

Arsenic burden survey among refuse incinerator workers

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ABSTRACT

Background: Incinerator workers are not considered to have arsenic overexposure although they have the risk of overexposure to other heavy metals.

Aim: To examine the relationship between arsenic burden and risk of occupational exposure in employees working at a municipal refuse incinerator by determining the concentrations of arsenic in the blood and urine.

Settings and Design: The workers were divided into three groups based on their probability of contact with combustion-generated residues, namely Group 1: indirect contact, Group 2: direct contact and Group 3: no contact. Healthy age- and sex-matched residents living in the vicinity were enrolled as the control group.

Materials and Methods: Heavy metal concentrations were measured by atomic absorption spectrophotometer. Downstream rivers and drinking water of the residents were examined for environmental arsenic pollution. A questionnaire survey concerning the contact history of arsenic was simultaneously conducted. Statistical analysis: Non-parametric tests, cross-tabulation and multinomial logistic regression.

Results: This study recruited 122 incinerator workers. The urine and blood arsenic concentrations as well as incidences of overexposure were significantly higher in the workers than in control subjects. The workers who had indirect or no contact with combustion-generated residues had significantly higher blood arsenic level. Arsenic contact history could not explain the difference. Airborne and waterborne arsenic pollution were not detected.

Conclusion: Incinerator workers run the risk of being exposed to arsenic pollution, especially those who have incomplete protection in the workplace even though they only have indirect or no contact with combustion-generated pollutants.

KEY WORDS: Arsenic, refuse incinerator, lead, environmental pollution, heavy metals

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Volatile arsenic compounds in fly ash have been proved to cause occupational problems among coal-mining workers, coal combustion and gasification workers, farmers burning coal for crop drying, and copper refining workers.^[1,2] By contrast, refuse incinerator workers are not considered to be at risk of a similar occupational hazard, although they may have the risk of over-exposure to other heavy metals such as lead, cadmium, mercury, vanadium and beryllium.^[3-6] However, fly ash, slag and landfill emitted or produced by incinerators may contain arsenic and pollute air, soil or water. Some incinerators may still use arsenic-containing coal for combustion. Chronic airborne or waterborne arsenic exposure from coal burning or industrial sources has been demonstrated to cause keratosis, pigmentation, skin ulceration, skin cancer, lung dysfunction, neuropathy, nephrotoxicity, hepatomegaly, cirrhosis, liver cancer and children's intelligence impairment.^[7-11] We conducted this study to determine if the workers at refuse incinerators are at risk of occupational exposure to arsenic by determining the concentrations of arsenic in their blood and urine.

Materials and Methods

Municipal waste incinerator and samplings of ash, air and water

The incinerator, located in Taipei City, Taiwan, started operation on March 28, 1995. It only dealt with household waste with preliminary sorting. The plant was equipped with a heat recovery boiler that used recovered energy to operate the steam turbine generator and supplied power to other facilities in the plant. The incinerator had four kilns, each with a waste incineration capacity of 375 tons per day. The temperature of the combustion chamber ranged between 850 and 1050°C, and the decontaminated exhaust was released into the atmosphere via a chimney that was 147 meters high. The incinerator used slag extractors to cool bottom ash residues and kneading machines to solidify fly ash, which was collected from the waste gas treatment system. Other pollution prevention facilities included electrostatic precipitators to remove dust, liquid scrubbers to remove acidic gases, and selective catalyst reactors to remove dioxin. All ash residues were disposed off in sanitary landfills.

Table 1 presents the data of toxic pollutants and metals in fly and bottom ashes and air samplings from the incinerator and a control

Table 1: Levels of selected toxic pollutants and metals in ash and air samplings at the incinerator and a control residence site in the vicinity

Toxic pollutants and metal	(unit)	Fly ash	Bottom ash	Permitted standard (Kiln)
Arsenic	mg/L	0.001-0.003	0.003	5
cadmium	mg/L	<0.004-0.038	0.049	1
Total chromium	mg/L	0.274-0.606	<0.039	5
chromium (VI)	mg/L	0.18-0.60	<0.01	2.5
Lead	mg/L	<0.05	0.07	5
Mercury	mg/L	0.0002-0.0027	<0.0019	0.2

