Bulletin of Environmental Contamination and Toxicology (2020) 105:173–179
https://doi.org/10.1007/s00128-020-02903-z

Environmental Exposure-Associated Human Health Risk of Dioxin Compounds in the Vicinity of a Municipal Solid Waste Incinerator in Shanghai, China

Y. Y. Deng[1,2,3] · P. A. Peng[1,2] · L. J. Jia[3] · W. L. Mao[3] · J. F. Hu[1] · H. W. Yin[3]

Received: 8 February 2020 / Accepted: 9 June 2020 / Published online: 6 July 2020

Abstract
In order to assess environmental exposure-associated human health risk of dioxin compounds for the population in the vicinity of a municipal solid waste incinerator (MSWI) in Shanghai, the atmospheric samples (n = 24) and soils samples (n = 96) were collected and analyzed to obtain the concentration level, pollution characteristics and seasonal changes of dioxin compounds in environmental medias. The toxicity equivalent concentration range of 2,3,7,8-substituted polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) was 30.9–409 fg WHO-TEQ·m^{-3} in atmosphere and 0.362–8.55 ng WHO-TEQ·kg^{-1} in soil. The non-carcinogenic health risk and carcinogenic health risk from PCDD/Fs environmental exposure of people living in the vicinity of the MSWI in Shanghai were all within the allowable range of the US Environmental Protection Agency, which implied that the MSWI in Shanghai did not produce additional risk for the population living in its vicinity.

Keywords Dioxins · Passive sampling · Solid waste · Incinerator · Health risk

With China's rapid progress in urbanization, many cities are facing the dilemma of garbage siege. As in 2017, Shanghai produced approximately 25,000 tons of municipal solid waste. Among these, 60% were incinerated, while the remaining was conducted with landfill and integrated treatment. The land resources of the city are very precious, and incineration would definitely be the main disposal method for urban domestic garbage in the future. However, the secondary pollution caused by domestic waste incineration technology has become a great concern, in terms of the pollutants of "dioxin" (Vilavert et al. 2012). In recent years, the Chinese government has given special attention to the emissions of dioxins and eliminating the emissions of dioxins from municipal solid waste incinerator (MSWI), in order to reduce the influence of MSWIs on the surrounding environment, based on the Chinese standard in recent years (0.1 ng I-TEQ N·m^{-3}) (Li et al. 2008). Besides the emission control by the standard, it is also vital to assess the environmental exposure-associated human health risk of dioxin compounds in the vicinity of the MSWI in Shanghai. However, due to sampling, analytical instrumentation and cost constraints, 2,3,7,8-substituted polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs) data in environmental medias, especially in the ambient atmosphere in the vicinity of the MSWI in Shanghai remains very limited (Li et al. 2008; Ying 2010; Tian et al. 2015).

Shanghai is the political, economic and technological center of China, and is the most important region in East China, with a population of more than 20 million. The present study area was in the vicinity of a MSWI, located at the center of Pudong district, with a daily capacity of 1000 tons. This plant officially began its operation in July 2003. Southeasterly or northwesterly winds prevail throughout the year in this area, which changes with the season. In the present study, 24 atmospheric samples were collected monthly for 12 consecutive sampling periods at the downwind and upwind directions of prevailing wind directions of the MSWI, from January 2017 to December 2017 respectively. In addition, 96 soils samples were collected from 12 directions of the

✉ Y. Y. Deng
dengyy@apm.sh.cn

1 State Key Laboratory of Organic Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China

2 University of Chinese Academy of Sciences, 19A Yuquan Road, Beijing 100049, China

3 Bioassay and Safety Assessment Laboratory, Shanghai Academy of Public Measurement, Shanghai 201203, China

MSWI in May of the same year. The present study aimed to obtain the concentration level, pollution characteristics and seasonal changes of dioxin compounds in the environmental medias in the vicinity of a MSWI in Shanghai. These monitoring data can provide effective data reference for comprehensively evaluating the PCDD/Fs environmental exposure health risk of people living around the MSWI, and technical support for environmental waste management.

