Rolling revision of the WHO Guidelines for drinking-water quality

Draft for review and comments
(Not for citation)

Health risks from drinking demineralised water

By F. Kozisek

World Health Organization
Geneva, 2004

Health risks from drinking demineralized water

F. Kozisek

1. INTRODUCTION

The composition of water varies widely with local geological conditions. Neither groundwater nor surface water has ever been chemically pure H_2O, since water contains small amounts of gases, minerals and organic matter of natural origin. The total concentrations of substances dissolved in fresh water considered to be of good quality can be hundreds of mg/l.

Thanks to epidemiology and advances in microbiology and chemistry since the 19th century, numerous waterborne disease causative agents have been identified. The knowledge that water may contain some constituents that are undesirable is the point of departure for establishing guidelines and regulations for drinking water quality. Maximum acceptable concentrations of inorganic and organic substances and microorganisms have been established internationally and in many countries to assure the safety of drinking water.

Awareness of the importance of minerals and other beneficial constituents in drinking water has existed for thousands years, being mentioned in the Vedas of ancient India. In the book Rig Veda, the properties of good drinking water were described as follows: “Sheetham (cold to touch), Sushihi (clean), Sivam (should have nutritive value, requisite minerals and trace elements), Istham (transparent), Vimalam lahu Shadgunam (its acid base balance should be within normal limits)“ (Sadgir and Vamanrao 2003). That water may contain desirable substances has received less attention in guidelines and regulations, but an increased awareness of the biological value of water has occurred in the past several decades.

Artificially-produced demineralized waters, first distilled water and later also deionized or reverse osmosis-treated water, had been used mainly for industrial, technical and laboratory purposes. These technologies became more extensively applied in drinking water treatment in the 1960's as limited drinking water sources in some coastal and inland arid areas could not meet the increasing water demands resulting from increasing populations, higher living standards, development of industry, and mass tourism. Drinking water supply was also of concern to ocean-going ships, and spaceships as well. The potential effects of totally unmineralized water had not generally been considered, since this water is not found in nature except possibly for rainwater and naturally formed ice. Although rainwater and ice are not used as community drinking water sources in industrialized countries where drinking water regulations were developed, they are used by individuals in some locations. In addition, many natural waters are low in many minerals or soft (low in divalent ions), and hard waters are often artificially softened.

Demineralization of water was needed where the primary or the only abundant water source available was highly mineralized brackish water or sea water. Initially, these water treatment methods were not used elsewhere since they were technically exacting and costly. In this chapter, demineralized water is defined as water almost or completely free of dissolved minerals as a result of distillation, deionization, membrane filtration (reverse osmosis or nanofiltration), electrodialysis or other technology. The total dissolved solids (TDS) in such water can vary but TDS could be as low as 1 mg/l. The electrical conductivity is generally less than 2 mS/m and may even be lower (<0.1 mS/m).

Although the technology had its beginnings in the 1960's, demineralization was not widely used at that time. However, some countries focused on public health research in this field, mainly the former USSR where desalination was introduced to produce drinking water in some Central Asian cities. It was clear from the very beginning that desalinated or demineralised water without further enrichment with some minerals might not be fully appropriate for consumption. There were three evident reasons for this:

- Demineralised water is highly aggressive and if untreated, its distribution through pipes and storage tanks would not be possible. The aggressive water attacks the water distribution piping and leaches metals and other materials from the pipes and associated plumbing materials.
- Distilled water has poor taste characteristics.
- Preliminary evidence was available that some substances present in water could have beneficial effects on human health as well as adverse effects. For example, experience with artificially fluoridated water showed a decrease in the incidence of tooth caries, and some epidemiological studies in the 1960's reported lower morbidity and mortality from some cardiovascular diseases in areas with hard water.

Therefore, researchers focused on two issues: 1) what are the possible adverse health effects of demineralised water, and 2) what are the minimum and the desirable or optimum contents of the relevant substances (e.g., minerals) in drinking water needed to meet both technical and health considerations. The traditional regulatory approach, which was previously based on limiting the health risks from excessive concentrations of toxic substances in water, now took into account possible adverse effects due to the deficiency of certain constituents.

At one of the working meetings for preparation of guidelines for drinking water quality, the World Health Organization (WHO) considered the issue of the desired or optimum mineral composition of desalinated drinking water by focusing on the possible adverse health effects of removing some substances that are naturally present in drinking water (WHO 1979). In the late 1970's, the WHO also commissioned a study to provide background information for issuing guidelines for desalinated water. That study was conducted by a team of researchers of the A.N. Sysin Institute of General and Public Hygiene and USSR Academy of Medical Sciences under the direction of Professor Sidorenko and Dr. Rakhmanin. The final report, published as an internal working document (WHO 1980), concluded that "not only does completely demineralised water (distillate) have unsatisfactory organoleptic properities, but it also has a definite adverse influence on the animal and human organism." After evaluating the available health, organoleptic, and other information, the team recommended that demineralised water contain 1.) a minimum level for dissolved salts (100 mg/l), bicarbonate ion (30 mg/l), and calcium (30 mg/l),; 2.) an optimum level for total dissolved salts (250-500 mg/l for chloride-sulfate water and 250-500 mg/l for bicarbonate water); 3.) a maximum level for alkalinity (6.5 meq/l), sodium (200 mg/l), boron (0.5 mg/l), and bromine (0.01 mg/l). These recommendations are discussed in greater detail in this chapter.

During the last three decades, desalination has become a widely practised technique in providing new fresh water supplies. There are more than 11 thousand desalination plants all over the world with an overall production of more than 6 billion gallons of desalinated water per day. In some regions such as the Middle East and Western Asia more than half of the drinking water is produced in this way. Desalinated waters are commonly further treated by adding chemical constituents such as calcium carbonate or limestone, or blended with small volumes of more mineral-rich waters to improve their taste and reduce their aggressiveness to the distribution network as well as plumbing materials. However, desalinated waters may vary widely in composition because numerous existing facilities were developed on a case-by-case basis without compliance with any uniform guidelines (apart from the WHO Guidelines for

Drinking Water Quality) for final product quality in terms of the minimum TDS content.

