Drinking water screening value for Iodide – Technical Summary

A drinking water screening value of 0.24 mg/L (240 µg/L) is established for iodide.

Screening Values: Health Canada's screening values identify limits for contaminants in water that could be used as a source of drinking water. A lifetime of exposure to these contaminants up to the screening value, both by drinking the water or by using it for showering or bathing, is not expected to increase health risks for any Canadian, including children.

Screening values are established for contaminants that are not commonly found in Canadian drinking water (either source or treated) and therefore Guidelines for Canadian Drinking Water Quality are not established. Health Canada establishes screening values for contaminants at the request of federal departments, provinces and territories (jurisdictions). These requests are usually made when there is a concern for human health because the presence of a contaminant is suspected or detected in local source water and that contaminant does not have an established limit in drinking water. Since 2020, the technical summaries for screening values are typically published online when Health Canada expects that screening values may be needed by more than one stakeholder or jurisdiction.

Screening values do not replace or supersede existing regulations. However, screening values may help jurisdictions and the public understand the potential health effects of a contaminant.

Screening values are based on a review of scientific research and international regulatory information available at the time of their development. In addition, screening values are externally peer-reviewed to ensure scientific integrity.

Health Canada is committed to keeping pace with new science, including the potential health risks from contaminants that are not typically found in drinking water and do not have Guidelines for Canadian Drinking Water Quality. To this end, Health Canada includes contaminants with screening values in its cyclical prioritization of contaminants for full guideline development.

Exposure Considerations

Identity and Sources

Iodine (I) is a non-metallic trace element that exists as a bluish-black or violet-black lustrous solid. For the purposes of this screening value, iodine is used to refer to the element in any form while iodide refers to the anion I^- and molecular iodine is used to refer to I_2. Iodine occurs naturally in minerals, seawater, seafood, seaweed and underground brines (water containing dissolved salts and ions) associated with natural gas and oil deposits. Iodine is used in a number of applications including in photography, the formulation of inks and colouring agents, making batteries, fuels and lubricants, in pharmaceuticals and as an antiseptic or sanitising agent (ATSDR, 2004). In agriculture, iodine is added as a supplement to animal feed and is used in teat sanitizers for dairy herds (Borucki Castro et al., 2010). In some countries, including Canada, iodine is added to table salt in the form of potassium iodide to compensate for iodine-deficient diets (CFIA, 2015). Although not used for disinfecting larger drinking water supplies, iodine is used for emergency or short-term disinfection of drinking water (WHO, 2020). Iodine used for emergency or short-term disinfection of drinking water may result in exposures above the screening value. However, this is not expected to be a health concern since the screening value is based on lifetime exposure.

In water, iodine exists in its molecular form (I_2) and as iodide (I^-) and iodate (IO_3^-) (Fuge and Johnson, 1986). Most iodine compounds are moderately or highly soluble in water (Table 1). Iodine is generally mobile in the environment; it readily migrates in water and is transferred to the atmosphere primarily through photochemical oxidation (Fuge and Johnson, 1986). The taste and odour thresholds for iodine range from 0.147 to 0.204 mg/L in water (Ruth, 1986).

Table 1. Properties of iodine relevant to its presence in drinking water

	Iodine	**Potassium Iodide**
CAS RN	1918-00-9	7681-11-0
Molecular formula	I_2	KI
Molecular weight (g/mol)	253.809	166.02
Water solubility (g/L) at 25°C	0.33	1,429
Vapour pressure (volatility)	0.305 mm Hg at 25°C	No data
Log octanol-water partition coefficient (Log Kow)	2.49	No data
Henry's Law constant	No data	No data

Source: ATSDR (2004)

Exposure

The main source for Canadian's exposure to iodine is through food and iodized salt. Salt sold for general household use in Canada contains 0.01% potassium iodide and approximately 380 µg of iodine per teaspoon (Dieticians of Canada, 2014; CFIA, 2015). In terms of food, saltwater seafood is one of the largest sources of iodine.

To a lesser extent, Canadians are exposed to iodine through drinking water. In a study of 65 small, medium and large water treatment systems across Canada, concentrations of iodide ranged from < 0.018 to 131 µg/L in summer (median = 0.222 µg/L) and < 0.018 to 117 µg/L in winter (median = 0.075 µg/L) (Tugulea et al., 2018). Higher levels of iodide have been found in regions previously covered by the Champlain Sea (i.e., Ontario, Quebec). Levels in groundwater throughout southern Ontario ranged from below the detection limit (5 µg/L) to 6 650 µg/L in a total of 2 091 samples. The median value was 11.2 µg/L while the 90th percentile was 140 µg/L (Hamilton, 2015). In a follow-up study of locations known to have a greater potential for higher iodine concentrations in groundwater (n = 80), iodine concentrations ranged from below the detection limit (5 µg/L) to 2 100 µg/L with a mean concentration of 133 µg/L (Rogerson, 2018).

