liver, bone marrow, and striate muscle (6).

Daily losses of iron in adults are small (1 mg/day) and due mainly to cell exfoliation. About two-thirds of this loss occurs from the gastrointestinal tract and most of the remainder from the skin. Iron losses in urine and sweat are negligible (11). In adult females, there is an additional iron loss of about 15–70 mg each month in menstrual blood (12).

EFFECTS ON LABORATORY ANIMALS AND *IN VITRO* TEST SYSTEMS

Acute exposure

Wide variations in toxicity have been reported for different iron salts and animal species. Oral LD₅₀s for iron salts are about 300–600 mg/kg of body weight in the mouse and about 800–2000 mg/kg of body weight in the rat (13). The effects of toxic doses of iron include

depression, rapid and shallow respiration, coma, convulsions, respiratory failure, and cardiac arrest.

Reproductive toxicity, embryotoxicity, and teratogenicity

Iron compounds were not teratogenic in the chicken embryo test (14). In a study of iron(II) sulfate and iron(III) sodium diphosphate in mice and rats, neither maternal toxicity nor teratogenic effects were found (14,15). In an eight-generation reproduction study in rats, iron oxide was not toxic at an estimated intake of 25 mg of iron per day, and reproductive performance was better than expected (14,15). In a five-generation study, iron dextran administered by intramuscular injection had no effect on litter size or growth (16).

Mutagenicity and related end-points

A number of iron(II) and iron(III) salts have been tested for mutagenicity in *Saccharomyces cerevisiae* strain D-4 and *Salmonella typhimurium* strains TA1535, TA1537, and TA1538, with and without metabolic activation. Iron(II) lactate, iron(III) diphosphate, iron(III) orthophosphate, and iron(III) ferric diphosphate were inactive in all systems used. Iron(II) sulfate was active in the suspension tests with activation. Iron(II) gluconate was mutagenic for indicator strain TA1538 in activation tests with primate liver preparations (14). Iron dextran did not induce chromosomal aberrations in human leukocyte cultures (17).

Carcinogenicity

Iron dextran complex repeatedly injected subcutaneously or intramuscularly was considered by IARC to be carcinogenic to animals (18).

EFFECTS ON HUMANS

Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status, and iron bioavailability and range from about 10 to 50 mg/day (12).

The average lethal dose of iron is 200–250 mg/kg of body weight, but death has occurred following the ingestion of doses as low as 40 mg/kg of body weight (6). Autopsies have shown haemorrhagic necrosis and sloughing of areas of mucosa in the stomach with extension into the submucosa. Chronic iron overload results primarily from a genetic disorder (haemochromatosis) characterized by increased iron absorption and from diseases that require frequent transfusions (10). Adults have often taken iron supplements for extended periods without deleterious effects (10), and an intake of 0.4–1 mg/kg of body weight per day is unlikely to cause adverse effects in healthy persons (19).

CONCLUSIONS

Anaerobic groundwaters may contain iron(II) at concentrations up to several milligrams per litre without discoloration or turbidity in the water when directly pumped from a well. Taste is not usually noticeable at iron concentrations below 0.3 mg/litre, although turbidity and colour may develop in piped systems at levels above 0.05–0.1 mg/litre. Laundry and sanitary ware will stain at iron concentrations above 0.3 mg/litre.

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As a precaution against storage of excessive iron in the body, JECFA established a provisional maximum tolerable daily intake (PMTDI) in 1983 of 0.8 mg/kg of body weight (14), which applies to iron from all sources except for iron oxides used as colouring agents, and iron supplements taken during pregnancy and lactation or for specific clinical requirements. Allocation of 10% of this PMTDI to drinking-water gives a value of about 2 mg/litre, which does not present a hazard to health. The taste and appearance of drinking-water will usually be affected below this level, although iron concentrations of 1–3 mg/litre can be acceptable for people drinking anaerobic well-water.

No health-based guideline value for iron is proposed.

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