Materials and Methods

Two atmospheric sampling sites were established in the vicinity of the MSWI. According to the environmental impact assessment report of the MSWI, the predicted maximum ground-level concentration of PCDD/Fs was 714 m for typical days, and 1000 m for an annual average. And in our previous study, the maximum PCDD/Fs levels in soil samples were observed approximately at 1000 m from the MSWIs in Shanghai (Deng et al. 2011). And also considering the stability of the sampling site, as the sampling period was consecutive a year, Site A was established at the northwest (downwind direction of the prevailing wind direction in summer) of the MSWI, with the distance of 900 m in a garden. Site B was established at the southeast (downwind direction of the prevailing wind direction in winter) of the MSWI, with the distance of 750 m in a garden (Fig. 1).

Atmospheric samples in the vicinity of the MSWI were collected monthly using an outdoor passive air sampler (Tisch, TE-200-PAS), from January 1, 2017 to December 31, 2017, with polyurethane foam (PUF). Soil samples from 96 sampling sites were also collected in May of the same year. These soil samples were collected at 8 distances (400, 800, 1200, 1600, 2000, 2500, 3000 and 4000 m) and from 12 directions (north, northeast, east, east-southeast, southeast, south-southeast, south, southwest, west, west-northwest, northwest and north-northwest) (Fig. 1). According to the reference data, the passive atmospheric sampling rate for

