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Review Article

Exposure Evaluation of Dioxins in Municipal Waste Incinerator Workers

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Abstract: In Japan, the largest source of dioxin is solid waste incineration plants. Because workers employed at these plants handle fly ash and slag contaminated by dioxins, they can take dioxins into the body during work and their health may be adversely effected. This paper describes the dioxin exposure concentration, daily dioxin intake and blood dioxin level in workers employed at municipal incineration plants. The estimated dioxin exposure concentrations were 0.5 to 7.2 pg TEQ/m^3 in the daily operation and 0.2 to 92,000 pg TEQ/m^3 in the periodic maintenance. It was also expected that the daily dioxin intake can exceed the tolerable daily intake (TDI) in incineration plants with fly ash of high dioxin concentration. The mean of blood dioxin concentration was 346 pg TEQ/g lipid in the highest exposed worker group of the Toyono-gun incineration plant and those were 11 to 40 pg TEQ/g lipid in the other incineration plants.

Key words: Dioxins, Dioxin exposure, Daily dioxin intake, Blood dioxin level, Municipal waste incineration plant

Introduction

Polychlorinated dibenzo-*p*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and coplanar polychlorinated biphenyls (Co-PCBs) are chemically and biologically similar compounds and are also highly toxic chemicals. "Dioxins" is the general term for these chemicals. They have already contaminate the environment such as air, water and soil, and foods such as fish, meat and vegetables[1–3]. Dioxins are also found in human adipose tissue, blood and milk[1, 4–6]. The main sources of dioxins are from the production of organic chlorinated herbicides, bleaching of paper/pulp and incineration of waste[7–9]. In Japan, incinerators are the major source[10] because most domestic solid waste (kitchen refuse, paper, wood, cloth, plastic etc.) is incinerated in municipal waste incinerators without sufficient measures to prevent the generation of these chemicals. Indeed, the grounds surrounding some incineration plants are contaminated with high levels of dioxins, causing concern among the residents about the adverse health effects of dioxins. Workers employed at incineration plants are also concerned about adverse effects on their health. In Japan, about 1,500 municipal waste incineration plants for domestic waste and 3,700 private incineration plants for industrial waste are in operation[11, 12] and tens of thousands of workers are estimated to be employed at them. Because the workers handle fly ash and slag contaminated by dioxins, they may intake dioxins during their work. The present paper reviews the exposure evaluation of dioxins in municipal waste incinerator workers in Japan.

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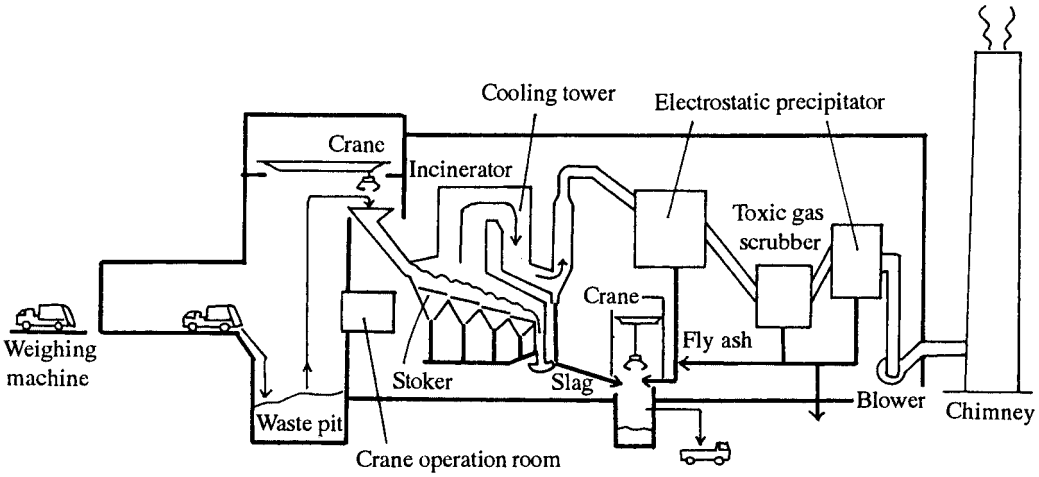

Fig. 1. Incineration process in a municipal waste incineration plant[13].