Air sample	(unit)	Kiln 1	Kiln 2	Kiln 3	Kiln 4	Control site	Permitted standard (Kiln)	Permitted standard (living place)
Inspirable Particles	mg/m ³	3.97	2.71	4.88	256	0.071		125
CO	ppm	10.62	4.8	10.15	12.72	0.74	150	35
Nox	ppm	80.11	85.97	80.88	79.45	25.61	220	
Sox	ppm	4.22	5.19	1.8	5.24		150	
HCl	ppm	2.8	2.21	2.83	5.96		60	
Cadmium	µg/m ³	<0.0017	0.0019	<0.0012	ND*		0.5	
Lead	µg/m ³	0.03	0.043	<0.011	ND*		3	
Mercury	µg/m ³	0.0016	0.0084	0.0031	ND*		0.5	
Dioxin	ng-TEQ/Nm ³	ND*	0.0084-0.026	0.033-0.045	0.028-0.044		0.1	
Non-methane hydrocarbon	ppm					0.2		
Total Hydrocarbon	ppm	3.34	2.16	2.19	3.81	2.33		
NO ₂	ppm					20.23		250
SO ₂	ppm					2.57		100
Ozone	ppm					21.02		120

Table 2: Analysis of water samplings from incinerator sewage and underground water of six wells in the vicinity during the study period

Water	(unit)	Incinerator sewage	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Permitted standard (incinerator)	Permitted standard (living place)
Temperature	C	34.3	23.4	23	23	23	22.7	24.5	<45	
pH		7.4	6.7	6.5	6.5	6.6	6.1	6.1	5.0~9.0	
suspended solids	mg/L	96.1							<600	
Biochemical oxygen demand	mg/L	255.5							<600	
conductivity	µmhos/cm		482	768	541	656	600	190		
NH ₃ -N	mg/L		0.16	0.07	0.15	0.46	0.58	0.3		
chloride salt	mg/L		<-1.2	<-1.2	<-1.2	<-1.2	1.4	7.1		
Sulfate	mg/L		39	47.5	56.4	57.3	28	50.4		
Nitrite nitrogen	mg/L		0.2	0.66	0.02	0.05	0.02	0.05		100
Total dissolved solids	mg/L		293	479	456	368	471	148		
Total hardness	mg/L		210	394	239	260	242	54		
copper	mg/L		0.089	0.094	0.087	0.066	0.01	0.222		10
Zinc	mg/L		0.174	0.078	0.06	0.1	0.077	0.437		50
Lead	mg/L		<-0.01	<-0.01	<0.01	<-0.01	<-0.001	<-0.01		0.5
Cadmium	mg/L		0.001	0.002	<-0.00009	<-0.00009	0.001	0.002		0.05
Mercury	mg/L		<0.0001	0.001	<-0.00001	<-0.00001	0.0014	<-0.0001		0.02

residence in the vicinity; while Table 2 displays water sampling of the incinerator sewage and underground water of six wells in the vicinity. The range of arsenic concentrations prior to the study were 0.001-0.007 mg/L for fly ash and <0.002-0.025 mg/L for slag.

Subjects and samples

Employees of the refuse incinerator were enrolled in the study that was conducted in May 2004 after obtaining informed consent. Prior to blood and urine sample collection, the employees were requested to refrain from ingesting seafood. The workers were requested to fill up a questionnaire concerning present and previous occupations, dietary habit, past history of arsenic exposure, domicile and herbal drug

intake, as well as medical history of themselves and their families [Table 3]. Blood samples were collected within 10 hours of their finishing the assigned shift. Blood lead concentration was also evaluated as another indicator of heavy metal exposure. The workers were divided into three groups according to the potential risk of arsenic exposure at the workplace:

Group 1: Subjects with indirect exposure to combustion pollutants. They were machine maintenance and repair technicians, mechanics, electricians, ash crane drivers, workstation central control and management executives, and labour safety inspectors involved in refuse incinerator operation, environmental pollution prevention, mechani-