The potential for adverse health effects from long term consumption of demineralised water is of interest not only in countries lacking adequate fresh water but also in countries where some types of home water treatment systems are widely used or where some types of bottled water are consumed. Many brands of bottled water are produced by demineralising fresh water and then adding minerals for desirable taste. Persons consuming certain types of water may not be receiving the additional minerals that would be present in more highly mineralized waters. Consequently, the exposures and risks should be considered at the individual or family level as well as at the community level.

2. HEALTH RISKS FROM CONSUMPTION OF DEMINERALISED OR LOW-MINERAL WATER

Knowledge of some effects of consumption of demineralised water is based on experimental and observational data. Experiments have been conducted in laboratory animals and human volunteers, and observational data have been obtained from populations supplied with desalinated water, individuals drinking reverse osmosis-treated demineralised water, and infants given beverages prepared with distilled water. Because limited information is available from these studies, we should also consider the results of epidemiological studies where health effects were compared for populations using low-mineral (soft) water and more mineral-rich waters. Demineralised water that has not been remineralised is considered an extreme case of low-mineral or soft water because it contains only small amounts of dissolved minerals such as calcium and magnesium that are the major contributors to hardness.

The possible health consequences of low mineral content water consumption are discussed in the following categories:

- Direct effects on the intestinal mucous membrane, metabolism and mineral homeostasis or other body functions.
- Practically zero calcium and magnesium intake.
- Low intake of other essential elements and microelements.
- Loss of calcium, magnesium and other essential elements in prepared food.
- Possible increased dietary intake of toxic metals leached from water pipe.
- Possible bacterial re-growth.

2.1 Direct effects of low mineral content water on the intestinal mucous membrane, metabolism and mineral homeostasis or other body functions

Distilled and low mineral content water (TDS < 50 mg/l) can have negative taste characteristics to which the consumer may adapt with time. This water is also reported to be less thirst quenching (WHO 1980). Although these are not considered to be health effects, they should be taken into account when considering the suitability of low mineral content water for human consumption. Poor organoleptic and thirst-quenching characteristics may affect the amount of water consumed or cause persons to seek other, possibly less satisfactory water sources.

A study by Williams (1963) reported that distilled water introduced into the intestine caused abnormal changes in epithelial cells of rats, possibly due to osmotic shock. However, the same conclusions were not reached by Schumann *et al*. (1993) in a more recent study based on 14-day experiments in rats. Histology did not reveal any signs of erosion, ulceration or inflammation in the oesophagus, stomach and jejunum. Altered secretory function in animals (i.e., increased secretion and acidity of gastric juice) and altered stomach muscle tone were reported in studies for WHO (1980), however, based on currently available data, a direct negative effect of low mineral content water on the gastrointestinal mucous membrane has not been unambiguously demonstrated.

It has been adequately demonstrated that consuming water of low mineral content has a negative effect on homeostasis mechanisms, compromising the mineral and water metabolism in the body. An increase in urine output (i.e., increased diuresis) is associated with an increase in excretion of major intra- and extracellular ions from the body fluids, their negative balance, and changes in body water levels and functional activity of some body water management-dependent hormones.

Experiments in animals, primarily rats, for up to one-year periods have repeatedly shown that the intake of distilled water or water with TDS ≤ 75 mg/l leads to: 1) increased water intake, diuresis, extracellular fluid volume, and serum concentrations of sodium (Na) and chloride (Cl) ions and their increased elimination from the body, resulting in an overall negative balance if it is not adequately compensated from food, and 2) lower volumes of red cells and some other hematocrit changes (WHO 1980). Although recent studies (Rakhmanin *et al*. 1989) did not find mutagenic or gonadotoxic effects of distilled water, they did add new knowledge about decreased secretion of tri-iodothyronine and aldosterone, increased secretion of cortisol, morphological changes in the kidneys including a more pronounced atrophy of glomeruli, and swollen vascular endothelium limiting the blood flow. Reduced skeletal ossification was also found in rat foetuses whose dams were given distilled water in a one-year study. Apparently the reduced mineral intake from water was not compensated by their diets.

Results of experiments in human volunteers evaluated by researchers for the WHO report (1980) are in agreement with those reported in animal experiments. Low-mineral water markedly: 1) increased diuresis (almost by 20%, on average), body water volume, and serum sodium concentrations, 2) decreased serum potassium concentration, and 3) increased the elimination of sodium, potassium, chloride, calcium and magnesium ions from the body. The basic mechanism of the effects of water low in TDS (e.g. < 100 mg/l) on water and mineral homeostasis was suggested as follows (WHO 1980). Low-mineral water acts on osmoreceptors of the gastrointestinal tract, causing an increased flow of sodium ions into the intestinal lumen and slight reduction in osmotic pressure in the portal venous system with subsequent enhanced release of sodium into the blood as an adaptation response. This osmotic change in the blood plasma results in the redistribution of body water; that is, there is an increase in the total extracellular fluid volume and the transfer of water from erythrocytes and interstitial fluid into the plasma and between intracellular and interstitial fluids. In response to the changed plasma volume, baroreceptors and volume receptors in the bloodstream are activated, inducing a decrease in aldosterone release and thus an increase in sodium elimination. Reactivity of the volume receptors in the vessels may result in a decrease in ADH release and an enhanced diuresis. The German Society for Nutrition reached similar conclusions, warning the public against drinking distilled water (DgfE 1993). This warning was published in response to the German edition of *The Shocking Truth About Water* (Bragg and Bragg 1993), whose authors recommended drinking distilled water instead of "ordinary" drinking water. The Society in its position paper explains that water in the human body always contains electrolytes (e.g. potassium and sodium) at certain concentrations controlled by the body. Water resorption by the intestinal epithelium is also enabled by sodium transport. If distilled water is ingested, the intestine has to add electrolytes to this water first, taking them from the body reserves. Since the body never eliminates fluid in form of "pure" water but always together with salts, adequate intake of electrolytes must be ensured. Ingestion of distilled water leads to the dilution of the electrolytes dissolved in the body water. Inadequate body water redistribution between compartments may compromise the function of vital organs. Symptoms at the very beginning of this condition include tiredness, weakness and headache; more severe symptoms are muscular cramps and impaired heart rate.

