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Inorganic Tin in Drinking-water

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

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.

Acknowledgements

Inorganic Tin in Drinking-water, Background document for development of WHO *Guidelines for Drinking-water Quality*, is an update of the background document published in the second edition of the Guidelines. The update was prepared by Mr J. Fawell and Mr R. Mascarenhas, United Kingdom, to whom special thanks are due.

The work of the following working group coordinators was crucial in the development of this document and others in the third edition:

Mr J.K. Fawell, United Kingdom (*Organic and inorganic constituents*)
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The contribution of peer reviewers is greatly appreciated. The draft text was posted on the world wide web for comments from the public. The revised text and the comments were discussed at the Final Task Force Meeting for the third edition of the GDWQ, held on 31 March to 4 April 2003, at which time the present version was finalized. The input of those who provided comments and of participants in the meeting is gratefully reflected in the final text.

The WHO coordinators were as follows:

Dr J. Bartram, Coordinator, Water Sanitation and Health Programme, WHO Headquarters, and formerly WHO European Centre for Environmental Health
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Ms C. Vickers provided a liaison with the International Chemical Safety Programme, WHO Headquarters.

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

Many individuals from various countries contributed to the development of the GDWQ. The efforts of all who contributed to the preparation of this document and in particular those who provided peer or public domain review comment are greatly appreciated.

Acronyms and abbreviations used in the text

AAS	atomic absorption spectrometry
LD_{50}	median lethal dose
NOAEL	no-observed-adverse-effect level
PTWI	provisional tolerable weekly intake
TDI	tolerable daily intake
USA	United States of America

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1. GENERAL DESCRIPTION

1.1 Identity

Tin in its most common form is a silvery white metal. Of the various tin-bearing minerals, cassiterite is an oxide, while the remainder are complex sulfides. Tin forms two series of compounds — namely, those of bivalent tin (tin(II)) and quadrivalent tin (tin(IV)). The most important inorganic compounds of tin are the oxides, chlorides, fluorides and halogenated sodium stannates and stannites. Tin can form 1–4 covalent bonds with carbon (Stokinger, 1978; Magos, 1986).

1.2 Physicochemical properties

Property	*Value*
Melting point	232 °C
Boiling point	2260–2270 °C at 100 kPa
Density	7.3 g/cm^3
Water solubility	Insoluble

1.3 Major uses

Approximately 50% of the world production of tin is used for plating. Tin coatings are used for food containers and food-processing equipment. Tin is also used in alloys, such as solders, bronzes and pewters. Inorganic tin compounds are used as pigments in the ceramic and textile industry (JECFA, 1989). Tin has been proposed for use as a corrosion inhibitor.

2. ANALYTICAL METHODS

Total tin is determined by atomic absorption spectrometry (AAS) with either direct aspiration into a flame or a furnace technique. The graphite furnace AAS procedure is highly sensitive. Picric acid, a simple and very efficient matrix modifier, greatly improves the determination of tin in toluene solution by furnace AAS. When combined with toluene–tropolone extraction from acidified aqueous solutions, this procedure lowers the detection limit for inorganic tin from 1 to 0.01 µg/litre (Pinel et al., 1988).

3. ENVIRONMENTAL LEVELS AND HUMAN EXPOSURE

3.1 Air

The background level of tin in air is about 0.01 µg/m^3, increasing to 0.3 µg/m^3 in urban areas and to 5 µg/m^3 near industrial emissions (WHO, 1980; Magos, 1986).

3.2 Water

The concentration of tin in rivers, estuaries and oceans is generally less than 5 ng/litre, but the use of organotin biocides can produce significantly higher concentrations (e.g., 26–91 ng/litre near the coast of California, USA; 200–3300 ng/litre in Lake Michigan, USA) (Magos, 1986). In seawater, levels of 0.3–980 ng/litre have been found. In rivers, levels were usually 6–10 ng/litre, but a concentration of 300 ng/litre was found in the Rhine (Weber, 1985).

Levels of <42–295 µg/litre were found in 37 different bottled mineral waters (Allen et al., 1989). A mean range of 1.1–2.2 µg/litre (maximum 30 µg/litre) was found in a survey of water supplies in the USA. Values greater than 1–2 µg/litre are exceptional (WHO, 1980).

3.3 Food

Most natural foods contain tin in trace amounts, but concentrations are increased by the use of organotin pesticides and the storage of liquids in cans (Magos, 1986). In most unprocessed foods, tin levels are generally less than 1 µg/g. Higher concentrations are found in canned foods as a result of dissolution of the tin coating or tin plate, the levels depending largely on the type and acidity of the food, the presence of oxidants, the duration and temperature of storage and the presence of air in the can headspace. Tin concentrations in foodstuffs frequently exceed 100 µg/g in unlacquered cans but are below 25 µg/g in lacquered cans (WHO, 1980; JECFA, 1989).