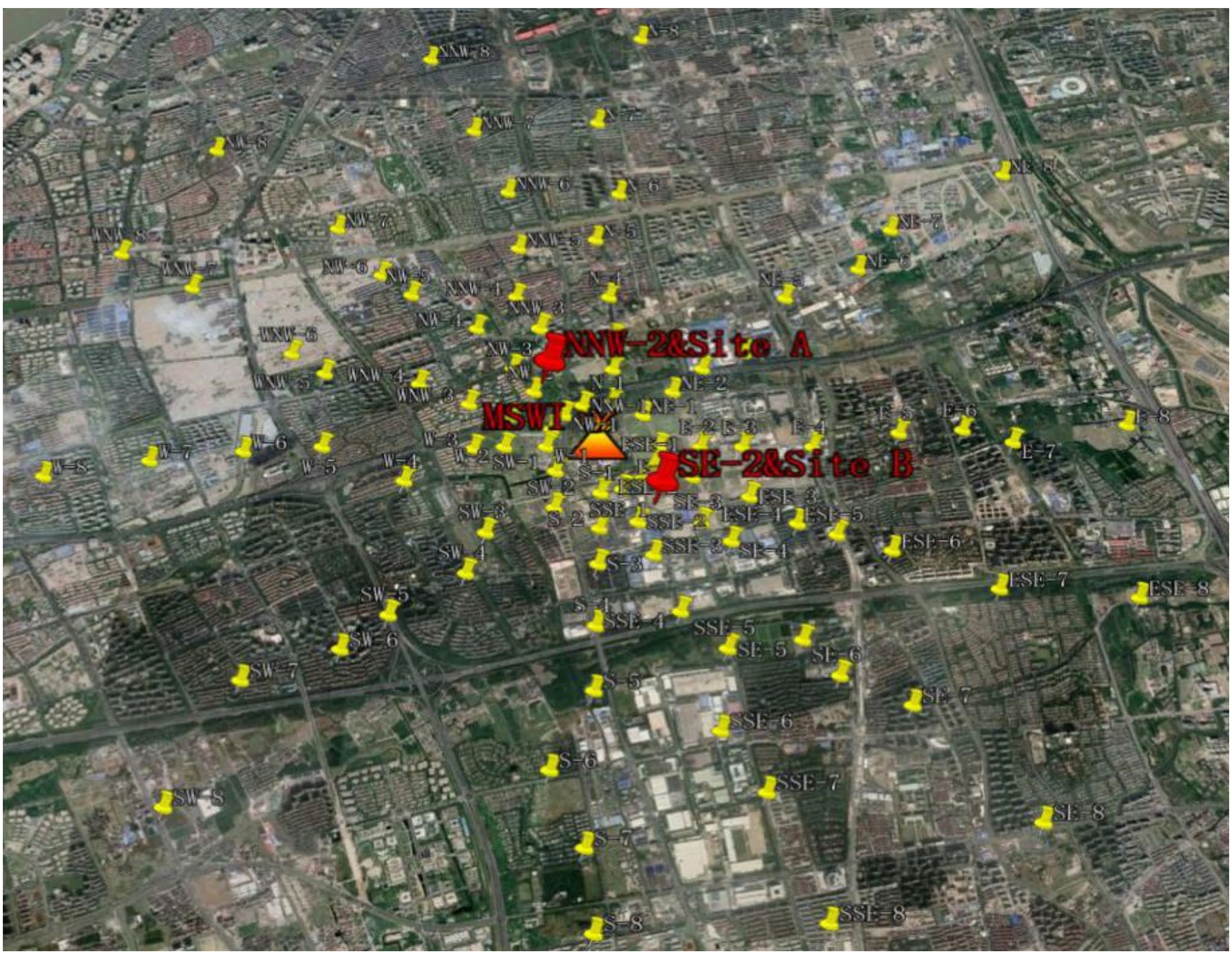

Fig. 1 The sampling sites 84 in the vicinity of a MSWI in Shanghai, China

PCDD/Fs was set as 2.0 $m^3 \cdot d^{-1}$ (Mari et al. 2008). The PUF cotton used for sampling was previously cleaned by Soxhlet extraction (Buchi, B-811) (dichloromethane: *n*-hexane = 1:1, 16 h). Then, the extracted PUF cotton was dried and immediately wrapped with tin foil, and stored at −20°C in a sealed bag for later use. These atmospheric passive samples were spiked with ^{13}C-labeled sampling internal standards prior to sampling. The soil sampling method and the analytical method was the same as the previous study (Deng et al. 2011).

During the experiment, one program blank was analyzed each month. The blank control results indicated that there was no background interference in the experiment. For the atmospheric samples, the ^{13}C-labeled sampling internal standard recovery ranged from 77% to 98%. The ^{13}C-labeled cleanup internal standard recovery ranged from 76% to 94%. And these were all in line with the quantitative requirements of the EPA23 method. For the soil samples, the ^{13}C-labeled cleanup internal standard recovery ranged from 40% to 130%, and this was in line with the quantitative requirements of the EPA1613 method.

In the present study, the PCDD/Fs environmental exposure of the people living in the vicinity of the MSWI include inhalation exposure from the atmosphere, and dermal exposure and ingestion from the soil and dust. The PCDD/Fs exposure via inhalation from the atmosphere was calculated based on the most updated US EPA methodology (US EPA 2009). The PCDD/Fs exposure via ingestion and dermal contact from soil was calculated based on the models in VLIER-HUMAAN (Van Hall Instituut 1997). The specific equations and associated local parameters can be found elsewhere (Nouwen et al. 2001; US EPA 2009; Zhao and Duan 2014; Duan 2016). The non-carcinogenic risk index and the carcinogenic risk index were calculated based on the technical method recommended by the National Academy of Sciences (NAS) in the United States (Van Hall Instituut 1997; WHO 1998; US EPA 2005).

The SPSS Statistics version 17.0 was used to perform data statistics and plotting.

Results and Discussion

Figure 2 presents the TEQ concentration of PCDD/Fs in the atmosphere at two sampling sites in different months in the vicinity of a MSWI in Shanghai in 2017. From January, 2017 to December, 2017, a total of 24 samples were collected. The TEQ concentrations of PCDD/Fs at Site A and Site B were 30.9–195 fg WHO-TEQ·m^{-3} (mean value: 113 fg WHO-TEQ·m^{-3}) and 43.2–409 fg WHO-TEQ·m^{-3} (mean value: 119 fg WHO-TEQ·m^{-3}) respectively. The TEQ concentrations of PCDD/Fs in the atmosphere in the vicinity of the MSWI (passive sampling) in Shanghai were similar to those in Tianjin, China and Seoul, Korea (Ding et al. 2013; Yoonki et al. 2014); but they were slightly lower than those in the industrial area of Gyeonggi province of South Korea (Heo et al. 2014) and the industrial area of Bou-lsmail, Algeria (Moussaoui et al. 2012); although, they were slightly higher than those in the urban background area of Shanghai (Tian, et al. 2015), and significantly higher than those in the area around a Spanish incinerator (Vilavert et al. 2015) and in rural and urban areas of Buenos Aires, Argentina (Cappelletti et al. 2016). In the study area, the MSWI represents the main PCDD/Fs emission sources, which is the normal situation in big urban areas. And in industrial area, where has more kinds of PCDD/Fs emission sources, might show a higher PCDD/Fs concentrations. As all the important PCDD/Fs emission sources are related to human actives, which may be the reason of lower atmospheric PCDD/Fs concentrations in lower population density areas.