Additional evidence comes from animal experiments and clinical observations in several countries. Animals given zinc or magnesium dosed in their drinking water had a significantly higher concentration of these elements in the serum than animals given the same elements in much higher amounts with food and provided with low-mineral water to drink. Based on the results of experiments and clinical observations of mineral deficiency in patients whose intestinal absorption did not need to be taken into account and who received balanced intravenous nutrition diluted with distilled water, Robbins and Sly (1981) presumed that intake of low-mineral water was responsible for an increased elimination of minerals from the body.

Regular intake of low-mineral content water could be associated with the progressive evolution of the changes discussed above, possibly without manifestation of symptoms or causal symptoms over the years. Nevertheless, severe acute damage, such as hyponatremic shock or delirium, may occur following intense physical efforts and ingestion of several litres of low-mineral water (Basnyat *et al.* 2000). The so-called "water intoxication" (hyponatremic shock) may also occur with rapid ingestion of excessive amounts not only of low-mineral water but also tap water. The "intoxication" risk increases with decreasing levels of TDS. In the past, acute health problems were reported in mountain climbers who had prepared their beverages with melted snow that was not supplemented with necessary ions. A more severe course of such a condition coupled with brain oedema, convulsions and metabolic acidosis was reported in infants whose drinks had been prepared with distilled or low-mineral bottled water (CDC 1994).

2.2 Practically zero calcium and magnesium intake from low-mineral water

Calcium and magnesium are both essential elements. Calcium is a substantial component of bones and teeth. In addition, it plays a role in neuromuscular excitability (i.e., decreases , the proper function of the conducting myocardial system, heart and muscle contractility, intracellular information transmission and the coagulability of blood. Magnesium plays an important role as a cofactor and activator of more than 300 enzymatic reactions including glycolysis, ATP metabolism, transport of elements such as sodium, potassium, and calcium through membranes, synthesis of proteins and nucleic acids, neuromuscular excitability and muscle contraction.

Although drinking water is not the major source of our calcium and magnesium intake, the health significance of supplemental intake of these elements from drinking water may outweigh its nutritional contribution expressed as the proportion of the total daily intake of these elements. Even in industrialized countries, diets not deficient in terms of the quantity of calcium and magnesium, may not be able to fully compensate for the absence of calcium and, in particular, magnesium, in drinking water.

Since the early 1960's, epidemiological studies in many countries all over the world have reported that soft water (i.e., water low in calcium and magnesium) and water low in magnesium is associated with increased morbidity and mortality from cardiovascular disease (CVD) compared to hard water and water high in magnesium. An overview of epidemiological evidence is provided by recent review articles (Sauvant and Pepin 2002; Donato *et al.* 2003; Monarca *et al*. 2003; Nardi *et al.* 2003) and is summarized in other chapters of this monograph (Calderon and Craun, Monarca *et al*.). Recent studies also suggest that the intake of soft water, i.e. water low in calcium, may be associated with higher risk of fracture in children (Verd Vallespir *et al*. 1992), certain neurodegenerative diseases (Jacqmin *et al*. 1994), pre-term birth and low weight at birth (Yang *et al*. 2002) and some types of cancer (Yang *et al*. 1997; Yang *et al*. 1998). In addition to an increased risk of sudden death (Eisenberg 1992; Bernardi *et al*. 1995; Garzon and Eisenberg 1998), the intake of water low in magnesium seems to be associated with a higher risk of motor neuronal disease (Iwami *et al*. 1994), pregnancy disorders (so-called preeclampsia) (Melles & Kiss 1992), and some types of cancer (Yang *et al*. 1999a; Yang *et al*. 1999b; Yang *et al*. 1999c; Yang *et al*. 2000).

Specific knowledge about changes in calcium metabolism in a population supplied with desalinated water (i.e., distilled water filtered through limestone) low in TDS and calcium, was obtained from studies carried out in the Soviet city of Shevchenko. The local population showed decreased activity of alkaline phosphatase, reduced plasma concentrations of calcium and phosporus and enhanced decalcification of bone tissue. The changes were most marked in women, especially pregnant women and were dependent on the duration of residence in Shevchenko. (WHO 1980; Pribytkov 1972; Rakhmanin *et al*. 1973).

The importance of water calcium was also confirmed in a one-year study of rats on a fully adequate diet in terms of nutrients and salts and given desalinated water with added dissolved solids of 400 mg/l and either 5 mg/l, 25 mg/l, or 50 mg/l of calcium (WHO 1980; Rakhmanin *et al*. 1976). The animals given water dosed with 5 mg/l of calcium exhibited a reduction in thyroidal and other associated functions compared to the animals given the two higher doses of calcium.

While the effects of most chemicals commonly found in drinking water manifest themselves after long exposure, the effects of calcium and, in particular, those of magnesium on the cardiovascular system are believed to reflect recent exposures. Only a few months exposure may be sufficient consumption time effects from water that is low in magnesium and/or calcium. (Rubenowitz *et al*. 2000). Illustrative of such short-term exposures are cases in the Czech and Slovak populations who began using reverse osmosis-based systems for final treatment of drinking water at their home taps in 2000-2002. Within several weeks or months various health complaints suggestive of acute magnesium (and possibly calcium) deficiency were reported (NIPH 2003**).** Among these complaints were cardiovascular disorders, tiredness, weakness or muscular cramps. These are essentially the same symptoms listed in the warning of the German Society for Nutrition.

2.3 Low intake of some essential elements and microelements in low-mineral water

Although drinking water, with some rare exceptions, is not the major source of essential elements for humans, its contribution may be important for several reasons. The modern diet of many people may not be an adequate source of minerals and microelements. In the case of borderline deficiency of a given element, even the relatively low intake of the element with drinking water may play a relevant protective role. This is because the elements are usually present in water as free ions and therefore, are more readily absorbed from water compared to food where they are mostly bound to other substances.

Animal studies are also illustrative of the significance of microquantities of some elements present in water. For instance, Kondratyuk (1989) reported that a variation in the intake of microelements was associated with up to six-fold differences in their content in muscular tissue. These results were found in a 6-month experiment in which rats were randomized into 4 groups and given: a) tap water, b) low-mineral water, c) low-mineral water supplemented with iodide, cobalt, copper, manganese, molybdenum, zinc and fluoride in tap water, d) low-mineral water supplemented with the same elements but at ten times higher concentrations. Furthermore, a negative effect on the blood formation process was found to be associated with non-supplemented demineralised water. The mean ulphate in content of red blood cells was as much as 19% lower in the animals that received non-supplemented demineralised water compared to that in animals given tap water. The haemoglobin differences are even greater when compared with animals given the supplemented water.