Low tin levels have been found in flour (10 ng/g), dried milk (50 ng/g), spinach (20 ng/g) and fish (4–8 µg/g); higher levels were reported in canned fruit (30–100 µg/g) and canned grapefruit juice (245–260 µg/g) (Weber, 1985). Vegetables grown on soils with high tin content contained less than 1 µg/g. Diets consisting of fresh vegetables, meat and cereals contributed less than 1 mg to the daily intake (Magos, 1986).

3.4 Estimated total exposure and relative contribution of drinking-water

Food, particularly canned food, represents the major route of human exposure to tin. Intake from this source varies widely and for some segments of the population can reach several milligrams per kilogram of body weight (JECFA, 1989). Estimates of the mean daily intake of tin are numerous (e.g., 0.1–100 mg; 0.2–17 mg; 3.6 mg; 1.5–8.8 mg) (WHO, 1980; Mance et al., 1988; JECFA, 1989). In a study on duplicate portions of the 24-h diet in the Netherlands, the median daily intake of tin was 0.21 mg in 1976–1978 (range <0.08–17.4 mg) and 1984–1985 (range <0.09–9.81) (Vaessen & Van Ooik, 1988).

The contribution of air to the daily intake of humans is less than 1 µg per person. For the general population, drinking-water is not a significant source of tin. Based on a maximum value of 2 µg/litre, its contribution will be 4 µg (WHO, 1980; Magos, 1986; JECFA, 1989).

4. KINETICS AND METABOLISM IN LABORATORY ANIMALS AND HUMANS

Both tin and inorganic tin compounds are poorly absorbed from the gastrointestinal tract; in most studies, absorption was less than 5%, although values as high as 20% have been reported (WHO, 1980). Gastrointestinal absorption is influenced by the oxidation state; studies with radiolabelled tin in the rat indicated that absorption of tin(II) was 4 times greater than that of tin(IV) (2.8% and 0.6%, respectively). The anion may also influence the rate of absorption (Hiles, 1974). Highest tissue concentrations of tin after both oral and parenteral administration were found in bone (principal site of distribution), kidney and liver (WHO, 1980).

Absorbed tin is excreted primarily via the kidneys and only to a smaller extent via the bile (Mance et al., 1988). Rats given oral doses of different tin salts excreted 50% of the absorbed tin in the first 48 h. Following intravenous administration of tin(II) or tin(IV) salts to rats, 12% of the tin(II) and only 4% of the tin(IV) appeared in the faeces, indicating that the biliary route is probably more important in the elimination of tin(II) compounds (94% within 24 h) compared with tin(IV) compounds (Hiles, 1974).

Half-times ranging from 3 to 4 months and from 34 to 40 days were reported in the bones of rats after intramuscular and oral administration, respectively. Elimination of tin(II) chloride after intraperitoneal and intravenous administration to the mouse, rat, monkey and dog was a four-component process that was similar in all the species studied, the half-time for the longest component being over 3 months (WHO, 1980).

5. EFFECTS ON LABORATORY ANIMALS AND IN VITRO TEST SYSTEMS

5.1 Acute exposure

The acute toxicity of metallic tin and inorganic tin compounds (except tin hydrides) to animal species is low; the oral LD_{50} values for tin(II) chloride for mice and rats are 250 and 700 mg/kg of body weight, respectively. The rabbit is less sensitive, the oral LD_{50} being 10 000 mg/kg of body weight (WHO, 1980). Tin hydrides, like many other metallic hydrides, are highly toxic to animals; they exert their effects mainly on the central nervous system (Browning, 1969). High doses of inorganic tin compounds (of the order of the LD_{50}) affect the central nervous system, producing effects such as ataxia, muscular weakness and central nervous system depression (WHO, 1980). The species-related differences illustrated by the LD_{50} values are apparent even at low levels of exposure. The cat was found to be more sensitive to the oral administration of tin than either the dog or the rat; vomiting and diarrhoea were observed only in cats after oral administration of tin-containing fruit beverages (472 mg/litre; >5.4 mg of tin per kg of body weight) or a complex of tin(IV) chloride and sodium citrate (9 mg of tin per kg of body weight) (JECFA, 1982).