Table 3: Questions related to arsenic pollution and poisoning

I. Information on domicile and living:	
(a) Domicile history:	1. Have you ever lived in black foot disease*prevalent areas?() Yes () No. If yes, how long? _____ 2. Have you ever lived in arsenic-contaminated areas? () Yes () No.If yes, how long? _____ 3. Do you know lived in arsenic-polluted facility? () Yes () No If yes ,I live near a () Pyrite,copper or lead refinery () Electronic or opto-electronic factory () Semiconductor Factory () Sewage disposal plant () Refuse incinerator 4. Do you smell a garlic odor [†] in the gas emitted from the adjoining facility? () Yes () No
(b) Dietary habit	1. Does your drinking water comes from a well or other underground sources? () Yes () No 2. Do you often eat potential arsenic-contaminated food? () Yes () No If Yes,I often eat () oyster () fish () other kinds of sea food. Please specify _____
II. Health status:	
(a) Medical history:	1. Have you or your family members ever had the following diseases related to arsenic intoxication?() Yes () No If yes ,please specify the kind of disease () Blackfoot disease () Muscle wasting/myositis () Haemolytic disease () Peripheral neuritis () Skin keratinization,skin pigmentation or carcinoma in situ () Shortness of breath () Oederma,liver disease ,or renal disease () Cancer of lung,liver,urinary bladder or skin 2. Have you ever taken any arsenic-polluted herbal medicine ? () Yes () No If yes ,what is the type [‡] ? _____ How often? _____
III. Past work experience:	Have you ever worked in an arsenic-polluted factory? () Yes () No If yes ,I have worked in a () Pyrite refinery () Copper or lead refinery () Electronic Factory () semiconductor factory () Opto-electronic factory () Sewage disposal plant () other refuse incinerator. Duration _____ Department _____
IV. Present work experience	Duration: _____ Department: _____

*Blackfoot disease is a peripheral vasculopathy disease previously prevalent in Taiwan^[17]

[†]Garlic odor denotes contamination of volatile arsenic compounds

[‡]Types of arsenic polluted herbs were obtained from the list published by our government

cal equipments repair as well as maintenance and management of entrance vehicles.

Group 2: Subjects had direct exposure to combustion pollutants. They were trash truck dumping operators, weighing bridge workers, refuse bunker workers, refuse feed hopper and grate operators, steam turbine generator operators, slag and fly ash disposal workers and sewage sludge handling workers involved in the operation of incinerator, boiler and generator, management of apparatus and electricity, and disposal of ashes.

Group 3: Subjects were not occupationally exposed to combustion residues. They were guards, cooks, computer technicians and administration executives involved in document and property management, purchasing and other miscellaneous chores.

Only Group 2 workers were wearing activated carbon facemask and gloves during working hours. Age- and sex-matched healthy residents, who lived in the vicinity of the incinerator plant for at least six months were recruited as the control group.

Samples of water collected from downstream rivers, including the river draining into a nearby reservoir supplying drinking water to the residents of this area, and drinking water were examined for environmental arsenic pollution.

Laboratory tests

Diluted nitric acid prepared from 65% nitric acid (GR for analysis, Merck Taiwan, Taipei) was added to urine and water samples for preservation before the examination. The whole blood samples used for arsenic study were mixed with Triton X-100[®] (Merck Taiwan, Taipei), also with diluted nitric acid added for preservation before the test. During the assay with AA800 atomic absorption spectrophotometer (Perkin-Elmer Taiwan, Taipei), the preparations were mixed with palladium standard solution (1000 mg/L, Merck Taiwan, Taipei) and standard solution (998 ± 2mg/L, Merck Taiwan, Taipei). The blood samples used for lead study were mixed with a modifier-mixed dilu-

ent containing 0.2% nitric acid, 0.5% Triton X-100[®] and 0.2% NH₄H₂PO₄ before the assay. The assay was conducted following the suggestions described in the software of the spectrophotometer. Calibration curve was delineated from the diluted arsenic standard solution (H₃AsO₄, 1,000 mg/L As; CertiPUR[®], Merck Taiwan, Taipei). Lyphochek urine metals control and whole blood metals control solutions (Bio-Rad Taiwan, Clinical Diagnostics, Taipei) were used to validate the assay. According to the published criteria of the Council of Labor Affairs in Taiwan, subjects with a urine arsenic level exceeding 62µg/g-creatinine, blood arsenic concentration equal or above 7µg/L, or blood lead concentration above 20µg/L were recognized as over-exposed. The permitted arsenic level for river and drinking water was set at 50µg/L.

Ethics

All the procedures were in accordance with the ethical standards of the committee responsible for human experimentation and with the Helsinki Declaration of 2000. The subjects gave written, informed consent before the study. The protocol was approved by the Human Subject and Ethics Committee of a local review board.