When water that contains iodine is disinfected with chlorine or chloramine, it can produce iodinated disinfection by-products. For example, iodinated disinfection by-products have been detected at drinking water treatment plants supplied by sources that had naturally occurring ammonium, high bromide, iodide and/or total iodine concentrations (Tugulea et al., 2018). Similarly, they have also been detected in treatment plants supplied by source waters with elevated sodium content (used as a marker for potentially high iodide and/or total iodine) and naturally occurring ammonium (Tugulea et al., 2015). Iodinated disinfection by-products are occasionally detected in drinking water from treatment plants located in coastal saltwater areas (Weinberg et al., 2002).

Exposure to iodine has been evaluated in the Canadian Health Measures Survey (CHMS) where iodine status is measured through median urinary iodine concentrations (UIC). During the 2009–2011 sampling period (Cycle 3 of the CHMS), children ages 6–11 years had a median UIC of 189 µg/L while adults 20–60 years old had median UICs of 122–126 µg/L (Statistics Canada, 2013; Hays et al., 2018). Biomonitoring equivalents have been calculated to help interpret biomonitoring data in light of recommended values. These values show that the median Canadian population values are above those required to prevent deficiency and well below the threshold for excessive intake (Hays et al., 2018). This interpretation is also consistent with World Health Organization (WHO) epidemiological criteria for assessing iodine nutrition status, which considers these iodine levels to be indicative of an adequate iodine status (WHO et al., 2007). An analysis of cycle five CHMS data (2016–2017 sampling period) also found adequate iodine intakes in school-aged children and other sex-age groups. However, the analysis did note that iodine intakes for some women of childbearing age were below estimated average requirements for pregnancy and lactation, thus indicating a possible insufficiency for women who are pregnant or breastfeeding (Bertinato et al., 2021).

Health Considerations

Kinetics

Iodine can be ingested in a variety of chemical forms, although most ingested iodine is reduced to iodide in the gastrointestinal tract before being absorbed (Zimmermann, 2009). Based on studies in humans, iodide salts are close to completely absorbed (100%) once ingested (Fisher et al., 1965; Ramsden et al., 1967). The presence of perchlorate, thiocyanates, isothiocyanates, nitrates, fluorides, calcium, magnesium and iron in food and water has been shown to interfere with iodide absorption (Ubom, 1991; Cengiz et al., 2022). The absorption of iodine is similar in adults, adolescents and children. However, the absorption of iodine in infants maybe 2%–20% lower than in children and adults (ATSDR, 2004). Iodide is cleared from circulation primarily by the thyroid and the kidneys and is turned over rapidly. With a normally functioning thyroid, iodine has a half-life in the plasma of approximately ten hours (Chung, 2014). The biological half-life of iodine from the whole body varies considerably between individuals and has been measured as approximately 66 days in individuals with normally functioning thyroids (Kramer et al., 2002).

Essentiality

Iodine is an essential element required for normal thyroid function. Iodide is used in the synthesis of the thyroid hormones thyroxine (T4) and triiodothyronine (T3). Through these hormones, iodine plays an important role in energy-yielding metabolism and on the expression of genes that affect many physiological functions including embryogenesis, growth and development, and neurological and cognitive functions (EFSA, 2014). Worldwide, the greatest public health concerns regarding iodine are associated with deficiencies rather than excess exposures (Iodine Global Network, 2021). People at risk of deficiency include those who do not use iodized salt, people who are pregnant, vegans (i.e., no/low consumption of dairy, seafood, eggs) and people living in areas with iodine deficient soils (NIH, 2020). Deficiency is not generally expected in the Canadian population because of salt iodization.

Iodine is an essential element; therefore, recommended dietary allowances have been established by the Food and Nutrition Board of the US Institute of Medicine (IOM, 2001) and Health Canada (2010) (Table 2). In addition, tolerable upper intake levels have been set due to the potential for adverse health effects from ingestion of high amounts of iodine.

Table 2. Dietary reference intakes for iodine according to age group as established by the U.S. Institute of Medicine (2001) and Health Canada (2010)

Age Group	Adequate Intake or Recommended Dietary Allowance (µg per day)[a]	Tolerable Upper Intake Levels (µg per day)
0–6 months	110	Not determinable
7–12 months	130	Not determinable
1–3 years	90	200
4–8 years	90	300
9–13 years	120	600
14–18 years	150	900
19 years and older	150	1 100
Pregnancy <18	220	900
Pregnancy <19–50 years	220	1 100
Lactation <18	290	900
Lactation <19–50 years	290	1 100

[a]The values for the 0–6 months and 7–12 months age groups are adequate intake values whereas the values for the rest of the age groups are recommended dietary allowances.

