



In the most severe case of Arsenic poisoning on record, tens of thousands of people in Bangladesh, India, have reported cancer and lesions all over their bodies, mainly on the hands and feet.

Photos courtesy of Richard Wilson and Harvard University (http://phys4.harvard.edu/~wilson/arsenic_project_pictures2.html)



Arsenic

in Drinking Water

Part 2: Human Exposure and Health Effects

By John T. O'Connor, EngD, P.E.

Editor's Note: Part 1 of this series provided a timeline for the development of a drinking water standard for arsenic. It also summarized the political and public reactions to the U.S. EPA decision to delay and withdraw the arsenic rule.

The discovery of exceptionally high arsenic levels in groundwater derived from shallow "tube wells" in Bangladesh and West Bengal, India, in 1993 brought worldwide attention to the chronic exposure of as many as 85 million people in what has been called the largest mass poisoning of a population in history. The publication in 2001 of the results of a survey conducted in 1999

(*Environmental Science and Technology* 2001, 35, 13) show similarly high concentrations of arsenic in well waters in Vietnam and the water supply for the City of Hanoi. The arsenic concentrations reported in these regions are often an order of magnitude greater than those observed in U.S. ground and surface waters. However, indications are that arsenic may be widespread in shallow well drinking water sources globally.

Taiwanese studies, reported in the *American Journal of Epidemiology* (153, 411 [2001]), have linked 10 to 50 $\mu\text{g}/\text{L}$ arsenic concentrations to urinary tract cancers in Taiwan. Some critics have discounted the significance of these

Taiwanese results citing lower arsenic levels and better nutrition in the U.S.

On-going health effects studies and research reports (2001) appear to support the argument for lowering the current EPA drinking water standard for arsenic. Studies conducted by EPA, the University of North Carolina and the University of British Columbia have indicated that methylated metabolites of trivalent arsenic are genotoxic. In other words, they damage DNA in human cells.

Animal studies at the Dartmouth Medical School, reported in *Environmental Health Perspectives* (109, 245 [2001]), indicate that exposure of rat liver cells to triva-

Organ System	Problems (after Dhaka [Bangladesh] Medical College, 1998)
Skin	Symmetric hyperkeratosis of palms and soles, melanosis or depigmentation, Bowen's disease, basal cell carcinoma and squamous cell carcinoma.
Liver	Enlargement, jaundice, cirrhosis, non-cirrhotic portal hypertension
Nervous System	Peripheral neuropathy, hearing loss
Cardiovascular System	Acrocyanosis and Raynaud's Phenomenon
Hemopoietic System	Megaloblastosis
Respiratory System	Lung cancer
Endocrine System	Diabetes mellitus and goiter

lent arsenic concentrations in the range of 5 to 70 µg/L disrupted a hormone receptor. Researchers believe that this may explain why exposure to arsenic in drinking water is associated with Type 2 diabetes and vascular disease. To further explore this possi-

bility, follow-up epidemiology studies are underway on humans exposed to arsenic in drinking water.

Johns Hopkins University researchers have reported (J. Clin. Invest. 2001, 108, 1,541-1,547) the results of studies aimed

at determining the mechanism linking arsenic to cancer. The exposure of cell lines to low levels of arsenic trioxide was observed to result in a decrease in the activity of the enzyme telomerase. This enzyme maintains the length of chromosomal ends (telomeres). The progressive decrease in the length of the telomeres after each healthy cell division could lead to the formation of cancerous cells.

Arsenic was previously known to increase the risk of cancer of the lungs, skin, bladder, liver, kidney, prostate and nasal passages. The Public Health Service, Agency for Toxic Substances and Disease Registry (ATSDR) has compiled a comprehensive review of studies related to arsenic and cancer. With respect to exposure through drinking water, the ATSDR Information Center (July, 2001) states that "An association between environmental exposure to arsenic through drinking water and skin cancer has been observed and confirmed; two cases of bladder cancer also were described, with latent periods of eight to 20 years. The latent periods for two cases of skin cancer related to arsenic in drinking-water were 20 and 23 years, and the concentrations or uptake of arsenic were reported to be 1.2 and 1 mg per day, respectively, with an estimated total ingested dose of about 8 g in one study. Epidemiological studies in areas with different frequencies of black-foot disease and where drinking-water contained 0.35-1.14 mg/L arsenic revealed elevated risks for cancers of the bladder, kidney, skin, lung, liver and colon in both men and women."

Arsenic also has been associated with a broad range of non-cancerous health effects. These include cardiovascular, neurological, pulmonary, immunological, endocrine, reproductive and developmental effects.