Statistical analysis

The SPSS software (version 12.0, Chicago, USA) was used for analyses. To compare the data of matched study and control groups, we used the McNemar test for dichotomous variables and Wilcoxon matched-pairs signed-ranks test for numerical variables. Median test and the Kruskal-Wallis test were employed to compare the dichotomous and numerical results among the three groups of incinerator workers. The Wilcoxon Mann-Whitney test was used for further paired comparisons between numerical variables. For dichotomous questionnaire items, we cross-tabulated the data and applied the Pearson chi-square test to evaluate the relationship between working groups and past histories of arsenic exposure. Three symmetric measures, namely phi, Cramer's V and contingency coefficient, were introduced to determine the strength of the relationship. Multiple logistic regression analysis was used to adjust for potential confounding variables with a P value <0.200 in univariate analysis of two groups. To

check the effect of the model, we computed three pseudo r-squares, namely Cox and Snell, Nagelkerke and McFadden. For correlation study between two laboratory variables or between one laboratory variable and age or employment duration, nonparametric Kendall's tau-b was calculated. The null hypothesis was rejected at a probability level of 95% ($P < 0.05$).

Results

All the 122 employees (105 males, 17 females, age range 26-60 years, mean 44.5 years) working at the municipal refuse incinerator were enrolled in the study. They were working at the site for periods varying from 3 months to 16 years (mean 101 months). The total number of workers, males and females in each group were as follows: Group 1: 50 workers, 47 males and 3 females; Group 2: 40 workers, 38 males and 2 females; and Group 3: 32 workers, with 20 males and 12 females. There was significant gender difference among the three groups (Chi-square $P < 0.001$, d. f. = 2).

Heavy metal concentrations in the blood and urine did not follow the Gaussian distribution. All the workers had blood lead concentration within the permitted range (0.7 - 13.6 $\mu\text{g/L}$). Table 4 shows the median, inter-quartile range and incidence of overexposure of the control subjects and the three groups of incinerator workers. The arsenic levels in the urine and blood samples of the incinerator workers were significantly higher than those of the control subjects (Wilcoxon $P < 0.001$ for both). Nineteen (15.57%) and eight (6.56%) incinerator workers but only four (3.28%) and one (0.82%) control subjects had urine and blood arsenic concentrations above the permitted ranges, respectively. Incidences of arsenic overexposure in the study group were also significantly higher than those of the control group (McNemar P for urine = 0.001, 95% CI = 4.69-16.11%; P for blood = 0.016, 95% CI = 1.03%-5.74%).

Marked difference in blood arsenic concentration was observed among the three groups of incinerator workers (Kruskal-Wallis $P = 0.012$, d. f. = 2), with the levels in Group 2 being significantly lower than those in the remaining study groups (Mann-Whitney $P = 0.003$ and 0.021 for Groups 2 vs. 1 and 2 vs. 3) [Figure 1]. The difference in urinary concentrations of arsenic amongst members of various study groups was not statistically

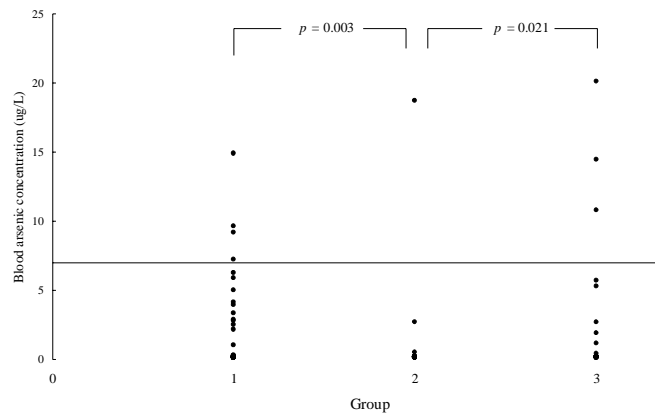


Figure 1: Comparison of blood arsenic concentration among the three groups of incinerator workers (Groups 1 to 3: workers of indirect, direct and no contact with waste and combustion-generated residues)