Recent epidemiological studies of an ecologic design among Russian populations supplied with water varying in TDS suggest that low-mineral drinking water may be a risk factor for hypertension and coronary heart disease, gastric and duodenal ulcers, chronic gastritis, goitre, pregnancy complications and several complications in newborns and infants, including jaundice, anemia, fractures and growth disorders (Mudryi 1999). However, it is not clear whether the effects observed in these studies are due to the low content of calcium and magnesium or other essential elements, or due to other factors.

Lutai (1992) conducted a large cohort epidemiological study in the Ust-Ilim region of Russia. The study focused on morbidity and physical development in 7658 adults, 562 children and 1582 pregnant women and their newborns in two areas supplied with water different in TDS. One of these areas was supplied with water lower in minerals (mean values: TDS 134 mg/l, calcium 18.7 mg/l, magnesium 4.9 mg/l, bicarbonates 86.4 mg/l) and the other was supplied with water higher in minerals (mean values: TDS 385 mg/l, calcium 29.5 mg/l, magnesium 8.3 mg/l, bicarbonates 243.7 mg/l). Water levels of ulphate, chloride, sodium, potassium, copper, zinc, manganese and molybdenum were also determined. The populations of the two areas did not differ from each other in eating habits, air quality, social conditions and time of residence in the respective areas. The population of the area supplied with water lower in minerals showed higher incidence rates of goiter, hypertension, ischemic heart disease, gastric and duodenal ulcers, chronic gastritis, cholecystitis and nephritis. Children living in this area exhibited slower physical development and more growth abnormalities, pregnant women suffered more frequently from edema and anemia. Newborns of this area showed higher morbidity. The lowest morbidity was associated with water having calcium levels of 30-90 mg/l, magnesium levels of 17-35 mg/l, and TDS of about 400 mg/l (for bicarbonate containing waters).The authors concluded that such water could be considered as physiologically optimum. The higher mineralized water was also relatively high in bicarbonate, and Lutai suggested that the desirable bicarbonate content of drinking water should be between 250 and 500 mg/l.

2.4 High loss of calcium, magnesium and other essential elements in food prepared in low-mineral water

When used for cooking, soft water was found to cause substantial losses of all essential elements from food (vegetables, meat, cereals). Such losses may reach up to 60 % for magnesium and calcium or even more for some other microelements (e.g., copper 66 %, manganese 70 %, cobalt 86 %). In contrast, when hard water is used for cooking, the loss of these elements is much lower, and in some cases, an even higher calcium content was reported in food as a result of cooking (WHO 1978; Haring and Van Delft 1981; Oh *et al.* 1986; Durlach 1988).

Since most nutrients are ingested with food, the use of low-mineral water for cooking and processing food may cause a marked deficiency in total intake of some essential elements that was much higher than expected with the use of such water for drinking only. The current diet of many persons usually does not provide all necessary elements in sufficient quantities, and therefore, any factor that results in the loss of essential elements and nutrients during the processing and preparation of food could be detrimental for them.

2.5 Increased risk from toxic metals

Low-mineralized water is unstable and therefore, highly aggressive to materials with which it comes into contact. Such water more readily absorbs metals and some organic substances from pipes, coatings, storage tanks and containers, hose lines and fittings, being incapable of forming low-absorbable complexes with some toxic substances and thus reducing their negative effects.
Among eight outbreaks of chemical poisoning from drinking water reported in the USA in 1993-1994, there were three cases of lead poisoning in infants who had blood-lead levels of 15 μg/dl, 37 μg/dl, and 42 μg/dl. The level of concern is 10 μg/dl. For all three cases, lead had leached from brass fittings and lead-soldered seams in drinking water storage tanks. The three water systems used low mineral drinking water that had intensified the leaching process (Kramer *et al.* 1996). First-draw water samples at the kitchen tap had lead levels of 495 to 1050 μg/l for the two infants with the highest blood lead; 66 μg/l was found in water samples collected at the kitchen tap of the third infant (Anon. 1994).

Calcium and, to a lesser extent, magnesium in water and food are known to have antitoxic activity. They can help prevent the absorption of some toxic elements such as lead and cadmium from the intestine into the blood, either via direct reaction leading to formation of an unabsorbable compound or via competition for binding sites (Thompson 1970; Levander 1977; Oehme 1979; Hopps and Feder 1986; Nadeenko *et al.* 1987; Durlach *et al.* 1989; Plitman *et al*. 1989). Although this protective effect is limited, it should not be dismissed. Populations supplied with low-mineral water may be at a higher risk in terms of adverse effects from exposure to toxic substances compared to populations supplied with water of average mineralization and hardness.

2.6 Possible bacterial contamination of low-mineral water

All water is prone to bacterial contamination either at source or as a result of microbial re-growth in the pipe system. Bacterial re-growth within the pipe system is encouraged by higher initial temperatures, higher temperatures of water in the distribution system due to hot climates, lack of a residual disinfectant and possibly greater availability of nutrients due to the aggressive nature of the water to materials in contact with it. In the absence of a disinfectant residual regrowth may also occur in desalinated water. Although an intact desalination membrane should remove all bacteria, it may not be 100 %

effective (perhaps due to leaks) as can be documented by an outbreak of typhoid fever caused by reverse osmosis-treated water in Saudi Arabia in 1992 (al-Qarawi *et al.* 1995). The risk of bacterial contamination of water treated with different types of home water treatment devices was reported by Geldreich *et al.* (1985) and Payment *et al.* (1989, 1991).

The Czech National Institute of Public Health (NIPH, 2003) in Prague has tested the safety of products intended for contact with drinking water and found that the pressure tanks of the reverse osmosis units are prone to bacterial re-growth. They contain a rubber bag whose surface appears to be favourable for bacterial growth.