Health Effects

The toxicity curve of iodine is U-shaped in that both too little and too much iodine can cause thyroid dysfunction. Exposure to excess levels of iodine is generally well tolerated, as a healthy thyroid gland is very adaptable to fluctuations in iodine intake (Pennington, 1990; Farebrother et al., 2019). Most healthy people can tolerate an excess of ≥ 1 500 µg per day without clinical symptoms. At these high concentrations, a persistent drop of serum T4 and T3 and a rise of thyroid stimulating hormone (TSH) has been observed, although levels remain in the normal range (Backer and Hollowell, 2000; Burgi, 2010).

The primary effects of excessive iodine ingestion are on the thyroid gland and regulation of thyroid hormone production and secretion. Disruption of the thyroid gland affects many organ systems including the skin, cardiovascular system, pulmonary system, kidneys, gastrointestinal tract, liver, blood, neuromuscular system, central nervous system, skeleton, reproductive systems, and numerous endocrine organs, including the pituitary and adrenal glands (ATSDR, 2004).

Chronic exposure (greater than 6 months) to greater than 0.03 mg/kg bw per day (e.g., 2 100 µg per day for a 70 kg adult) has been associated with many adverse health effects (ATSDR, 2004). Iodine-induced hypothyroidism (underactive thyroid, inadequate production of thyroid hormones) in humans can lead to neurological effects (delayed or deficient brain and neuromuscular development) in sensitive populations, particularly in the fetus and in newborn infants (Boyages, 2000) as well as reproductive effects including changes in the menstrual cycle, spontaneous abortions, stillbirths, and premature births (Dunn and Delange, 2001). Hyperthyroidism (overactive thyroid, overproduction of thyroxine) in humans has been associated with accelerated growth linked to accelerated pituitary growth hormone turnover or a direct effect of thyroid hormone on bone maturation and growth (Snyder, 2000). It has also been linked to reproductive effects including changes in gonadotropin release and sex hormone-binding globulin, and changes in the levels and metabolism of steroid hormones in both females and males (Krassas et al., 2010).

Iodine freely diffuses across the placenta and infants can be exposed to iodine in breast milk. Goitre and hypothyroidism have been reported in the offspring of mothers exposed to pharmacological doses of iodine and iodide (EGVM, 2003; Connelly et al., 2012).

Generally, acute, sub-chronic and chronic toxicity studies in animals support the findings from human studies. However, animal data are of limited value in assessing the toxicity of iodide because of significant species differences in basal metabolic rates and iodine metabolism (Hetzel and Maberly, 1986).

Iodine is not considered to be mutagenic (ATSDR, 2004). In humans, the link between iodine intake and the development of thyroid cancer has been explored in a number of investigations but the relationship remains uncertain (Prete et al., 2015; Zimmermann and Galetti, 2015; Cao et al. 2017; Lee et al., 2017). The International Agency for Research on Cancer (IARC) has not reviewed the carcinogenicity of iodide, nor has the United States Environmental Protection Agency (US EPA).

Mode of Action

Iodide is an essential element and is the rate-limiting chemical in the synthesis of thyroid hormones by the thyroid gland. Iodide is transferred into the thyroid cell by the sodium/iodine symporter where it combines with the amino acid tyrosine to make the hormones T4 and T3. These hormones are released into the blood stream and are circulated throughout the body where they are responsible for the regulation of metabolism. Feedback mechanisms exist and a healthy thyroid gland can adapt to varying levels of iodide. However, when the normal adaptive function of the thyroid fails, various morbidities may ensue. The mechanisms of action for various iodide-induced thyroid disorders are reviewed by Prete et al. (2015).

Selection of Key Studies

The critical effects associated with excessive iodine intake are on the thyroid gland and regulation of thyroid hormone production and secretion. Relevant toxicity studies, including those used by Health Canada and other international jurisdictions to set tolerable upper intake levels, are summarized in Table 3. Together, these studies indicate that the point of departure for iodine is approximately 0.01 mg/kg bw per day for both short and longer-term studies. This point of departure also applies to both adults and children.