Based on the health effects evidence, the EPA has classified arsenic as a human carcinogen and has restricted or canceled many uses of arsenic compounds in pesticides. OSHA has set a standard for arsenic in workplace air. In assessing the health benefits of a lowered standard, EPA has focussed on bladder and lung cancer and estimated that a 10 µg/L arsenic drinking water MCL would

ADI INTL
1/4 STD FLOATING
IN 1/3 SQUARE

- prevent between 19 and 31 cases and 5 to 8 deaths due to bladder cancer annually,
- prevent 19 to 25 cases and 16 to 22 deaths from lung cancer annually, and
- reduce the incidence of noncancer health effects from arsenic exposure.

In a move aimed at still further reducing exposure of the public to arsenic, U.S. EPA announced on February 12, 2002, a voluntary decision by the lumber industry to “move consumer use of treated lumber from a variety of pressure-treated wood that contains arsenic by December 31, 2003, in favor of new alternative wood preservatives.” By 2004, EPA will not allow chromated copper arsenate (CCA) products for specified residential uses.

Water Industry and Utility Responses to the Previously Proposed EPA 5 µg/L Arsenic Standard

In initially proposing a 5 µg/L arsenic standard, EPA estimated that implementation of the rule nationally would cost \$374 million per year for the next 20 years. EPA estimated a \$28 average annual household cost for arsenic removal for systems serving more than 10,000 people. However, most affected utilities utilize groundwater and serve populations less than 10,000. Since an estimated 75 percent of these smaller utilities already have treatment plants, the incremental cost of arsenic removal for these systems would be far lower than if the construction of new facilities were required.

Agreeing that the existing standard should be reduced, but opposing the establishment of a 5 µg/L standard, the American Water Works Association (AWWA) has contended that a standard below 20 µg/L cannot be justified. Moreover, AWWA countered EPA with cost estimates of \$600 million per year to meet a 10 µg/L standard and \$1.5 billion per year to meet a 5 µg/L standard. One industry spokesman suggested that some consumers would face bill increases of as much as \$1,900 annually.

While conceding the need to reduce arsenic levels, the Association of California Water Agencies challenged the scientific

Table 1: Theoretical Maximum Likelihood Estimates of Excess Lifetime Risk of Lung Cancer and Bladder Cancer for U.S. Populations Exposed at Various Concentrations of Arsenic in Drinking Water (Incidence per 10,000 people)

Arsenic, µg/L	Bladder Cancer		Lung Cancer	
	Females	Males	Females	Males
3	4	7	5	4
5	6	11	9	7
10	12	23	18	14
20	24	45	36	27

justification and economic feasibility of the previously proposed 5 µg/L standard.

A Western Coalition of (Seven) Arid States (WESTCAS) called for an interim standard of 20 µg/L. Arguing that compliance should be eight years rather than the proposed three, WESTCAS has contended that no available technologies exist for water providers to implement arsenic removal within three years.

At issue is the cost-benefit ratio of increased arsenic removal. It has long been recognized that the establishment of any health-based standard is, in effect, an attempt to place a value on human life or the quality of human life. To quantify (monetize) the benefits of avoiding mortality from bladder and lung cancer, EPA utilizes a Value of Statistical Life (VSL) estimate. The VSL value used by the Agency as of 1999 is \$6.1 million. In addition, EPA uses a Willingness to Pay (WTP) value to monetize the cancer cases that do not result in a mortality. Since a WTP value for avoiding a non-fatal cancer has not been established, EPA uses a proxy WTP estimate of \$607,000 established for the value of reducing the number of chronic bronchitis cases. Non-cancer health effects are considered essentially non-quantifiable.

NAS-NRC 2001 Arsenic in Drinking Water—Risk Report

At the request of the EPA Administrator, the National Academy of Sciences, National Research Council (NAS-NRC) appointed a new panel to review and update the 1999 NAS-NRC report on Arsenic in Drinking Water. The new NAS-NRC panel issued its updated report in September 2001, noting that several hundred new relevant articles had been published since the 1999 report

and that four major epidemiological studies had been conducted.

In their 200-page report, the NAS-NRC health effects panel concluded that the cancer risk from arsenic has been underestimated. While in the past EPA has used a risk level of 1 in 10,000 for establishing standards, the NAS report indicates that, even at 3 µg/L, the risk of bladder and lung cancer is between 4 and 7 deaths per 10,000 people. At 10 µg/L, the risk increases to between 12 and 23 deaths per 10,000 people (Table 1). In addition, the health effects panel cited increased evidence that arsenic causes high blood pressure and diabetes.

Based on three new epidemiological studies conducted in Chile and Taiwan, the panel also concluded that existing data “provide a sound and sufficient database showing an association between bladder and lung cancers and chronic arsenic exposure in drinking water.” Moreover, the earlier Taiwan data that had been criticized as scientifically flawed by industry spokesmen, was found to be “appropriate for use in dose-response assessment of arsenic in drinking water.”

Part 3 of this series will summarize currently available data on the occurrence of arsenic in U.S. waters.

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