3. DESIRABLE MINERAL CONTENT OF DEMINERALIZED DRINKING WATER

The corrosive nature of demineralised water and potential health risks related to the distribution and consumption of low TDS water has led to recommendations of the minimum and optimum mineral content in drinking water and then, in some countries, to the establishment of obligatory values in the respective legislative or technical regulations for drinking water quality. Organoleptic characteristics and thirst-quenching capacity were also considered in the recommendations. For example, human volunteer studies (WHO 1980) showed that the water temperatures of 15-35^0 C best satisfied physiological needs. Water temperatures above 35^0 or below 15^0 C resulted in a reduction in water consumption. Water with a TDS of 25-50 mg/l was described tasteless (WHO 1980).

3.1 The 1980 WHO report

Salts are leached from the body under the influence of drinking water with a low TDS. Because adverse effects such as altered water-salt balance were observed not only in completely desalinated water but also in water with TDS between 50 and 75 mg/l, the team that prepared the 1980 WHO report recommended that the minimum TDS in drinking water should be 100 mg/l. The team also recommended that the optimum TDS should be about 200-400 mg/l for chloride-sulphate waters and 250-500 mg/l for bicarbonate waters (WHO 1980). The recommendations were based on extensive experimental studies conducted in rats, dogs and human volunteers. Water exposures included Moscow tap water, desalinated water of approximately 10 mg/l TDS, and laboratory-prepared water of 50, 100, 250, 300, 500, 750, 1000, and 1500 mg/l TDS using the following constituents and proportions: Cl (40%), HCO_3 (32%),

SO_4 (28%) / Na (50%), Ca (38%), Mg (12%). A number of health outcomes were investigated including: dynamics of body weight, basal and nitrogen metabolism, enzyme activity, water-salt homeostasis and its regulatory system, mineral content of body tissues and fluids, hematocrit, and ADH activity. The optimal TDS was associated with the lowest incidence of adverse effect, negative changes to the human, dog, or rat, good organoleptic characteristics and thirst-quenching properties, and reduced corrosivity of water.

In addition to the TDS levels, the team (WHO 1980) recommended that the minimum calcium content of desalinated drinking water should be 30 mg/l. These levels were based on health concerns with the most critical effects being hormonal changes in calcium and phosphorus metabolism and reduced mineral saturation of bone tissue. Also, when calcium is increased to 30 mg/l, the corrosive activity of desalinated water would be appreciably reduced and the water would be more stable (WHO 1980). The team (WHO 1980) also recommended a bicarbonate ion content of 30 mg/l as a minimum essential level needed to achieve acceptable organoleptic characteristics, reduced corrosivity, and an equilibrium concentration for the recommended minimum level of calcium.

3.2 Recent recommendations

More recent studies have provided additional information about minimum and optimum levels of minerals that should be in demineralised water. For example, the effect of drinking water of different hardness on the health status of women aged from 20 to 49 years was the subject of two cohort epidemiological studies (460 and 511 women) in four South Siberian cities (Levin *et al* 1981; Novikov *et al* 1983). The water in City A water had the lowest levels of calcium and magnesium (3.0 mg/l calcium and 2.4 mg/l magnesium). The water in city B had slightly higher levels (18.0 mg/l calcium and 5.0 mg/l magnesium). The highest levels were in city C (22.0 mg/l calcium and 11.3 mg/l magnesium) and city D (45.0 mg/l calcium and 26.2 mg/l magnesium). Women living in cities A and B more frequently showed cardiovascular changes (as measured by ECG), higher blood pressure, somatoform autonomic dysfunctions, headache, dizziness, and osteoporosis (as measured by X-ray absoptiometry compared to those of cities C and D. These results suggest that the minimum magnesium content of drinking water should be 10 mg/l and the minimum calcium content should be 20 mg/l rather than 30 mg/l as recommended in 1980 (WHO 1980).

Based on the currently available data, various researchers have recommended that the following levels of calcium, magnesium, and water hardness should be in drinking water:

- For magnesium, a minimum of 10 mg/l (Novikov *et al*. 1983; Rubenowitz *et al.* 2000) and an optimum of about 20-30 mg/l (Durlach *et al.* 1989; Kozisek 1992);
- For calcium, a minimum of 20 mg/l (Novikov *et al*. 1983) and an optimum of about 50 (40-80) mg/l (Rakhmanin *et al*. 1990; Kozisek 1992);
- For total water hardness, the sum of calcium and magnesium should be 2 to 4 mmol/l (Plitman *et al.* 1989; Lutai 1992; Muzalevskaya *et al.* 1993; Golubev and Zimin 1994).

At these concentrations, minimum or no adverse health effects were observed. The maximum protective or beneficial health effects of drinking water appeared to occur at the estimated desirable or optimum concentrations. The recommended magnesium levels were based on cardiovascular system effects, while changes in calcium metabolism and ossification were used as a basis for the recommended calcium levels. The upper limit of the hardness optimal range was derived from data that showed a higher risk of gall stones, kidney stones, urinary stones, arthrosis and arthropathies in populations supplied with water of hardness higher than 5 mmol/l.

Long-term intake of drinking water was taken into account in estimating these concentrations. For short-term therapeutic indications of some waters, higher concentrations of these elements may be considered.

3.3 Guidelines and directives for calcium, magnesium, and hardness levels in drinking water

The WHO in the 2nd edition of *Guidelines for Drinking-water Quality* (WHO 1996) evaluated calcium and magnesium in terms of water hardness but did not recommend either minimum levels or maximum limits for calcium, magnesium, or hardness.

The first European Directive (European Union 1980) established a requirement for minimum hardness for softened or desalinated water ($\geq$ 60 mg/l as calcium or equivalent cations). This requirement appeared obligatorily in the national legislations of all EEC members, but this Directive expired in December 2003 when a new Directive (European Union 1998) became effective. The new Directive does not contain a requirement for calcium, magnesium, or water hardness levels. On the other hand, it does not prevent member states from implementing such a requirement into their national legislation. Only a few EU Member States (e.g. the Netherlands) have included calcium, magnesium, or water hardness into their national regulations as a binding requirement. Some EU Member States (e.g. Austria, Germany) included these parameters at lower levels as unbinding regulations, such as technical standards (e.g., different measures for reduction of water corrosivity).