Incineration Process and Tasks of Incineration Workers

Incinerators are classified according to the incineration system, e.g., stoker, fluid bed and other types, and also according to their operation hours, e.g., full continuously burning type (24 hr), semi continuously burning type (16 hr) and batch type (8 hr).

Figure 1 shows an incinerator of the stoker type[13]. First, the collected waste is weighed and put into the waste pit. Next, the waste is transported into the incinerator by crane. In the incinerator, the waste is dried and burned while being conveyed to the bottom by the stoker. The combustion gas is passed through the cooling tower, electrostatic precipitator (EP) and toxic gas scrubber, and emitted from the chimney. Slag remaining at the bottom of the incinerator and fly ash collected by EP are transported into the ash pit. The slag and fly ash accumulated in the ash pit are loaded onto a truck and carried to reclaimed land. In this process, if the conditions of combustion and cooling are not appropriate, dioxins are synthesized in the incinerator, cooling tower and EP, and contaminate the slag, fly ash and exhaust gas. Recently, a bag filter (BF) has been substituted for EP at many incineration plants, because EP generates high levels of dioxins.

For the fluid bed type, hot air is blown into the incinerator from many holes at the bottom, and sand in the incinerator is heated and flung upward. Next, waste is transported into the incinerator and the waste is burned by contact with the hot sand. The combustion gas is passed through the cooling tower, EP and toxic gas scrubber, and emitted from the chimney. Because control of the burning condition is more difficult for the fluid bed type than for the stoker type, dioxins are more easily synthesized.

The median of dioxin concentrations in the exhaust gas of municipal waste incinerators is 1.0 ng TEQ/m^3 (= 1,000 pg TEQ/m^3) in 2000[11], which is about 8,000 times that in general air (0.13 pg TEQ/m^3) in 2001[14]. Medians of dioxin concentrations in the slag and fly ash are 0.02 and 3 ng TEQ/g (= 20 pg and 3,000 pg TEQ/g) in 1998–99[15], respectively, which are about 6 and 900 times that in general soil (3.2 pg TEQ/g, 2001)[14].

The tasks of incinerator workers are classified into "daily operation" and "periodic maintenance". The daily operation consists of weighing of waste, crane operation, incinerator operation, carrying slag and fly ash, and daily inspection and maintenance. The periodic maintenance is conducted several times in a year. First, the insides of the incinerator, cooling tower, EP and BF are cleaned by the incinerator workers or outside workers employed at maintenance companies. Next, these apparatuses are inspected and repaired mainly by the outside workers.

Estimated Dioxin Exposure Concentrations during Work Activities

It is difficult to directly measure dioxin exposure concentrations during work activities, because flow rate of personal sampler is too low to collect enough airborne dust to quantitatively determine dioxins. Thus, total dust concentrations in the breathing zone of incinerator workers were measured and the dioxin exposure concentrations were estimated by multiplying the total dust exposure concentrations by the dioxin concentrations in deposited dust,

Table 1. Total dust exposure concentrations and estimated dioxin exposure concentrations of incinerator workers (from Ref. 13)

	Plant	Sample number	Total dust exposure concentration (mg/m^3)		Estimated dioxin exposure concentration ($pgTEQ/m^3$)		Work duration (hr)
			Mean	Range	Mean	Range	
Daily operation	A, C	8	0.39	0.11–1.50	2.0	0.5–7.2	8
Periodic maintenance (cleaning the inside of equipment)							
1. Incinerator							
I. Removing clinker	A, C	6	55	30–97	29	9.2–48	1*
II. Removing clinker and slag	B	3	420	130–780	1.7	0.5–3.1	4*
2. Duct under stoker	A, C	6	82	12–170	36	13–70	1*
3. Cooling tower	A, B	5	210	53–420	48	0.2–110	1*
4. Electrostatic precipitator							
I. Removing fly ash deposited at discharge position	A	3	120	51–200	880	370–1500	0.5*
II. Removing fly ash by compressed air	B	2	1800	1500–2000	81000	71000–92000	1*

*: Work duration during one periodic maintenance.

fly ash and slag[13].

