**WHO/HSE/WSH/09.01/7**
**English only**

# Potassium in drinking-water

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

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Printed by the WHO Document Production Services, Geneva, Switzerland

## Preface

One of the primary goals of the World Health Organization (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 third edition of the GDWQ was published in 2004, the first addendum to the third edition was published in 2006 and the second addendum to the third edition was published in 2008. The fourth edition will be published in 2011.

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 and 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 of potential health concern in drinking-water. In the first and second editions, these constituted Volume 2 of the GDWQ. Since publication of the third edition, they comprise a series of free-standing monographs, including this one.

For each chemical contaminant or substance considered, a lead institution prepared a background document evaluating the risks for human health from exposure to the particular chemical in drinking-water. Institutions from Canada, Japan, the United Kingdom and the United States of America (USA) prepared the documents for the fourth edition.

Under the oversight of a group of coordinators, each of whom was responsible for a group of chemicals considered in the GDWQ, 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. The draft documents were also released to the public domain for comment and submitted for final evaluation by expert meetings.

During the preparation of background documents and at expert 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**

The first draft of Potassium in Drinking-water, Background document for development of WHO *Guidelines for Drinking-water Quality* (GDWQ), was prepared by staff at Health Canada, Ottawa, Canada, to whom special thanks are due. This background document is an update of the background document published in the addendum to the second edition of the GDWQ.

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

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The draft text was discussed at the Expert Consultation for the fourth edition of the GDWQ, held on 19–23 June 2008. The final version of the document takes into consideration comments from both peer reviewers and the public. The input of those who provided comments and of participants at the meeting is gratefully acknowledged.

The WHO coordinators were Mr R. Bos and Mr B. Gordon, WHO Headquarters. Ms C. Vickers provided a liaison with the International Programme on Chemical Safety, WHO Headquarters. Mr M. Zaim, Public Health and the Environment Programme, WHO Headquarters, provided input on pesticides added to drinking-water for public health purposes.

Ms P. Ward provided invaluable administrative support at the Expert Consultation and throughout the review and publication process. Ms M. 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 comments are greatly appreciated.

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The following is a short background document to provide guidance on potassium in drinking-water. It will be of particular interest to those using potassium permanganate for water treatment or potassium chloride for water softening.

## *1. INTRODUCTION*

Potassium is an essential element in humans and is seldom, if ever, found in drinking-water at levels that could be a concern for healthy humans. It occurs widely in the environment, including all natural waters. It can also occur in drinking-water as a consequence of the use of potassium permanganate as an oxidant in water treatment. In some countries, potassium chloride is being used in ion exchange for household water softening in place of, or mixed with, sodium chloride, so potassium ions would exchange with calcium and magnesium ions. Possible replacement or partial replacement of sodium salts with potassium salts for conditioning desalinated water has been suggested. The latter seems to be an unlikely development at this stage, in view of the cost difference.

The move to using potassium is driven by concerns over the total dietary intake of sodium, particularly in developed countries where there are concerns regarding the high intake of salt from processed foods. In contrast, there are also concerns that some diets may be low in potassium. This is not a concern for the general population; however, increased exposure to potassium could result in significant health effects in people with kidney disease or other conditions, such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia, older individuals who have reduced physiological reserves in their renal function and/or individuals who are taking medications that interfere with the normal handling of potassium in the body. Infants also have a limited renal reserve and immature kidney function and may therefore be more vulnerable.

## *2. EXPOSURE TO POTASSIUM*

Potassium is an essential element and is present in all animal and plant tissues. The primary source of potassium for the general population is the diet, as potassium is found in all foods, particularly vegetables and fruits. Some food additives are also potassium salts (e.g. potassium iodide). Some individuals require potassium supplements, which are given under medical supervision; others take potassium supplements without supervision, although this is not recommended.

Potassium permanganate may be used in the drinking-water treatment process. Resulting levels of potassium in drinking-water are relatively low compared with levels resulting from the use of water softeners using potassium chloride. Where potassium permanganate is used in water treatment, concentrations of added potassium can be up to a maximum of 10 mg/l, but normally concentrations would be less than this.

Although concentrations of potassium normally found in drinking-water are generally low and do not pose health concerns, the high solubility of potassium chloride and its use in treatment devices such as water softeners can lead to significantly increased exposure. In the United Kingdom, a survey carried out for the Regional Heart Study (Powell, Bailey & Jolly, 1987) found a mean potassium concentration of 2.5 mg/l in

drinking-water, with an upper 90th-percentile concentration of 5.2 mg/l. Data from Canada indicate that average concentrations of potassium in raw and treated drinking-water in different areas vary between <1 and 8 mg/l. However, concentrations ranged up to 51 mg/l in Saskatchewan, which is the largest production area for potassium chloride in Canada (Health Canada, 2008).