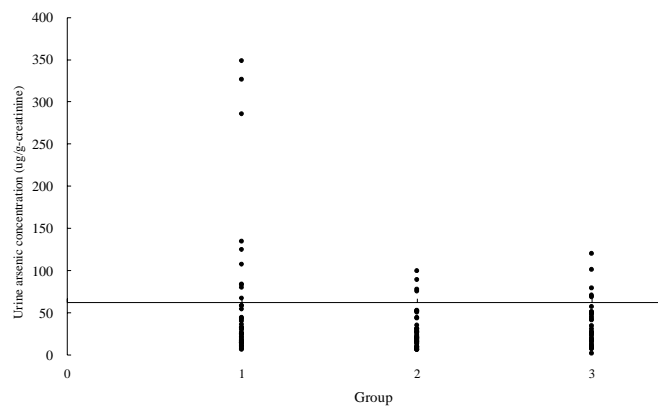


Figure 2: Comparison of urine arsenic concentration among the three groups of incinerator workers. (Groups 1 to 3: workers of indirect, direct and no contact with waste and combustion-generated residues)

significant (Kruskal-Wallis $P = 0.506$, d. f. = 2) [Figure 2]. No significant difference was seen in the incidence of blood and urine arsenic overexposure among the three groups of workers (Median $P = 0.436$ and 0.430, d. f. = 2). There existed no correlation between blood and urine arsenic concentrations or between blood arsenic and blood lead concentrations (Kendall's tau-b $P = 0.249$ and 0.079). No significant difference in blood arsenic concentration was found between the genders (Mann-Whitney $P = 0.414$) but the difference in urine arsenic concentration between the genders was significant (Mann-

Table 4: Comparison of arsenic burden in various groups of incinerator workers and control residents

Arsenic burden		Control (n=122)	Incinerator workers (n=122)			Control vs Incinerator	Three work group comparison
			Group 1* (n=50)	Group 2* (N=40)	Group 3* (n=32)	<i>P</i>	<i>P</i>
							Significant difference
Urine (< 62 $\mu\text{g/g-creatinine}$)	Median ($\mu\text{g/g-creatinine}$)	16.76	25.32	27.14			
	Interquartile range ($\mu\text{g/g-creatinine}$)	9.91-28.16	14.64-55.25	13.98-41.30	15.86-49.89	0.000	0.506
	Overexposure (n)	4	10	4	5	0.001	0.430
Blood (<7 $\mu\text{g/L}$)	Median ($\mu\text{g/L}$)	<0.01	<0.01	<0.01	<0.01		
	Interquartile range ($\mu\text{g/L}$)	<0.01-<0.01	<0.01-2.57	<0.01-<0.01	<0.01-0.95	0.000	0.012
	Overexposure (n)	1	4	1	3	0.016	0.436

*Groups 1 to 3: incinerator workers of indirect, direct and no contact, respectively with waste and combustion-generated residues

Whitney $P = 0.012$). Age or employment duration of incinerator workers showed no relationship with urine or blood arsenic levels (Kendall's tau-b $P = 0.819, 0.085; 0.525$ and 0.983 , respectively).

The downstream rivers were found to have no arsenic pollution (ranged from 0.000 to $7.847 \mu\text{g/L}$). The drinking water arsenic concentrations of the residents ranged from 0.000 to $13.870 \mu\text{g/L}$, also within the permitted range.

There was significant difference amongst the various groups for the questionnaire variable "residence in the vicinity of arsenic-polluted factory" (Chi-square $P = 0.044$, symmetric measure values 0.220 - 0.226 , d. f. = 2). The incidence in Group 3 was significantly higher than that of Group 2 (Chi-square $P = 0.013$, symmetric measure values 0.282 - 0.294 , d. f. = 1). There were no significant difference amongst the groups as far as the other questionnaire items (Chi-square P ranged from 0.107 to 0.923) were concerned. Using the multiple logistic regression model and after adjusting for confounding variables with $P < 0.200$ (such as living place in the vicinity of arsenic-polluted factory, frequent seafood intake and working history in arsenic-polluted plant), it was found that in individuals belonging to Groups 2 and 3, there was a correlation between working in an arsenic-polluted plant and residence in the vicinity of an arsenic-polluted factory on the one hand and overexposure: $\text{logit}(\text{worker's group}) = 0.823 + 2.129 \times (\text{working history in arsenic-polluted plant}) - 1.367 \times (\text{living place in the vicinity of arsenic-polluted factory})$, $P = 0.003$, pseudo r-squares 0.116 - 0.197 ; and the overall percent of cases correctly classified was 68.10% .