Table 1 shows the total dust exposure concentrations and the estimated dioxin exposure concentrations. In daily operations, the total dust exposure concentrations were 0.11 to 1.50 mg/m^3 with a mean of 0.39 mg/m^3. Using the dioxin concentrations in dust deposited in the workplace, the dioxin exposure concentrations were estimated to be 0.5 to 7.2 pg TEQ/m^3 with a mean of 2.0 pg TEQ/m^3 (Table 1). The Ministry of Health, Labor and Welfare, Japan, recommends an administrative level of 2.5 pg TEQ/m^3 for airborne dioxins in workplace[16]. The above estimation of dioxin exposure concentration suggests that though the mean value is less than the administrative level, the maximum value exceeded the administrative level even in the daily operation. Consequently, in such cases, dust emission must be reduced in the workplace and/or protective respirators and clothing should be worn.

For the periodic maintenance, two methods of cleaning the inside of the incinerator and EP were found in the above study. At plants A and C, the workers removed glassy lumps (clinker) adhering to the wall with a stick in the incinerator and removed fly ash adhering to the discharge hole in the EP (method I). At plant B, the workers removed clinker and all slag remaining on the stoker by shovel in the incinerator and removed all fly ash adhering to the wall using compressed air in the EP (method II). The inside of incinerator and EP was extremely dusty with slag and fly ash during the cleaning process by method II, and the mean values of total dust exposure concentrations were 420 mg/m^3 in the incinerator and 1800 mg/m^3 in the EP. On the other hand, with method I, the mean values of total dust exposure concentrations were 55 mg/m^3 in the incinerator and 120 mg/m^3 in the EP, which were still high but about 1/10 those of method II.

By multiplying the total dust exposure concentrations by the dioxin concentrations in slag (0.004 to 1.1 ng TEQ/g), the dioxin exposure concentrations during cleaning of the inside of the incinerator were estimated to be 0.5 to 48 pg TEQ/m^3. By multiplying the total dust exposure concentrations by the dioxin concentrations in fly ash (7.3 to 64 ng TEQ/g), the dioxin exposure concentrations during cleaning of the inside of the EP were estimated to be 370 to 92,000 pg TEQ/m^3, which were 150 to 37,000 times the administrative level. Consequently, highly efficient protective respirators and clothing should be worn during equipment cleaning procedures.

Estimated Daily Dioxin Intake

How much dioxin does an incinerator worker take into the body? Daily dioxin intake was estimated for the cases of fly ash of 1, 10, 100 and 1000 ng TEQ/g based on the following assumptions[13]. It is assumed that the body weight is 60 kg and the respiratory ventilation is 1 m^3/hr. In one year, there are 250 working days and the periodic maintenance is done 4 times. Total dust exposure concentration during each work is assumed to be the same as the mean value shown in Table 1. The worker inhales the same dust as the deposited dust during the daily operation, the slag while cleaning the inside of the incinerator and cooling tower, and the fly ash while cleaning the inside of the EP. Dioxin concentrations in the slag and in the deposited dust are 1/100 and 1/10 times, respectively, that in the fly ash[13]. Environmental intake, such as through meals and the air, is