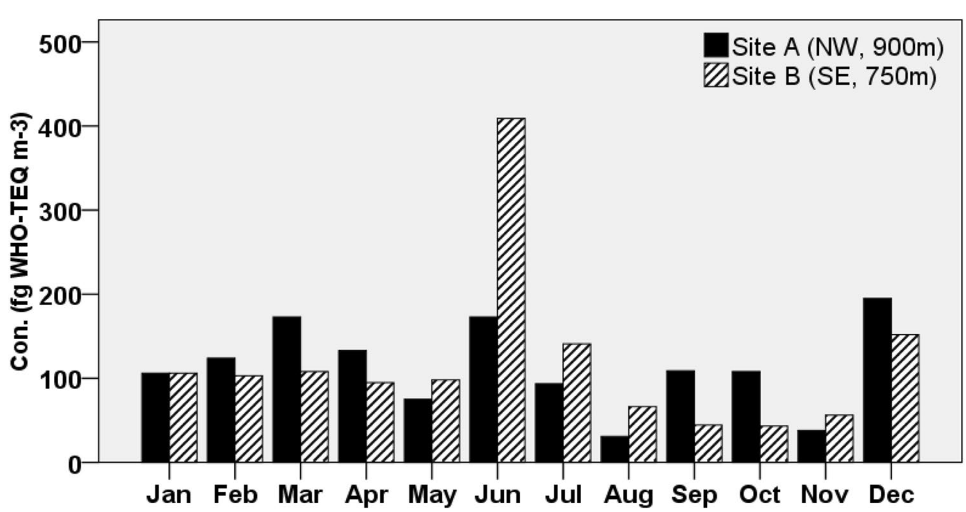

Fig. 2 The TEQ concentrations of PCDD/Fs in the atmosphere

The TEQ concentration of PCDD/Fs in the atmosphere in vicinity of the incinerator was the lowest in autumn (Sep, Oct, Nov.), similar in winter (Dec., Jan., Feb.) and spring. The average TEQ concentrations in winter were 142 ± 47.1 fg WHO-TEQ·m^{-3} (Site A) and 121 ± 27.5 fg WHO-TEQ·m^{-3} (Site B), which were slightly higher than the TEQ concentrations of PCDD/Fs in spring (Mar., Apr., May) (127 ± 49.3 fg WHO-TEQ·m^{-3}, Site A; 100 ± 6.81 fg WHO-TEQ·m^{-3}, Site B), and were higher than that in autumn (Sep, Oct, Nov) (85.0 ± 40.7 fg WHO-TEQ·m^{-3}, Site A; 48.0 ± 7.00 fg WHO-TEQ·m^{-3}, Site B). The data in summer (Jun, Jul, Aug) showed great deviation and Spatial difference. The TEQ concentration of PCDD/Fs in the atmosphere was 99.3 ± 71.2 fg WHO-TEQ·m^{-3} (Site A) and 205 ± 180 fg WHO-TEQ·m^{-3} (Site B), respectively.

It was found that the average TEQ concentration of PCDD/Fs in the atmosphere at Site A in summer (99.3 ± 71.2 fg WHO-TEQ·m^{-3}) was slightly lower than that in winter (142 ± 47.1 fg WHO-TEQ·m^{-3}), but there was no significant difference (P value: 0.606). This seasonal trend is consistent with most studies (Gao et al. 2014). The average TEQ concentration of PCDD/Fs in the atmosphere at Site B in summer was 205 ± 180 fg WHO-TEQ·m^{-3}, which was significantly higher than that at Site B in winter (121 ± 27.5 fg WHO-TEQ·m^{-3})(P value: 0.048). This seasonal trend was different from that obtained by active sampling technology in most literature, but was consistent with the seasonal trend obtained by passive sampling technology in some literature (Hao et al. 2017). Firstly, the passive sampling rate would be susceptible to environmental factors such as wind speed, temperature and particulate matter. The difference would be even greater in urban environments with high atmospheric particulate pollution. Since dioxins are semi-volatile persistent organic pollutants, the distribution of dioxins in the gas–solid phase would be greatly affected by climate. In summer, due to the high atmospheric temperature, the proportion of dioxins in the gas phase would be higher than that in winter. The passive sampling results are mainly represented the dioxins concentration in gas phase. This characteristic, together with the rising dioxins concentration in winter, may lead to the difference in the seasonal characteristics of passive atmospheric data. The difference in PCDD/Fs concentrations between sampling points was not significant except for a few months. In urban areas, due to the barrier of buildings and traffic trunk lines, the dominant wind direction had little influence on PCDD/Fs concentration at sampling points. In summer (Jun., Jul., Aug.), the TEQ concentrations of PCDD/Fs at Site B (Atmospheric data) were higher than those from Site A (Atmospheric data). The PCDD/Fs concentration in soil at sampling Site B was 5.86 pg WHO-TEQ·g^{-1}, which was obviosly higher than that at sampling Site A (1.58 pg pg WHO-TEQ·g^{-1}). The average highest temperature were 33.4 °C, 39.6 °C and 38.1 °C in June, July and August, respectively (Shanghai Pudong new area bureau of statistics 2018) in Shanghai. The higher temperature in summer may induce PCDD/Fs to evaporate into the air from the soil.

