Airborne arsenic and urinary excretion of metabolites of inorganic arsenic among smelter workers

Marie Vahter¹, Lars Friberg¹, Barbro Rahnster¹, Åke Nygren², and Peter Nolinder²

¹ National Institute of Environmental Medicine and Karolinska Institute, Departments of Toxicology and Environmental Hygiene, P.O. Box 60208, S-10401 Stockholm, Sweden
² Boliden Metall AB, 93200 Skelleftehamn, Sweden

Summary. The relationship between airborne concentrations of arsenic and the urinary excretion of inorganic arsenic metabolites (inorganic arsenic + methylarsonic acid + dimethylarsinic acid) have been studied among smelter workers exposed to arsenic trioxide. The urinary concentrations of arsenic metabolites were found to increase steadily during the first day of the working week (after 2–3 d off from work), whereafter they reached a steady state. The concentration in the late evening after a day of exposure was very similar to that in the early morning after. Both were well correlated to the total daily excretion. In the second part of the study, comprising 18 subjects, the first-void morning urine of each participant was collected for 2 to 3 d during the steady-state phase. Total concentration of arsenic in the breathing zones was measured by personal air samplers. Airborne arsenic (8-h values) varied between 1 and 194 μg As/m³, and urinary arsenic between 16 and 328 μg As/g creatinine. With the urinary arsenic concentrations (mean values of 2–3 d for each subject) plotted against the corresponding airborne arsenic concentrations, the best fit was obtained by a power curve with the equation y = 17 × x⁰.₅₆. However, four of the participants were found to excrete far more (105–260%) arsenic in the urine than possibly could have been inhaled, most likely due to oral intake of arsenic via contaminated hands, cigarettes or snuff. If these four were excluded, the best fit was obtained by a straight regression line with the slope 2.0 and the intercept 29 μg As/g creatinine (coefficient of correlation 0.92; P < 0.001).

Key words: Arsenic trioxide – Inhalation – Urine – Metabolites

Introduction

The most common route of occupational exposure to chemicals is through inhalation, and exposure levels are almost always estimated from data on the con-
centration in air. A major disadvantage with air measurements is that they only provide rough estimates of the inhaled amount, even if the concentration of the substance is measured in the breathing zone. The actual dose may vary to a great extent between individuals due to variations in the burden of work, which will influence the rate of respiration, and due to exposure via other routes, e.g. ingestion or skin absorption. Using a biological indicator of exposure, it may be possible to obtain a more precise estimate of the total dose of many compounds.

In the case of exposure to inorganic arsenic, which is common, e.g. in non-ferrous smelters, in the production and use of arsenical pesticides, as well as in the production of glass (NAS 1977; WHO 1981), the concentration in urine may be used to estimate exposure, since the main route of excretion is via the kidneys (WHO 1981). A study on smelter workers has, however, shown a rather low correlation between airborne arsenic and the total concentration of arsenic in urine (Pinto et al. 1976). One explanation for this may be that the total arsenic content in urine is greatly influenced by dietary intake of organic arsenic compounds, mainly arsenobetaine, which may be present in very high concentrations in certain fish species and crustaceans (Cannon et al. 1981; Luten et al. 1982; Norin et al. 1983), and which is rapidly excreted in the urine (Freeman et al. 1979; Tam et al. 1982; Vahter et al. 1983). One single meal of this type of food may give rise to more than 1000 µg As/l urine (Norin and Vahter 1981), compared to 5 to 30 µg As/l urine in persons who have not eaten this type of food and have not been excessively exposed via, e.g. the working environment (Braman and Foreback 1973; Buchet et al. 1980; Valkonen et al. 1983; Foa et al. 1984). Occupationaly exposed subjects may have levels of some hundreds of µg As/l (Pinto et al. 1976; Buchet et al. 1980). Experience has shown that the total arsenic concentration in urine may be elevated even if the subjects under study refrain from eating fish (Pinto et al. 1976).

Inorganic arsenic, trivalent as well as pentavalent, is methylated in the body to methylarsonic acid (MMA) and dimethylarsinic acid (DMA), which may be considered to be detoxification products since they have a lower affinity for tissue constituents than the original form or premethylation metabolites (Buchet et al. 1981a; Vahter and Marafante 1983; Vahter et al. 1984). Urinary arsenic normally consists of 10 to 20% unmethylated arsenic, 10 to 20% MMA and 60 to 80% DMA (Smith et al. 1977; Buchet et al. 1980; Tam et al. 1979). The purpose of the present study was to determine the concentrations of these metabolites in the urine of smelter workers exposed to arsenic trioxide, using an analytical method that is not influenced by the presence of organic arsenic compounds which originate from intake via food, and to correlate the urinary concentrations to the prevailing air concentrations of arsenic.

Materials and methods

Study design

The studies were carried out in two departments of a smelter producing copper, arsenic and other metals in northern Sweden. At the arsenic trioxide refinery, the crude arsenic trioxide from the roasters is refined by dissolution of soluble contaminants and recrystallization of the pure arsenic trioxide (white arsenic), which is then dried and packed in barrels. The exposure