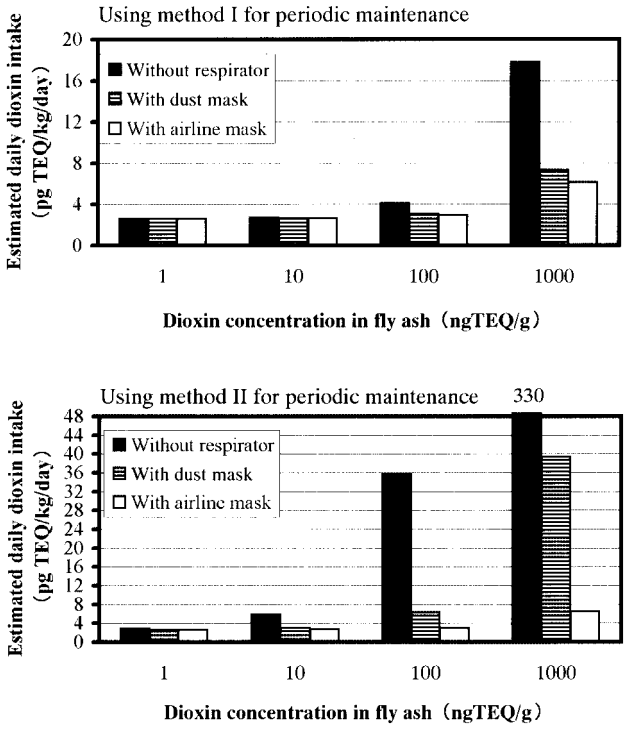

Fig. 2. Estimated daily dioxin intake in workers employed at continuously burning incineration plants.
The graphs are based on data in Reference 13.

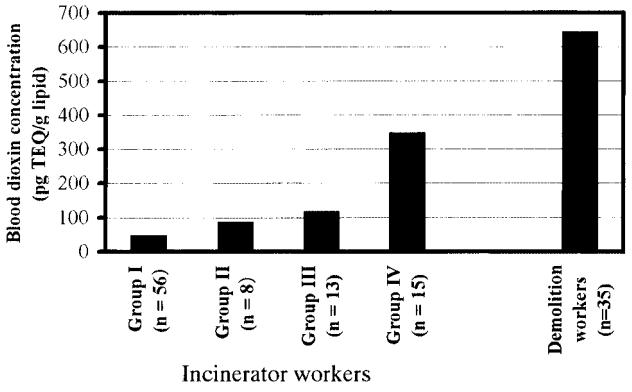

Fig. 3. Blood dioxin concentrations in incinerator workers and demolition workers at the Toyono-gun incineration plant.
Blood dioxin concentration = PCDDs + PCDFs + CoPCBs. Group I: workers who had not work in the incineration building and not handled slug and fly ash, Group II: workers who had not worked in the incineration building but handled the solidified ash, Group III: workers who had worked in the incineration building, Group IV: workers who had worked in the incineration building as well as engaged in maintenance of the incinerator. This graph is based on References 21 and 22.

2.60 pg TEQ/kg/day, as reported by the National Environmental Council[17]. The protection factors of dust masks and airline masks are 10 and 1000, respectively[18].

Figure 2 shows results of the estimation[13]. With method I, the estimated dioxin intakes for the fly ash of 1 and 10 ng TEQ/g are less than the tolerable daily intake (TDI: 4 pg TEQ/kg/day) recommended by the National Environmental Council[19], but the intake for the fly ash of 100 ng TEQ/g exceeds TDI if protective respirator is not worn during the cleaning of the inside of incinerator, and the intake for the fly ash of 1000 ng TEQ/g exceeds TDI even if an airline mask is worn. With method II, the estimated dioxin intake for the fly ash of 1 ng TEQ/g is less than TDI, but the intake for the fly ash of 10 ng TEQ/g exceeds TDI if protective respirator is not worn, the intake for the fly ash of 100 ng TEQ/g exceeds TDI even if a dust mask is worn, and the intake for the fly ash of 1000 ng TEQ/g exceeds TDI even if an airline mask is worn. In the case of the fly ash of 1000 ng TEQ/g, because the airborne dust in the incineration plants must be highly contaminated, dioxin intake during daily operation can be high even if an airline mask is worn only during the cleaning of the inside of incinerator. In a report of the former Ministry of Welfare[20], dioxin concentrations in fly ash ranged from 0.01 to 240 ng TEQ/g for continuously burning incineration plants to which the old dioxin guideline was not applicable, and ranged from 0.00 to 24 ng TEQ/g for the plants to which the guideline was applicable. Thus, in incineration plants with fly ash of high dioxin concentration, the daily dioxin intake of the workers can exceed TDI.