Figure 3 presents the TEQ concentrations of PCDD/Fs in soil samples in the vicinity of the MSWI in different wind directions in Shanghai in May, 2017. The TEQ concentrations of PCDD/Fs in soil samples were ranged from 0.362 to 8.55 ng WHO-TEQ·kg^{-1} (mean: 2.08 ng WHO-TEQ·kg^{-1}), which is consistent with the PCDD/Fs level of the background agricultural field in Shanghai (Deng et al. 2008). The statics showed that no significant variations in PCDD/Fs concentrations were observed among the different directions (P value: 0.299). Due to the barrier of buildings and traffic trunk lines, the dominant wind direction had little influence on the PCDD/Fs concentrations at the sampling points.

Soil samples from three of these 12directions of the same MSWI were also investigated in 2007 in our previous study (Deng et al. 2011). The TEQ concentrations of PCDD/Fs in soil samples in the vicinity of the MSWI in 2007 and 2017 were shown in Table 1. When compared with the previous study in 2007, which we investigated the soil samples from west, northwest and southeast directions of the same MSWI, there was no statistical difference between the PCDD/Fs concentration levels in soil samples from sampling period in 2007 and 2017 (P value: 0.535 (W direction), 0.583 (NW direction), 0.448 (SE direction)).

According to the seasonal average TEQ concentrations of the PCDD/Fs in the atmosphere, the PCDD/Fs inhalation exposure of people living in the vicinity of the MSWI ranged from 9.13 to 39.1 fg WHO-TEQ/(kg•d) for adults and 18.5–79.1 fg WHO-TEQ/(kg•d) for children, which was in good agreement with those in other parts of China: the corresponding data in Beijing ranged from 1.8

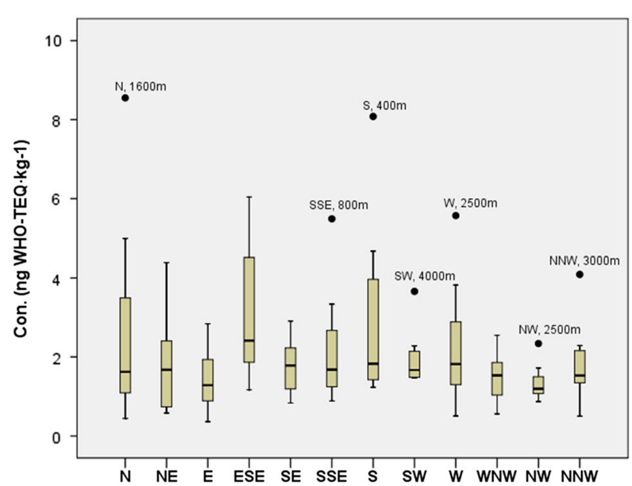

Fig. 3 The standard box-plots for the TEQ concentrations of 96 soil samples in different directions

Table 1 The TEQ concentrations of PCDD/Fs in soil samples in the vicinity of the MSWI in 2007 and 2017