In contrast, all four Central European countries that became part of the EU in May 2004 have included the following requirements in their respective regulations but varying in binding power;

- Czech Republic (2004): for softened water ≥ 30 mg/l calcium and ≥ 10 mg/l magnesium; guideline levels of 40-80 mg/l calcium and 20–30 mg/l magnesium (hardness as Σ Ca + Mg = 2.0 – 3.5 mmol/l).
- Hungary (2001): hardness 50 – 350 mg/l (as CaO); minimum required concentration of 50 mg/l must be met in bottled drinking water, new water sources, and softened and desalinated water.
- Poland (2000): hardness 60–500 mg/l (as $CaCO_3$).
- Slovakia (2002): guideline levels > 30 mg/l calcium and 10 – 30 mg/l magnesium.

The Russian technical standard *Astronaut environment in piloted spaceships – general medical and technical requirements* (Anonymous 1995) defines qualitative requirements for recycled water intended for drinking in spaceships. Among other requirements, the TDS should range between 100 and 1000 mg/l with minimum levels of fluoride, calcium and magnesium being specified by a special commission separately for each cosmic flight. The focus is on how to supplement recycled water with a mineral concentrate to make it "physiologically valuable" (Sklyar *et al.* 2001).

4. CONCLUSIONS

Drinking water should contain minimum levels of certain essential minerals (and other components such as carbonates). Unfortunately, over the two past decades, little research attention has been given to the beneficial or protective effects of drinking water substances. The main focus was on contaminants and their toxicological properties. Nevertheless, some studies have attempted to define the minimum content of essential elements or TDS in drinking water, and some countries have included requirements or guidelines for selected substances in their drinking water regulations. Although these are exceptional cases, the issue is relevant not only where drinking water is obtained by desalination (if not adequately re-mineralised) but also where home treatment or central water treatment reduces the content of important minerals and low-mineral bottled water is consumed.

Although drinking water manufactured by desalination is stabilized with some minerals, this is usually not the case for water demineralised as a result of household treatment. Even when stablized, the final composition of some waters may not be adequate in terms of providing health benefits. Although desalinated waters are supplemented mainly with calcium (lime) or other carbonates, they may be deficient in magnesium and other microelements such as fluorides and potassium, as are most natural waters. Furthermore, the quantity of calcium that is supplemented is based on technical considerations (i.e., reducing the aggressiveness) rather than on health concerns. Possibly none of the commonly used ways of re-mineralization could be considered optimum, since the water does not contain all of its beneficial components. Current methods of stabilization are primarily intended to decrease the corrosive effects of demineralised water.

Demineralised water that has not been remineralized , or low-mineral content water – in the light of the absence or substantial lack of essential minerals in it – is not considered ideal drinking water, and therefore, its regular consumption may not be providing adequate levels of some beneficial nutrients. This chapter provides a rationale for this conclusion.

The evidence in terms of experimental effects and findings in human volunteers related to highly demineralised water is mostly found in older studies, some of which may not meet current methodological criteria. However, these findings and conclusions should not be dismissed. Some of these studies were unique, and the intervention studies, although undirected, would hardly be scientifically, financially, or ethically feasible to the same extent today. The methods, however, are not so questionable as to necessarily invalidate their results. The older animal and clinical studies on health risks from drinking demineralised or low-mineral water yielded consistent results both with each other and with more recent research, and recent research has tended to be supportive.

Sufficient evidence is now available to confirm the health risk from drinking water deficient in calcium or magnesium. Many studies show that higher water magnesium is related to decreased risks for CVD and especially for sudden death from CVD. This relationship has been independently described in epidemiological studies with different study designs, performed in different areas (with different populations), and at different times. The consistent epidemiological observations are supported by the data from autopsy, clinical, and animal studies. Biological plausibility for a protective effect of magnesium is substantial, but the specificity is less evident due to the multifactorial aetiology of CVD. In addition to an increased risk of sudden death, it has been suggested that intake of water low in magnesium may be associated with a higher risk of motor neuronal disease, pregnancy disorders (so-called preeclampsia, and sudden death in infants) and some types of cancer. Recent studies suggest that the intake of soft water, i.e. water low in calcium, is associated with higher risk of fracture in children, certain neurodegenerative diseases, pre-term birth and low weight at birth and some types of cancer. Furthermore, the possible role of water calcium in the development of CVD cannot be excluded.

International and national authorities responsible for drinking water quality should consider guidelines for desalination water treatment, specifying the minimum content of the relevant elements such as calcium and magnesium and TDS. If additional research is required to establish guidelines, these authorities should promote targeted research in this field to elaborate the health benefits. If guidelines are established for substances that should be in deminerialized water, authorities should ensure that the guidelines also apply to uses of certain home treatment devices and bottled waters.

5. REFERENCES

Anonymous (1995) GOST R 50804-95 Astronaut environment in piloted spaceships – general medical and technical requirements. (In Russian.) Russian Governmental Standard. Gosstandard Rossii, Moscow.

Anonymous (1994) Epidemiologic notes and reports lead-contaminated drinking water in bulk-storage tanks—Arizona and California, 1993. *MMWR* 43(41), 751; 757-758.

Basnyat, B., Sleggs, J. and Spinger, M. (2000) Seizures and delirium in a trekker: the consequences of excessive water drinking? *Wilderness Environ. Med.* **11**, 69-70.

Bernardi, D., Dini, F.L., Azzarelli, A., Giaconi, A., Volterrani, C. and Lunardi, M. (1995) Sudden cardiac death rate in an area characterized by high incidence of coronary artery disease and low hardness of drinking water. *Angiology* 46, 145-149.

Bragg, P.C. and Bragg, P. (1993) *The Shocking Truth about Water.* 27th ed. Health Science, Santa Barbara, CA.

CDC (1994) Hyponatremic seizures among infants fed with commercial bottled drinking water – Wisconsin, 1993. *MMWR* **43**, 641-643.

DgfE (Deutsche Gesellschaft für Ernährung) (1993) Drink distilled water? (In German.) *Med. Mo. Pharm.* **16**, 146.