Blood Dioxin Level in Incinerator Workers

Figure 3 shows blood dioxin concentrations in workers employed at the Toyono-gun incineration plant[21]. The blood dioxin concentration in workers who had not work in the incineration building and not handled slug and fly ash (group I) was 46 pg TEQ/g lipid on the average, which was almost the same level as that of the general population. The blood dioxin concentration in workers who had not worked in the incineration building but handled the solidified ash (group II) and that in workers who had worked in the incineration building (group III) were 85 and 115 pg TEQ/g lipid, respectively, which were higher than the general level. The blood dioxin concentration in workers who had worked in the incineration building as well as engaged in maintenance of the incinerator (group IV) was 346 pg TEQ/g lipid, which was about ten times the general level.

In the plant, dioxin concentration in the fly ash remaining in the EP was 320 ng TEQ/g and that in the ash solidifying machine was 1,500 ng TEQ/g. This finding suggests that

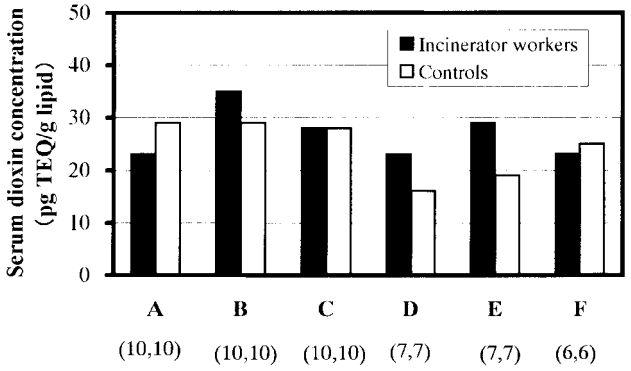

Fig. 4. Serum dioxin concentrations in incinerator workers and controls in six cities.
Serum dioxin concentration = PCDDs + PCDFs. ( ): Number of subjects.
This graph is based on References 24 and 25.

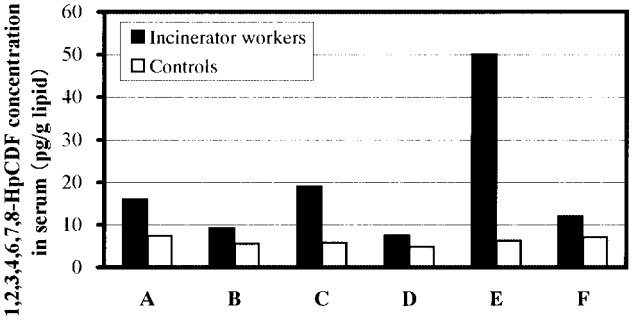

Fig. 5. 1,2,3,4,6,7,8-Heptachlorodibenzofuran concentrations in serum in incinerator workers and controls.
This graph is based on References 24 and 25.

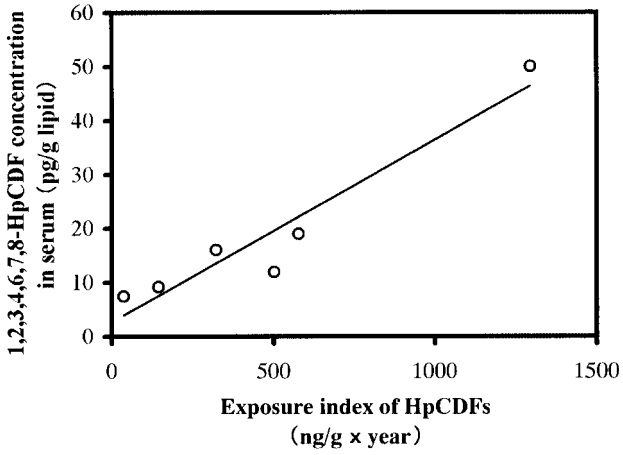

Fig. 6. Relationship between exposure index and serum concentration.