Directions	Year 2007 (Deng et al. 2011)			Year 2017		
	Distance(m) from the MSWI	Soil Con ng WHO-TEQ·kg^{-1}	Mean and SD	Distance(m) from the MSWI	Soil Con ng WHO-TEQ·kg^{-1}	Mean and SD
West of the MSWI	400	2.48	Mean = 1.82 SD = 0.871	400	1.19	Mean = 2.26 SD = 1.64
	700	1.25		800	1.96	
	1000	3.29		1200	0.509	
	1500	0.751		1600	1.91	
	2000	1.28		2000	1.41	
	2500	2.16		2500	5.57	
	3090	1.53		3000	3.82	
	–	–	–	4000	1.73	
Northwest of the MSWI	400	1.55	Mean = 1.73 SD = 1.86	400	0.87	Mean = 1.34 SD = 0.472
	724	1.61		800	1.72	
	1000	0.813		1200	1.03	
	1500	0.55		1600	1.14	
	1900	0.83		2000	1.25	
	2500	5.85		2500	2.34	
	3100	0.878		3000	1.28	
	–	–	-	4000	1.12	
Southeast of the MSWI	300	1.2	Mean = 1.46 SD = 0.830	400	2.65	Mean = 1.77 SD = 0.727
	700	0.907		800	2.91	
	1000	1.73		1200	1.81	
	1500	0.651		1600	1.78	
	1500	1.68		2000	1.79	
	2400	0.92		2500	0.836	
	3000	3.1		3000	0.984	
	–	–	–	4000	1.4	

to 38.4 fg WHO-TEQ/(kg•d) for adults, and ranged from 3.2 to 68.0 fg WHO-TEQ/(kg•d) for children (Hao et al. 2017); the corresponding data in urban areas of Shenzhen ranged from 2.0 to 97.0 fg WHO-TEQ/(kg•d) for adults, and ranged from 2.0 to 147.0 fg WHO-TEQ/(kg•d) for children (Peng et al. 2015); the corresponding data for adults in Guangzhou ranged from 5.27 to 35.5 fg I-TEQ/(kg•d) (Liu et al. 2016); the corresponding data in the Shenyang urban area ranged from 1.0 to 86.0 fg WHO-TEQ/(kg•d) for adults, and ranged from 3.0 to 197.0 fg WHO-TEQ/(kg·d) for children (Zhang et al. 2013). In China, the government document about the management of the environmental impact assessment of biomass power generation projects (Huanfa [2008] No. 82) indicated that the tolerable PCDD/Fs inhalation exposure of people around a MSWI should be below 10% of the WHO recommended tolerable daily intake of 4 pg TEQ·kg^{-1} body weight/day. The PCDD/Fs inhalation exposure of people around the MSWI in the Shanghai area was far below the tolerable PCDD/Fs inhalation exposure of people around a MSWI, which indicated that the PCDD/Fs inhalation exposure of people living in the vicinity of the MSWI in Shanghai area was at an acceptable level.

The dermal exposure and ingestion level of PCDD/Fs via soil and dust for the population in vicinity of the MSWI ranged from 2.38 to 8.71 fg WHO-TEQ/(kg·d) for adults and from 10.3 to 37.5 fg WHO-TEQ/(kg·d) for children, according to the maximum soil concentration at each direction as the worst scenario.

The non-carcinogenic risk and the carcinogenic risk were calculated according to the maximum PCDD/Fs inhalation exposure, dermal exposure and ingestion level of people living in vicinity of the MSWI. It can be observed in Table 4 that the daily average PCDD/Fs exposure of children in general was higher than that of adults. Furthermore, inhalation exposure was the main way of PCDD/Fs environmental exposure of residents in the survey area, accounting for 67.9% and 81.8% of the PCDD/Fs environmental exposure of children and adults, respectively. And this is consistent with the results of most related surveys (Table 2). The non-carcinogenic health risk of PCDD/Fs environmental exposure for the people living in the

Table 2 Comparison of PCDD/Fs environmental exposure and health risk of people living around a domestic waste incinerator in various countries

Country	Year	Receptor	PCDD/Fs environmental exposure (ng TEQ/(kg·d))				Health risk of PCDD/Fs environmental exposure		References
			Inhalation exposure	Soil/Dust dermal exposure	Soil/Dust Ingestion	Sum	Non carcinogenic risk	Carcinogenic risk	
Belgium	1997	Child	1.15E-05	1.47 E-05	6.81 E-05	9.43 E-05	2.36 E-05	1.41 E-05	Nounew et al. 2001
		Adult	6.51 E-06	7.30 E-06	7.8 7 E-06	2.17 E-05	5.42 E-03	3.25 E-06	
Korea	2005	Child	3.05E-05	1.26E-06	4.06E-06	9.13E-05	7.65E-03	4.56E-06	Lee et al. 2007
		Adult	1.71E-05	1.64E-08	6.42E-09	1.71E-05	4.28E-03	2.56E-06	
Spain	2011–2013	Adult	2.87E-06	3.15E-07	3.15E-07	3.50E-06	8.75E-04	5.25E-07	Rovira et al. 2015
China	2008, Zhejiang	Child	8.60E-05	1.26E-06	4.06E-06	9.13E-05	2.28E-02	1.37E-05	Xu 2009
		Adult	6.53E-05	1.59E-06	1.85E-06	6.87E-05	1.72E-02	1.03E-05	
	2011–2012, Beijing	Child	0.32–6.80E-05	–	–	0.32–6.80E-05	–	0.32–6.80E-06	Hao et al. 2017
		Adult	0.18–3.84E-05	–	–	0.18–3.84E-05	–	0.18–3.84E-06	
	2017, Shanghai	Child	7.91E-05	5.19E-06	3.23E-05	1.17E-04	2.92E-02	1.75E-05	The present study
		Adult	3.91E-05	5.90E-06	2.81E-06	4.79E-05	1.20E-02	7.18E-06	