Table 3. Summary of relevant toxicity studies for iodide in drinking water

Reference	Population	Exposure duration	Critical effect(s)	POD
Gardner et al. (1988)	30 men aged 22 to 40 years given iodine supplementation	500, 1 500, or 4 500 µg NaI per day for 14 days	Significant decreases in T4 concentration and free thyroxine index values; significant increases in baseline and TRH-stimulated serum TSH	LOAEL = 1 800 µg per day[a] NOAEL = 800 µg per day equivalent to 0.01 mg/kg bw per day
Paul et al. (1988)	9 men aged 26 to 56 years and 23 women aged 23 to 44 years given iodine supplementation	250, 500, or 1 500 µg NaI per day for 14 days	Significant decreases in T4 and T3 concentrations; significant increase in baseline and TRH-stimulated serum TSH	LOAEL = 1 700 µg per day[a] NOAEL = 700 µg per day equivalent to 0.01 mg/kg bw per day
Chow et al. (1991)	Women aged 25–54 and thyroid antibody positive (n = 20) or antibody negative (n = 30), or aged 60–75 and from area with adequate iodine (n = 29) or from iodine deficient area (n = 35).	500 µg KI per day or placebo for 28 days	Significant decreases in T4 levels and significant increases in TSH levels	0.01 mg/kg bw per day[b]
Li et al. (1987)	Children aged 7–15 years, who resided in two areas where iodide in drinking water were either 462 µg/L (n = 120) or 54 µg/L (n = 51)	Equivalent to 1 150 µg per day (0.029 mg/kg per day) and 400 µg per day (0.010 mg/kg per day) in the high and low iodide groups	Subclinical hypothyroidism in healthy human children	NOAEL = 0.01 mg/kg bw per day
Boyages et al. (1989)	Children aged 7–15 years, who resided in two areas where iodide in drinking water were either 462 µg/L (n = 29) or 54 µg/L (n = 26)			

KI: potassium iodide; LOAEL: lowest observed adverse effect level; NaI: sodium iodide; NOAEL: no observed adverse effect level; POD: point of departure; T3: triiodothyronine; T4: thyroxine; TRH: thyrotropin-releasing hormone; TSH: thyroid stimulating hormone

[a] Includes background levels of iodine estimated from urinary excretion.

[b] A NOAEL or LOAEL could not be defined since only one dose was tested. The concentration at which effects were observed was approximately 0.01 mg/kg bw per day based on a total iodide intake of 750 µg per day, which is comprised of the 500 µg per day iodide supplement plus a background intake level of 250 µg per day.

Derivation of the Screening Value

Based on a weight of evidence approach, the tolerable daily intake of iodide is 0.01 mg/kg bw per day. No uncertainty factors were applied to the point of departure since the relevant studies were conducted in humans and the point of departure is similar for children, adults and the elderly (i.e., no need to account for human sensitivity) (Boyages et al.,1989; Chow et al., 1991).

Based on the above tolerable daily intake, a screening value can be derived as follows:

Equation 1

$$\text{Screening value} = \frac{0.01 \text{ mg/kg bw per day} \times 74 \text{ kg} \times 0.50}{1.53 \text{ L per day}}$$

$$= 0.24 \text{ mg/L } (240 \text{ µg/L})$$

where:

- 0.01 mg/kg bw per day is the tolerable daily intake, as derived above;
- 74 kg is the average body weight for an adult (Health Canada, 2021);
- 0.50 is the allocation factor: the proportion of exposure to iodide from drinking water, as opposed to other media (i.e., food, consumer products, air, soil). Given that food and water represent the main source of exposure, a value of 0.50 (50%) was applied (Krishnan and Carrier, 2013);
- 1.53 L per day is the drinking water intake rate for a Canadian adult (Health Canada, 2021). Exposure to iodide from showering or bathing is unlikely to be significant. Consequently, a multi-route exposure assessment, as outlined by Krishnan and Carrier (2008), was not performed.

A screening value of 0.24 mg/L (240 µg/L) for iodide in drinking water is recommended by Health Canada. This is a conservative value as the critical effects identified in the relevant toxicity studies are biochemical in nature and not clinically adverse effects.

Although iodine is not recommended for use as a primary disinfectant in drinking water treatment, it can be used for emergency or short-term disinfection of drinking water. Use in these situations could result in exposures above the screening value. However, this is not expected to be a health concern since the iodide screening value is based on lifetime exposure. Because of the public health risk associated with microbiologically unsafe water, disinfection should not be compromised. Further information on the use of iodine as a drinking-water disinfectant is provided by the WHO (2018).

International Considerations

Drinking water quality guidelines, standards and/or guidance established by foreign governments or international agencies may vary due to the science available at the time of assessment, as well as the utilization of different policies and approaches, such as the choice of key study, and the use of different consumption rates, body weights and allocation factors.

Australia has developed a drinking water guideline for iodide of 0.5 mg/L (500 µg/L) based on subtracting a background daily dietary intake of 200 µg per person from a tolerable daily intake of 1 100 µg per person then dividing by an adult drinking water consumption rate of 2 L per day (NHMRC, 2011). The US EPA, the European Union and the WHO do not have regulatory guidelines for iodide in drinking water.

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