the daily dioxin intake in the workers can exceed TDI based on the above estimation. Dioxin concentration in the dust deposited at the bottom of the toxic gas scrubber and that of the chimney were 96,000 and 120,000 ng TEQ/g, respectively, which were much higher than that in the fly ash. These extremely high levels were due to accumulation of dioxins in alkaline liquid circulating in the toxic gas scrubber. This finding suggests that attention should be paid to dust other than fly ash.

The Toyono-gun incineration plant was demolished in 2000. The workers wore airline masks inside the equipment and dust masks outside it. They also wore protective clothing. However, the blood dioxin concentrations increased to 680 pg TEQ/g lipid on the average at the end of the work (Fig. 3)[22]. In order to clarify why the blood dioxin level increased, heating tests of the dust remaining inside the equipment was conducted[23]. The results showed that when the workers cut the parts of the equipment with a gas burner, dioxins in the dust adhering to the parts were vaporized and the workers inhaled the vapor passing through the dust mask. This means that adhering dust should be removed before heating the parts and workers should wear respirators that shut out vapor.

In 1998–2000, we measured serum dioxin concentrations of 50 workers at six municipal waste incineration plants[24, 25]. For these plants, the dioxin concentrations in the exhaust gas were 0.072 to 590 ng TEQ/m^3, which were representative of Japanese municipal waste incineration plants. For comparison, 50 controls matched for age (± 5 years) were selected from the general population. The mean serum dioxin concentrations in the incinerator workers at each plant ranged from 23 to 35 pg TEQ/g lipid (PCDDs + PCDFs), while that in the controls ranged from 16 to 29 (Fig. 4). This finding suggests that the dioxin level in the incinerator workers was almost the same as that in the controls.

However, significant increases in the serum 1,2,3,4,6,7,8-HpCDF concentration were found at all six plants (Fig. 5). Figure 6 shows the relationship between the occupational exposure index and serum concentration, where the occupational exposure index was defined as the product of the employment duration at the incineration plant and the 1,2,3,4,6,7,8-HpCDF level in the deposited dust. As the occupational exposure index increases, the serum concentration also increases. This finding suggests that the incinerator workers took dioxins into their bodies while they were working.

The Ministry of Health, Labor and Welfare also carried out blood dioxin measurements of 298 workers at 26 municipal waste incineration plants in 1999–2001[26–28]. For these plants, dioxin concentrations in the exhaust gas were

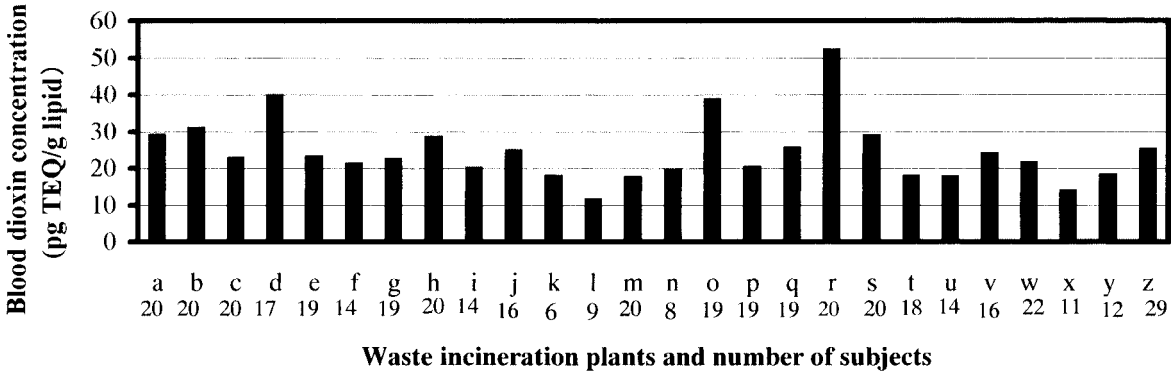

Fig. 7. Mean blood dioxin concentrations in workers employed at 26 waste incineration plants.
Blood dioxin concentration = PCDDs + PCDFs + Co-PCBs. This figure graph is based on References 26, 27 and 28.