vicinity of the MSWI in Shanghai was 2.92E-02 for children and 1.20E-02 for adults, which was way below the acceptable level "1" (US EPA 2018). The carcinogenic health risk of PCDD/Fs environmental exposure for the people living in vicinity of the MSWI in Shanghai was 1.75E-05 for children and 7.18E-06 for adults, which was also within the allowable range of EPA (10^{-6} to 10^{-4}) (US EPA 2018).

Compared with the environment exposure and healthy risk value of people living in vicinity of the MSWI in China and abroad, the PCDD/Fs environmental exposure and health risk value of the people living in vicinity of the MSWI in Shanghai in the present study was at the same level as those in Zhejiang Province (Xu 2009), Beijing (Hao et al. 2017), Belgium (Nounew et al. 2001) and Korea (Lee et al. 2007), and were higher than those in Spain (Rovira et al. 2015).

In conclusion, without considering food exposure, inhalation is the main way of PCDD/Fs environmental exposure for residents in the survey area. According to the calculation results of these three exposure routes, it was found that the PCDD/Fs environmental exposure of children and adults in this area is in an order of magnitude with that of domestic and foreign studies. The non-carcinogenic and carcinogenic health risk of PCDD/Fs environmental exposure for the people living in the vicinity of the MSWI in Shanghai was all at the acceptable level. These long-term results provide very important complementary information for PCDD/Fs emission monitoring for the government.

Acknowledgements The financial support by Shanghai Pudong New Area District Science and Technology Development Fund (Contract number: PKJ2015-C04) is greatly acknowledged.

References

Cappelletti N, Astoviza M, Migoya MC, Colombo JC (2016) Airborne PCDD/F profiles in rural and urban areas of Buenos Aires province. Argentina Science of the Total Environment 573(15):1406–1412

Deng YY, Jia LJ, Yin HW (2008) Preliminary study on the level of dioxin-like compounds in soil of Shanghai. J Environ Occupational Med 25(4):353–359

Deng YY, Jia LJ, Li K et al (2011) Levels of PCDD/Fs in Agricultural Soils near Two Municipal Waste Incinerators in Shanghai, China. Bull Environ Contam Toxicol 86(1):65–70

Ding L, Li YM, Wang P et al (2013) Spatial concentration, congener profiles and inhalation risk assessment of PCDD/Fs and PCBs in the atmosphere of Tianjin. China Chinese Science Bulletin 58(9):971–978

Duan XL (2016) Highlights of the Chinese exposure factors handbook(Children). China Environmental Science Press, Beijing, pp 31&170.

Gao L, Zhang Q, Liu L, Li C, Wang Y (2014) Spatial and seasonal distributions of polychlorinated dibenzo-p-dioxins and dibenzofurans and polychlorinated biphenyls around a municipal solid waste incinerator, determined using polyurethane foam passive air samplers. Chemosphere 114:317–326

Hao, Y. , Li, Y. , Wang, T. , Hu, Y. , Sun, H. , & Matsiko, J. , et al. (2017). Distribution, seasonal variation and inhalation risks of polychlorinated dibenzo-p-dioxins and dibenzofurans, polychlorinated biphenyls and polybrominated diphenyl ethers in the atmosphere of beijing, china. Environmental Geochemistry & Health, 1–12.