Donato, F., Monarca, S., Premi, S., and Gelatti, U (2003) Drinking water hardness and chronic degenerative diseases. Part III. Tumors, urolithiasis, fetal malformations, deterioration of the cognitive function in the aged and atopic eczema. (In Italian.) *Ann. Ig.* **15**, 57-70.

Durlach, J. (1988) The importance of magnesium in water. In *Magnesium in Clinical Practice* (ed. J.Durlach), pp 221-222, John Libbey & Co Ltd, London.

Durlach, J., Bara, M. and Guiet-Bara, A. (1989) Magnesium level in drinking water: its importance in cardiovascular risk. In *Magnesium in Health and Disease* (ed. Y.Itokawa and J.Durlach), pp. 173-182, J.Libbey & Co Ltd, London.

Eisenberg, M.J. (1992) Magnesium deficiency and sudden death. *Am. Heart J.* 124, 544-549.

European Union (1980) Council Directive 80/778/EEC of 15 July 1980 relating to the quality of water intended for human consumption. *Off. J. Eur. Commun.* **L229**, 11-29.

European Union (1998) Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. *Off. J. Eur. Commun.* **L330**, 32-54.

Garzon, P. and Eisenberg, M.J. (1998) Variation in the mineral content of commercially available bottled waters: implication for health and disease. *Am. J. Med.* 105, 125-130.

Geldreich, E.E., Taylor, R.H., Blannon, J.C. and Reasoner, D.J. (1985) Bacterial colonization of point-of-use water treatment devices. *Journal AWWA* **77**, 72-80.

Golubev, I.M. and Zimin, V.P. (1994) On the standard of total hardness in drinking water. (In Russian.) *Gig. Sanit.* No. 3/1994 (volume not given), 22-23.

Haring, B.S.A. and Van Delft, W. (1981) Changes in the mineral composition of food as a result of cooking in "hard" and "soft" waters. *Arch. Environ. Health* **36**, 33-35.

Hopps, H.C. and Feder, G.L. (1986) Chemical qualities of water that contribute to human health in a positive way. *Sci. Total Environ.* **54**, 207-216.

Iwami, O., Watanabe, T., Moon, Ch.S., Nakatsuka, H. and Ikeda, M. (1994) Motor neuron disease on the Kii Peninsula of Japan: excess manganese intake from food coupled with low magnesium in drinking water as a risk factor. *Sci. Total Environ.* 149, 121-135.

Jacqmin, H., Commenges, D., Letenneur, L., Barberger-Gateau, P. and Dartigues, J.F. (1994) Components of drinking water and risk of cognitive impairment in the elderly. *Am. J. Epidemiol.* 139, 48-57.

Kondratyuk, V.A. (1989) On the health significance of microelements in low-mineral water. (In Russian.) *Gig. Sanit.* No.2/1989 (volume not given), 81-82.

Kozisek, F. (1992) *Biogenic value of drinking water.* (In Czech.) PhD thesis. National Institute of Public Health, Praha.

Kramer, M.H., Herwaldt, B.L., Craun, G.F., Calderon, R.L. and Juranek, D.D. (1996) Surveillance for Waterborne-Disease Outbreaks – United States, 1993-1994. In: CDC Surveillance Summaries, April 12, 1996. *MMWR* **45** (No. SS-1), 1-33.

Levander, O.A. (1977). Nutritional factors in relation to heavy metal toxicants. *Fed. Proc.* **36**, 1683-1687.

Levin, A.I., Novikov, J.V., Plitman, S.I., Noarov, J.A. and Lastochkina, K.O. (1981) Effect of water of varying degrees of hardness on the cardiovascular system. (In Russian.) *Gig. Sanit.* No. 10/1981 (volume not given), 16-19.

Lutai, G.F. (1992) Chemical composition of drinking water and the health of population. (In Russian.) *Gig. Sanit.* No. 1/1992 (volume not given), 13-15.

Melles, Z. and Kiss, S.A. (1992) Influence of the magnesium content of drinking water and of magnesium therapy on the occurrence of preeclampsia. *Magnes. Res.* 5, 277-279.

Monarca, S., Zerbini, I., Simonati, C. and Gelatti, U. (2003) Drinking water hardness and chronic degenerative diseases. Part II. Cardiovascular diseases. (In Italian.) *Ann. Ig.***15**, 41-56.

Mudryi, I.V. (1999) Effects of the mineral composition of drinking water on the population´s health (review). (In Russian.) *Gig. Sanit.* No.1/1999 (volume not given), 15-18.

Muzalevskaya, L.S., Lobkovskii, A.G. and Kukarina, N.I. (1993) Incidence of chole- and nephrolithiasis, osteoarthrosis, and salt arthropathies and drinking water hardness. (In Russian.) *Gig. Sanit.* No. 12/1993 (volume not given), 17-20.

Nadeenko, V.G., Lenchenko, V.G. and Krasovskii, G.N. (1987) Combined effect of metals during their intake with drinking water. (In Russian.) *Gig. Sanit.* No.12 /1987 (volume not given), 9-12.

Nardi, G., Donato, F., Monarca, S., and Gelatti, U. (2003) Drinking water hardness and chronic degenerative diseases. Part I. Analysis of epidemiological research. (In Italian.) *Annali di igiene - medicina preventiva e di comunita* **15**, 35-40.

NIPH (National Institute of Public Health) (2003) Internal data. Prague

Novikov, J.V., Plitman, S.I., Levin, A.I. and Noarov, J.A. (1983) Hygienic regulation for the minimum magnesium level in drinking water. (In Russian.) *Gig. Sanit.* No. 9/1983 (volume not given), 7-11.

Oehme, F.W. (ed.) (1979). *Toxicity of heavy metals in the environment*. Part 1. M.Dekker, New York.

Oh, C.K., Lücker, P.W., Wetzelsberger, N. and Kuhlmann, F. (1986) The determination of magnesium, calcium, sodium and potassium in assorted foods with special attention to the loss of electrolytes after various forms of food preparations. *Mag.-Bull.* **8**, 297-302.

Payment, P. (1989) Bacterial colonization of reverse-osmosis water filtration units. *Can. J. Microbiol.* **35**, 1065-1067.

Payment, P., Franco, E., Richardson, L. and Siemiatycki, J. (1991) Gastrointestinal health effects associated with the consumption of drinking water produced by point-of-use domestic reverse-osmosis filtration units. *Appl. Environ. Microbiol.* **57**, 945-948.