5.2 Short-term exposure

In 4- or 13-week feeding studies with rats given various tin salts (including tin(II) chloride) or tin oxides at levels of 50–10 000 mg/kg of food, concentrations above 3000 mg/kg caused anaemia, changes in a number of enzyme activities and extensive damage to liver and kidney, particularly with the more soluble tin salts (e.g., the chloride, orthophosphate and sulfate) (De Groot et al., 1973; JECFA, 1982). When male weanling rats were given doses up to 3 mg of tin per kg of body weight (as tin(II) chloride) at 12-h intervals for 90 days, an increase in acid phosphatase activity and a decrease in the calcium content and compressive strength of the femur were observed (Yamaguchi et al., 1980).

5.3 Long-term exposure

Two drinking-water studies with mice were carried out (JECFA, 1982). In the first study, the mice received 1000 or 5000 mg of tin per litre as sodium chlorostannate or 5000 mg of tin per litre as tin(II) oleate for 1 year; in the second study, mice were given 5 mg of tin per litre as tin(II) chloride over their lifetime. In neither study were any effects on growth rates or survival observed.

In a 115-week study, rats were exposed to 0, 200, 400 or 800 mg of tin per kg of food as tin(II) chloride. Anaemia was observed in weeks 4 and 13 at each treatment level, but not during the second year of the study. At autopsy, the only effect noted was a slight increase in the relative spleen weight at 400 and 800 mg/kg, but no histopathological changes were observed. A slightly increased tin content in the bones was seen at the highest dose level only. The NOAEL in this study was 400 mg/kg of food, equivalent to 20 mg/kg of body weight per day (JECFA, 1982).

5.4 Reproductive and developmental toxicity

Testicular degeneration was observed in rats receiving 10 mg of tin(II) chloride per kg in the feed for 13 weeks (De Groot et al., 1973). Tin(II) chloride with casein in an aqueous medium at dose levels of 0, 200, 400 or 800 mg/kg of feed did not affect the reproductive performance of rats, although a transient anaemia was observed in the offspring before weaning (JECFA, 1982).

Low transplacental transfer of tin was observed after the feeding of different tin salts (in amounts corresponding to tin levels of up to 500 mg/kg in the diet) to pregnant rats; no effects were seen in the fetuses (WHO, 1980).

Tin(II) chloride (at doses up to 50 mg/kg of body weight) was not teratogenic or fetotoxic in mice, rats or golden hamsters (WHO, 1980).

5.5 Mutagenicity and related end-points

Tin(II) chloride was found not to be mutagenic in a *rec*-assay in *Bacillus subtilis* (NTP, 1982).

5.6 Carcinogenicity

In an oral carcinogenicity study with $B6C3F_1$ mice (dose levels 0, 1000 or 2000 mg of tin(II) chloride per kg of food), a statistically significant dose-related increase in the incidence of hepatocellular adenomas and/or carcinomas was found in females. However, the highest incidence was within the historical range for female $B6C3F_1$ mice (NTP, 1982).

In a long-term feeding study in rats given sodium chlorostannate, three malignant tumours were observed at sacrifice, but the treatment groups were rather small (De Groot et al., 1973). In a study with F-344 rats receiving 0, 1000 or 2000 mg of tin(II) chloride per kg of diet for 105 weeks, no increased tumour incidences were observed (NTP, 1982).

6. EFFECTS ON HUMANS

Vomiting, diarrhoea, fatigue and headache were often observed following the consumption of canned products (tin concentrations as low as 150 mg/kg in canned beverages and 250 mg/kg in other canned foods) (JECFA, 1982). In contrast, no toxic effects were noted in nine male volunteers consuming packaged military rations (tin contents ranging from 13 to 204 mg/kg) for successive 24-day periods and in two other studies on human volunteers who ate canned food with tin contents ranging from 250 to 700 mg/kg for periods of 6–30 days (WHO, 1980). There are no data to indicate any adverse effects in humans associated with chronic exposure to tin (JECFA, 1982, 2000). JECFA (2000) concluded that there were insufficient data to establish an acute reference dose for inorganic tin but noted that concentrations of 150 mg/kg in canned beverages or 250 mg/kg in other canned foods may produce acute manifestations of gastric irritation in certain individuals.

7. CONCLUSIONS

The low toxicity of tin and inorganic tin compounds is largely the result of its low absorption, low tissue accumulation and rapid excretion, primarily in the faeces. JECFA (1989) established a PTWI of 14 mg/kg of body weight from a TDI of 2 mg/kg of body weight on the basis that the problem with tin is associated with acute gastrointestinal irritancy, the threshold for which is about 200 mg/kg in food. This was reaffirmed by JECFA in 2000. In view of its low toxicity, the presence of tin in drinking-water does not, therefore, represent a hazard to human health. For this reason, the establishment of a numerical guideline value for inorganic tin is not deemed necessary.

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