Heo J, Lee G (2014) Field-measured uptake rates of PCDDs/Fs and dl-PCBs using PUF-disk passive air samplers in Gyeonggi-do, South Korea. Sci Total Environ 491–492:42–50

Lee SJ, Choi SD, Jin GZ, Oh JE, Chang YS, Shin SK (2007) Assessment of pcdd/f risk after implementation of emission reduction at a mswi. Chemosphere 68(5): 0–863

Li HR, Feng HL, Sheng GY et al (2008) The pcdd/f and pbdd/f pollution in the ambient atmosphere of shanghai China. Chemosphere 70(4):576–583

Liu LJ, Han JL, Fu JP, Yin WH, Yang YY (2016) Distribution characteristics and health risk assessment of PCDD/Fs in ambient pm_(10) in guangzhou. J Environment Health 33(5):415–420

Mari M, Schuhmacher M, Feliubadaló J (2008) Air concentrations of PCDD/Fs, PCBs and PCNs using active and passive air samplers. Chemosphere 70(9):1637–1643

Ministry of environmental protection of the people's Republic of China. Notice on Further Strengthening the environmental impact assessment management of biomass power generation project (HF [2008] No. 82), 2008–9–4

Moussaoui Y, Tuduri L, Kerchich Y (2012) Atmospheric concentrations of PCDD/Fs, dl-PCBs and some pesticides in northern Algeria using passive air sampling. Chemosphere 88(3):270–277

Peng JL, Zhang JQ, Lu SY et al (2015) Levels of polychlorinated dibenzo-p-dioxins and dibenzofurans in airborne fine particulate matter and inhalation risk assessment for local residents of shenzhen. Journal of Hygiene Research 44(4):570–575

Rovira J, Vilavert L, Nadal M, Schuhmacher M, Domingo JL (2015) Temporal trends in the levels of metals, PCDD/Fs and PCBs in the vicinity of a municipal solid waste incinerator. Preliminary assessment of human health risks. Waste Manage 43:168–175

Tian YJ, Nie ZQ, Tian SL et al (2015) Passive air sampling for determining the levels of ambient PCDD/Fs and their seasonal and spatial variations and inhalation risk in shanghai China. Environ Sci Pollution Res 22(17):13243–13250

US EPA (2005) Human health risk assessment protocol for hazardous waste combustion facilities. US EPA Press.

US EPA (2009) Office of Solid Waste Emergency Response, Waste and Cleanup Risk Assessment. Risk Assessment Guidance for Superfund (RAGS), Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Interim.

US EPA (2018) Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina Technical Support Document EPA's 2014 National Air Toxics Assessment, 2014 NATA TSD

Van Hall Instituut (1997) VLIER-HUMAAN: a human exposure model embedded in flemish legislation. Risk Assessment in the Federal Government: Managing the Process. Washington D. C.: National Academy Press, 1983.

Vilavert L, Nadal M, Schuhmacher M, Domingo JL (2012) Long-term monitoring of dioxins and furans near a municipal solid waste incinerator: human health risks. Waste Manage Res 30(9):908–916

Vilavert L, Nadal M, Schuhmacher M, Domingo JL (2015) Two decades of environmental surveillance in the vicinity of a waste incinerator: human health risks associated with metals and PCDD/Fs. Arch Environ Contam Toxicol 69(2):241–253

Nouwen J, Cornelis C, Defre R (2001) Health risk assessment of dioxin emissions from municipal waste incinerators:the Neerlandquarter (Wilrijk, Belgium). Chemosphere 43(4–7):909–923

WHO (1998) Executive Summary Report of "Assessment of the health risks of dioxins: re-evaluation of the Tolerable Daily Intake (TDI).

Xu MX (2009) Environmental impact study on PCDD/F emissions from the municipal solid waste incineration plant (Doctoral dissertation, Zhejiang University)

Ying YY (2010) Preliminary study on levels of PCDD/Fs in typical areas atmosphere and soils of Shanghai (Doctoral dissertation, East China University of Science and Technology).

Yoonki M, Jongwon H, Meehye L (2014) Determination of toxic congeners of 17 PCDDs/PCDFs and 12 dl-PCBs using polyurethane foam passive air samplers in ten cities around Seoul. Sci Total Environ 491–492:17–27

Zhang LH, Wang E (2013) The ambient air dioxin levels and exposure risk in different functional zones of shenyang. Environ Pollution Control 35(2):82–84

Zhao XG, Duan XL (2014) Highlights of the Chinese exposure factors handbook(Adults). China Environmental Science Press, Beijing, pp 15&55.