0.035 to 450 ng TEQ/m^3. The mean blood dioxin concentration at each plant ranged from 11 to 40 pg TEQ/g lipid (Fig. 7, PCDDs + PCDFs + Co-PCBs). The mean values were similar to the general level, but the individual values were higher than 100 pg TEQ/g lipid in some cases, where dioxins were taken into the workers' bodies while they were working.

Strategy for Future Research

The number of municipal waste incineration plants where blood dioxin measurements have been carried out is probably less than 100. Except for the Toyono-gun plant, there has been no observation of very high blood dioxin levels. However, as there are about 1,500 municipal waste incineration plants in operation in Japan, this number is too small to conclude that the dioxin body burden of incinerator workers is not high, so that further research is necessary. But the cost of blood dioxin measurement is very high and the number of laboratories that can do blood measurements is small.

Under such circumstances, let us consider what can be done. As stated above, because the serum HpCDF level is correlated to the occupational exposure index, the serum level can be estimated from the HpCDF concentration in deposited dust and employment duration. There are many laboratories that can conduct dust measurements and the cost is lower than for blood measurements. Consequently, measurement of dioxin concentration in the deposited dust can be conducted in all municipal waste incineration plants of Japan in the first year. Based on the dust measurement results, plants needing further inspection can be identified, and the blood dioxin concentrations in the workers can be measured in the next year.

For our study at the six plants, there was no correlation of TEQ values between the serum and the exposure index, probably because the exposure index was low. If a similar study can be carried out for plants with high TEQ value and a correlation is found for TEQ values between the serum and the exposure index, our proposed strategy will be more efficient.

Guidelines for Control of Dioxin Exposure

In April 2001, the Ministry of Health, Labor and Welfare issued guidelines for controlling dioxin exposure at waste incineration plants[16]. The guidelines prescribe the election of work leader, education of workers on occupational health, establishment of measures against dioxin generation, direction of workers to use respiratory and skin protection, and control of workers' health. The workplace should be classified as control area I, II or III based on the airborne dioxin level measured every six months, and the working environment and work practices should be controlled to decrease dioxin exposure of the workers. Periodic general health examinations and special care of workers with anxiety about their health are also necessary. If there is the possibility of a high dioxin intake by the workers, such as in an accident, specific medical examinations should be done and the blood dioxin level should be measured if necessary.

The guidelines also include prescriptions for demolishing an incineration plant. The dioxin concentration in the dust adhering to the inside of the equipment and the airborne dioxin concentration in the workplace should be measured before the demolition work begins. Based on these measurements, the workplace will be classified as control area I, II or III, and the demolition method and grade of respiratory and skin protection are determined. For example,

if the dioxin concentration in the adhering dust is 4.5 ng TEQ/g or more, the workplace is classified as control area III, and portable electric tools and hydraulic cutters can be used, but not gas burners. When workers always handle highly contaminated dust (> 3.0 ng TEQ/g), they should wear air-supply respirators, airtight clothing and gloves for handling chemicals. If the work environment management and work practice are kept in good control according to the guidelines, the dioxin exposure of workers can be decreased considerably.

Exposure Evaluation of Dioxins for Outside Workers

This paper has focused on the dioxin exposure of workers employed at municipal waste incineration plants. Because for many municipal waste incineration plants, work with high dioxin exposure, such as cleaning and repairing the inside of equipment, is performed by the outside workers employed at maintenance companies, evaluation of their dioxin exposure is necessary. In the future, demolition will increase at old incinerators to which the Law Concerning Special Measures against Dioxins[29] is not applicable. Consequently, the evaluation of dioxin exposure for the demolition workers will also be necessary.

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