When used, potassium-based (usually mixed potassium and sodium) water softeners remove minerals such as calcium and magnesium ions from hard water, replacing them with potassium and sodium ions, rather than sodium ions alone. The intake of potassium from the consumption of drinking-water treated with a water softener using potassium chloride will vary depending on the level of hardness in the source water. Assuming that a 100% potassium chloride-regenerated water softener releases 14 mg of potassium ions per litre in water with a hardness of 17 mg of calcium carbonate per litre, the amount of potassium released in 1 litre of drinking-water can be calculated for different hardness levels. Table 1 shows that a water softener using potassium chloride can add significantly to the intake of potassium when compared with the amount that would be typically consumed in drinking-water, even when the water treated had water hardness levels generally considered to be acceptable (Health Canada, 2008). With a hardness of 100, 200 and 500 mg/l, the potassium concentrations would be 82, 164 and 411 mg/l.

**Table 1: Intake of potassium as a result of water softener use, by hardness level**

| Drinking-water hardness (mg/l as calcium carbonate) | $K^+$ concentration (mg/l) | Intake[c] (mg/kg body weight per day) |
|---|---|---|
| Treated tap water | 8.0[a] | 0.27 |
| 100 (acceptable)[b] | 82 | 2.7 |
| 200 (poor)[b] | 164 | 5.5 |
| 500 (unacceptable)[b] | 411 | 13.7 |

[a] Average $K^+$ concentration in drinking-water, based on the average potassium concentration in the Canadian province with the highest measured $K^+$ concentrations.
[b] Based on Health Canada's drinking-water quality guideline for hardness.
[c] Assuming consumption of 2 litres of water per day by a 60 kg adult.

## *3. ESSENTIAL INTAKES*

As indicated above, potassium is an essential element for human nutrition, and requirements are generally measured in grams per day. Potassium and sodium maintain the normal osmotic pressure in cells. Potassium is a cofactor for many enzymes and is required for the secretion of insulin, creatinine phosphorylation, carbohydrate metabolism and protein synthesis.

Excessive loss of salts, such as through severe diarrhoea or intense and prolonged sweating, can result in a loss of potassium, which can result in hypokalaemia if the loss is sufficient. This can cause a range of effects, including cardiac arrhythmia, muscle weakness, nausea and vomiting, and low muscle tone in the gut. Longer-term hypokalaemia is believed to cause a predisposition to hypertension (UKEVM, 2003).

**Table 2: Dietary reference intake values (as adequate intake), derived by IOM (2004)**

| | Age group | Dietary reference intake (g/day) |
|---|---|---|
| Infants | 0–6 months | 0.4 |
| | 7–12 months | 0.7 |
| Children | 1–3 years | 3.0 |
| | 4–8 years | 3.8 |
| Male youth and adults | 9–13 years | 4.5[a] |
| | 14–>70 years | 4.7[a] |
| Female youth and adults | 9–13 years | 4.5[a] |
| | 14–>70 years | 4.7[a] |
| Pregnancy | n/a | 4.7[a] |
| Lactation | n/a | 5.1[a] |

n/a, not applicable

[a] United Kingdom guidelines for adults are 3.7 g/day with no requirement for additional intake in pregnancy and lactation.

The adequate intake for adults (19–>70 years of age) is 4.7 g/day (IOM, 2004). This is equivalent to 78 mg/kg body weight per day for a 60 kg adult. The IOM (2004) adequate intake is based on potassium's effect of countering salt (sodium chloride) sensitivity in African Americans, as well as epidemiological evidence linking higher levels of potassium intake with decreased risk of bone loss and kidney stones.

## *4. INTERACTIONS WITH OTHER ELEMENTS*

It is known that the balance between sodium and potassium intake is very important, as excess sodium intake can result in depletion of potassium levels. In magnesium deficiency, there is a failure to retain potassium in sufficient quantities, and an excess intake of potassium can interfere with magnesium uptake.

## *5. EFFECTS OF HIGH POTASSIUM INTAKE*

Adverse health effects due to potassium consumption from drinking-water are unlikely to occur in healthy individuals. Potassium intoxication by ingestion is rare, because potassium is rapidly excreted in the absence of pre-existing kidney damage and because large single doses usually induce vomiting (Gosselin, Smith & Hodge, 1984).

Case-studies of toxicity resulting from high doses of salt substitutes have described chest tightness, nausea and vomiting, diarrhoea, hyperkalaemia, shortness of breath and heart failure. For example, a fatality resulted from hyperkalaemia and resultant asystole after ingestion of 21 g of salt substitute (approximately 11 g potassium) (Restuccio, 1992). A 2-month-old boy died after being given three doses of 1.5 g potassium chloride mixed with breast milk over 1.5 days (Wetli & Davis, 1978).