Plitman, S.I., Novikov, Yu.V., Tulakina, N.V., Metelskaya, G.N., Kochetkova, T.A. and Khvastunov, R.M. (1989) On the issue of correction of hygenic standards with account of drinking water hardness. (In Russian.) *Gig. Sanit.* No. 7/1989 (volume not given), 7-10.

Pribytkov Yu N. (1972) ….(In Russian.) *Gig. Sanit.* No…., 103-105.

Rakhmanin Yu A., Lycnikova, T.D., ., Michailova, R.I. (1973) Coll.: Water Hygiene and the Public Health Protection of Water Bodies (In Russian.), Moscow, Acad. Med. Sci. USSR, fasc. 3, 44-51.

Rakhmanin, Yu A., Bonasevskaya, T.I., Lestrovoy, A.P., Michailova, R.I., Guscina, L.M. (1976) *Coll.: Public Health Aspects of Environmental Protection* (In Russian.), Moscow, Acad. Med. Sci. USSR, fasc. 3, 68-71.

Rakhmanin, Yu.A., Mikhailova, R.I., Filippova, A.V., Feldt, E.G., Belyaeva, N.N., Lamentova, T.G. and Kumpan, N.B., (1989) On some aspects of biological effects of distilled water. (In Russian.) Gig. Sanit. No. 3/1989 (volume not given), 92-93.

Rachmanin, Yu.A., Filippova, A.V., Michailova, R.I., Belyaeva, N.N., Lamentova, T.G., Kumpan, N.B. and Feldt, E.G. 1990 Hygienic assessment of mineralizing lime materials used for the correction of mineral composition of low-mineralized water. (In Russian.) *Gig. Sanit.* No. 8/1990 (volume not given), 4-8.

Robbins, D.J. and Sly, M.R. (1981) Serum zinc and demineralized water. *Am. J. Clin. Nutr.* **34**, 962-963.

Rubenowitz, E., Molin, I., Axelsson, G. and Rylander, R. (2000) Magnesium in drinking water in relation to morbidity and mortality from acute myocardial infarction. *Epidemiology* **11**, 416-421.

Sadgir, P. and Vamanrao, A. (2003) Water in Vedic Literature. In *Abstract Proceedings of the 3rd International Water History Association Conference*, Alexandria 2003, (http://www.iwha.net/a_abstract.htm).

Sauvant, M-P. and Pepin, D. (2002) Drinking water and cardiovascular disease. *Food Chem. Toxicol.* **40,** 1311-1325.

Schumann, K., Elsenhans, B., Reichl, F.X., Pfob, H. and Wurster, K.H. (1993) Does intake of highly demineralized water damage the rat gastrointestinal tract? *Vet. Hum. Toxicol.* **35**, 28-31.

Sklyar, E.F., Amiragov, M.S., Berezkin, S.V., Kurochkin, M.G. and Skuratov, V.M. (2001) Recovered water mineralization technique. (In Russian.) *Aviakosm. Ekolog. Med.* **35**(5), 55-59.

Thompson, D.J. (1970) *Trace element in animal nutrition*. 3rd ed. Int. Minerals and Chem. Corp., Illinois.

Verd Vallespir, S., Domingues Sanches, J., Gonzales Quintial, M., Vidal Mas, M., Mariano Soler, A.C., de Roque Company, C. and Sevilla Marcos, J.M. (1992) Association between calcium content of drinking water and fractures in children (in Spanish). *An. Esp. Pediatr.* 37, 461-465.

WHO (1978) How trace elements in water contribute to health. *WHO Chronicle* **32**, 382-385.

WHO (1979) *Health effects of the removal of substances occurring naturally in drinking water, with special reference to demineralized and desalinated water*. Report on a working group (Brussels, 20-23 March 1978). EURO Reports and Studies 16. World Health Organization, Copenhagen.

WHO (1980) *Guidelines on health aspects of water desalination*. ETS/80.4. World Health Organization, Geneva.

WHO (1996) *Guidelines for Drinking-water Quality*. 2nd edn, vol. 2, *Health Criteria and Other Supporting Information.* pp 237-240. World Health Organization, Geneva.

Williams, A.W. (1963) Electron microscopic changes associated with water absorption in the jejunum. *Gut* **4**, 1-7.

Yang, Ch.Y., Chiu, H.F., Chiu, J.F., Tsai, S.S. and Cheng, M.F. (1997) Calcium and magnesium in drinking water and risk of death from colon cancer. *Jpn. J. Cancer Res.* 88, 928-933.

Yang, Ch.Y., Cheng, M.F., Tsai, S.S. and Hsieh, Y.L. (1998) Calcium, magnesium, and nitrate in drinking water and gastric cancer mortality. *Jpn. J. Cancer Res.* 89, 124-130.

Yang, Ch.Y., Chiu, H.F., Cheng, M.F., Tsai, S.S., Hung, Ch.F. and Lin, M.Ch. (1999a) Esophageal cancer mortality and total hardness levels in Taiwan's drinking water. *Environ. Research*, Section A 81, 302-308.

Yang, Ch.Y., Chiu, H.F., Cheng, M.F., Tsai, S.S., Hung, Ch.F. and Tseng, Y.T. (1999b) Pancreatic cancer mortality and total hardness levels in Taiwan's drinking water. *J. Toxicol. Environ. Health* A 56, 361-369.

Yang, Ch.Y., Tsai, S.S., Lai, T.Ch., Hung, Ch.F. and Chiu, H.F. (1999c) Rectal cancer mortality and total hardness levels in Taiwan's drinking water. *Environ. Research*, Section A 80, 311-316.

Yang, Ch.Y., Chiu, H.F., Cheng, M.F., Hsu, T.Y., Cheng, M.F. and Wu. T.N. (2000) Calcium and magnesium in drinking water and the risk of death from breast cancer. *J. Toxicol. Environ. Health*, Part A 60, 231-241.

Yang, Ch.Y., Chiu, H.F., Chang, Ch. Ch., Wu, T.N. and Sung, F.Ch. (2002) Association of very low birth weight with calcium levels in drinking water. *Environ. Research*, Section A 89, 189-194.