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INVITED COMMENTARY

Arsenic in Drinking Water: Is 10 μg/L a Safe Limit?

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Arsenic (As) is a naturally occurring element in the Earth's crust. Both anthropogenic and natural processes can release As into sources for drinking water supply. A substantial epidemiological evidence is available to support that the chronic exposure to high concentrations in drinking water (> 10 μg/L) is associated with several detrimental effects on human health including skin lesions [1] and cancer of the lung [2], bladder [3], kidney [4], and liver [4]. Furthermore, dermatological, developmental, neurological [5], respiratory [6], cardiovascular [7], immunological [8], and endocrine effects [9] as a result of chronic exposure to high As concentrations have been reported. However, there remains considerable uncertainty on the chronic risks due to As exposure at low concentrations (< 10 μg/L) and the shape of the dose-response relationship [10, 11]. It is therefore crucial to question whether the 10 μg/L limit ensures protection of human health from the adverse health effects of As.

The WHO Guideline in Retrospect

The World Health Organization (WHO) published the first version of International Standards for Drinking Water in 1953 which included As in the category of toxic substances and a maximum allowable concentration of 200 μg/L was proposed. In 1963, the 2nd edition of the International Standards for Drinking Water was published which included As in the same category of toxic substances; however, the maximum allowable limit was decreased to 50 μg/L. The 3rd edition (1971) of the International Standards reaffirmed the limit of 50 μg/L. In 1984, the 1st edition of the WHO Guidelines for Drinking Water Quality was published in which 50 μg/L was proposed as a guideline value for As in drinking water [12]. Supporting information of the 1984 Guidelines referred to the cases in Chile and Taiwan where 50 μg/L was not reported to cause adverse health effects. In 1993, the 2nd edition of the WHO Guidelines for Drinking Water was published which recommended a lower value of 10 μg/L as a provisional guideline value for As in drinking water [13]. The provisional guideline value was supported by the research of the International Agency for Research on Cancer (IARC) which found sufficient evidence for the carcinogenicity of As in humans and classified As in group I substances [13]. Towards deriving the guideline value, a multistage model was used to estimate the excess lifetime skin cancer risk associated with the ingestion of As in drinking water. The model based estimates showed that the concentration associated with an excess lifetime skin cancer risk of 10^{-5} (1 in 100,000) was 0.17 μg/L. The WHO, however, reasoned that the results of the model might have overestimated the actual skin cancer risk. Moreover, the practical quantification limit at that time was 10 μg/L for As in water [13, 14]. The same value and designation "provisional" were also taken into the following editions of the Guidelines, including the current one [15]. The WHO retained the drinking water guideline on the basis of "treatment performance and analytical achievability" [15] with the proviso that every effort should be made to keep concentrations as low as reasonably possible, since it is acknowledged that there are uncertainties with respect to the effects of low As exposure and the contribution of other sources of As to these effects, and the difficulties to demonstrate this experimentally.

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The Challenge of Setting a Health-Based Guideline for Arsenic in Drinking Water

Health effects of chronic exposure to low concentrations of As in drinking water, such as present in many parts of Western Europe and North America, are unclear [10, 11]. The main reason is that the mode of action (in particular with respect to the carcinogenic activity of As) and dose-response characteristics (especially at low As concentrations), which are required for identification of an acceptable exposure level, are not fully elucidated [10, 14, 16]. There are two distinct views. One view holds that As has a dose threshold below which exposures are not harmful. The other view suggests that this threshold might not exist due to direct genotoxic effects of As [11].

If As is regarded a threshold chemical, a tolerable daily intake (TDI) should be derived. The TDI is an estimate of the dose of a substance, expressed on a body weight basis (mg/kg of body weight), that can be ingested daily over a lifetime without appreciable health risk. In general, the TDI can be based on animal or human studies, but for As, the current risk evaluations prefer to rely on human data, because the (carcinogenic) effects of As on humans are difficult to reproduce in animal studies, probably due to differences in As metabolism and as a consequence differences in toxicological effects [10]. Further, complexity is introduced by the varying individual susceptibilities to the many toxic effects of As, which can also be ascribed to a variation in As metabolism between individuals [17]. The exact role of metabolism in As toxicity is as yet unclear. Exposure to As via (different types of) food and mobility of people in globalizing humanity is other factors that may contribute to exposure misclassification, resulting in lack of epidemiological evidence of effects of low-level As exposure.

On the other hand, if As is regarded a non-threshold chemical, the guideline value can be determined using a mathematical approach [10, 11]. In such a process, an acceptable risk level is defined and the toxicological reference value (the dose which corresponds to the acceptable risk level) is derived from the slope of the dose-response relationship, which usually results from linear extrapolation of an experimentally established dose-response relation (typically obtained from epidemiological studies) to the lower dose region. An important uncertainty in this approach is the extrapolation to low-exposure situations and corresponding low disease incidences that are difficult to demonstrate with an appropriate level of confidence in epidemiological studies. Linear extrapolation has the potential of risk overestimation. The acceptable cancer risk level varies between authorities; an extra risk of one extra case of cancer per 100,000 life-long exposed persons (1×10^{-5}) is often used, but in some cases, risk levels of 1×10^{-4} and 1×10^{-6} can be applied [10].

The Way Forward?

Utilities should make every effort to keep As concentrations as low as reasonably possible in drinking water. The mathematical approach of guideline setting could lead to highly ambitious As targets for drinking water, but it is the efficacy of the treatment and analytical technologies that will keep on defining the actual removal goals. Research in understanding the fate and behavior of As in various systems and improvement is the key. Perhaps something can be learnt from the drinking water utilities in New Jersey and Denmark where 5 μg/L As has been established as the maximum contaminant level since 2006 and 2017 respectively [18, 19], as well as from The Netherlands where drinking water companies are making efforts to reduce As in drinking water to below 1 μg/L [20, 21].

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