Potassium toxicity has been studied in relation to the use of high doses of salt substitutes. The symptoms described have been chest tightness, nausea and vomiting, diarrhoea, hyperkalaemia, shortness of breath and heart failure. However, the data are not considered adequate to derive an upper limit for intake. This is compounded by a number of high-risk groups, considered below. However, the United Kingdom Expert

Group on Vitamins and Minerals considers that for normal individuals, ingestion of potassium supplements of up to 3700 mg/day is likely to be without overt effects, although ingestion of potassium tablets may lead to some minor gastrointestinal mucosal erosion (UKEVM, 2003). This conclusion was based on studies by Grimm et al. (1988, 1990) and McMahon et al. (1982, 1984).

## *6. HIGH-RISK GROUPS*

Adverse effects due to higher than normal potassium plasma concentrations (hyperkalaemia) may occur in certain segments of the population when consuming drinking-water with unusually high levels of potassium arising from either the use of ion exchange treatment with particularly hard water or the accidental release of very high concentrations. Individuals most at risk are primarily those in which excretion of potassium ions might be reduced or compromised, including those with kidney disease or renal insufficiency, older individuals who have reduced physiological reserve in their renal function, as well as individuals with other conditions (heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency and existing hyperkalaemia) and/or individuals who are taking medications that interfere with normal potassium-dependent functions in the body. In addition, infants may also be more vulnerable because of a limited renal reserve and immature kidney function.

Kidney disease is not thought to be able to seriously affect potassium homeostasis until the kidney has reached less than 40% of normal function. This can be the case for many thousands of individuals, and the number is likely to increase as populations age. In Canada, it is estimated that approximately 44 000 individuals have stage 4 (15–30% of kidney function) and stage 5 (<15% of kidney function) kidney disease (Stignant, Stevens & Levin, 2003) and are at greater risk of developing hyperkalaemia under certain conditions, including potassium supplementation (potassium chloride-based water softener) and/or the consumption of certain medications.

## *7. MEDICATION THAT CAN INTERFERE WITH POTASSIUM HOMEOSTASIS*

A number of medications can cause hyperkalaemia when administered to individuals with kidney disease or diseases that affect potassium homeostasis. These drugs can be divided into two categories: those that interfere with the cellular mechanisms that regulate potassium uptake, and those that interfere with renal potassium excretion. The first category includes non-selective beta blockers, used in the treatment of hypertension, heart disease, coronary artery disease and fluid-retaining syndromes. The second category includes the following classes of drugs: potassium sparing diuretics (hypertension, heart disease, kidney and liver disease); non-steroidal anti-inflammatory drugs (pain treatment); angiotensin-converting enzyme inhibitors (heart disease, coronary artery disease, hypertension, diabetes, kidney disease); angiotensin II receptor blockers (heart disease, hypertension); trimethorprim (human immunodeficiency virus treatment); cyclosporin (immunosuppressive drug); and aldosterone inhibitors (heart disease, hypertension, birth control) (Perazella & Mahnensmith, 1997; Perazella, 2000; CCS, 2003; CHS, 2005).

Currently, it is recommended that groups at risk should not take any potassium supplementation except under close medical supervision.

Adverse effects may also occur when potassium plasma concentrations are lower (hypokalaemia) than the normal range (3.5–5.0 mmol/l). Both hyperkalaemia and hypokalaemeia result from disruptions in transcellular homeostasis or in the renal regulation of potassium excretion (Gennari, 2002).

## *8. DISCUSSION*

Currently, there is no evidence that potassium levels in municipally treated drinking-water, even water treated with potassium permanganate, are likely to pose any risk for the health of consumers. It is not considered necessary to establish a health-based guideline value for potassium in drinking-water.

Although potassium may cause some health effects in susceptible individuals, potassium intake from drinking-water is well below the level at which adverse health effects may occur. Health concerns would be related to the consumption of drinking-water treated by potassium-based water treatment (principally potassium chloride for regeneration of ion exchange water softeners), affecting only individuals in the high-risk groups (individuals with kidney dysfunction or other diseases such as heart disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia; people taking medications that interfere with normal potassium-dependent functions in the body; and older individuals or infants). It is recommended that susceptible individuals seek medical advice to determine whether they should avoid the consumption of water (for drinking or cooking) treated by water softeners using potassium chloride.

When high-risk individuals have been advised by a physician to avoid elevated potassium intake from water, the recommended strategy is to limit the addition of potassium to water that will be ingested or to avoid ingesting such water. This can be done by having a proportion of the water bypass the softener altogether; this approach is recommended by several countries. Although technologies are available to remove potassium, they are generally more expensive and redundant when combined with the softening treatment.

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