Discussion

Arsenic and other heavy metals were widely used in agricultural and industrial activities. Although most of these applications have been discontinued, residues from such activities, together with the ongoing generation from the smelting of various ores, have left a large quantity of heavy metal wastes to deal with.^[1,2,12,13] Refuse incinerators have been found to emit arsenic, lead and other heavy metals including cadmium, mercury, chromium, copper, nickel, antimony and zinc to the atmosphere,^[14] but only long-term exposure to lead, cadmium, mercury and vanadium has been reported to have an effect on incinerator workers and the inhabitants living in the vicinity of the plants.^[3,4,5,15] Although mining waste dumping with ore fragments, flotation tailings and medieval metallurgical slag may contain extremely high contents of arsenic,^[16,17] and chromated copper arsenate-treated wood and organoarsenic compounds used in poultry feed additives may emit volatile arsenic after combustion, these substances are not fed to the refuse incinerators in large quantities.^[18,19] At present, combustion of coal is the major source of atmospheric contamination with arsenic.^[5,20]

In this study, we have found that refuse incinerator workers do have higher levels of arsenic in their blood and urine samples indicating overexposure to arsenic. It is also interesting to note

that the workers who had indirect contact or no contact with combustion-generated residues had even higher blood arsenic level than those with direct contact. By contrast, the urine arsenic concentrations among the three worker groups showed no significant differences. Blood level could serve to indicate acute arsenic exposure within the 10 hours preceding the blood collection, while urine level would reveal more chronic arsenic exposure (usually 1-3 days but could be present for up to 10 days).^[21] Although most employees who have no direct contact with combustion-generated residues live near arsenic-polluted plants, this factor is not sufficient to explain the diverse blood arsenic levels among these three groups. The pollution cannot be due to coal or oil combustion because this incinerator uses electrical furnaces. Airborne arsenic pollution is not likely because this incinerator plant has authorized qualified institutions to monitor fly ash and slag arsenic concentrations and there is no arsenic overbalance record in this incinerator. The arsenic concentrations of fly- and bottom ashes before and during the study period were within the permitted range. In this study, drinking water was not noted to be polluted with arsenic and the number of workers whose domestic drinking water comes from groundwater showed no significant difference amongst the three groups of workers. Thus, water-borne arsenic pollution is unlikely to be the factor responsible for the arsenic overexposure. Dietary habits, especially consumption of seafood has been demonstrated to be associated with high levels of organic arsenic in urine in certain parts of Taiwan.^[22] However, in this study, seafood consumption had been restrained before the test. Moreover, the seafood in this area has never been reported to have arsenic overload, and there is no significant difference in seafood intake among the three worker groups. The rivers in the area of this study were also not found to accumulate arsenic in this study. Thus, dietary factor is not likely. On the other hand, only the workers who had direct contact with combustion-generated residues were asked to wear protective facemask and gloves during working hours. It is hypothesized that lack of wearing protective gear (preventive facemasks and gloves) by "no-contact" and "indirect-contact" employees is responsible for the arsenic overexposure.

The average arsenic levels of our incinerator workers are higher than those previously published.^[23-25] The data of toxic pollutants and metals in fly ash and slag of the incinerator, air sampling from the incinerator furnace and a control site, and underground water sampling from the wells near the incinerator were not significantly higher than those reported earlier.^[25] Although there are studies describing high arsenic contents of water or seafood in certain parts of Taiwan, these polluted areas are far from our study district.^[6,7,10,12,14,26] The high arsenic burden of our incinerator workers merits further investigation.

Our results indicate that incinerators cause arsenic pollution and less-protected workers are more likely to suffer arsenic contamination. However, further determination of inorganic arsenic with its metabolites using chromatography is necessary to clarify the source of arsenic pollution, because the atomic absorption spectrophotometer used in this study meas-

ures only total arsenic burden, instead of each kind of organic and inorganic arsenic and their methylated metabolites. Up to now, there is no arsenic intoxication case found among the incinerator workers. In view of high blood arsenic concentrations found in groups of workers with no direct contact with combustion-related activities, the mandatory requirement of wearing protective gear should be extended to all workers at the incinerator, irrespective of the nature, magnitude and degree of contact with combustion-generated residues.

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