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Evaluation of Incremental Population and Individual Carcinogenic Risks of PCDD/Fs from Steel and Iron Industry in Taiwan by a Site-specific Health Risk Assessment Method

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ABSTRACT

Sinter plants and electric arc furnaces are the most important emission sources of PCDD/Fs. In order to understand the contribution and distribution of PCDD/Fs risk from steel and iron industry, the incremental health risk assessment of PCDD/Fs has been accomplished for the all sinter plants and electric arc furnaces in Taiwan. The study combined the multimedia, multiple pathway exposure modeling and site-specific exposure scenario to evaluate dioxin risks contributed from the 22 major companies of steel and iron industry including 4 sinter plants and 21 electric arc furnaces. The incremental cancer risks to the resident living in the 25 km × 25 km impact range of the above emission sources ranged from 3.10E-10 to 5.73E-06 under the site-specific exposure scenario. Among these 22 emission sources, the stacks with higher exit flows and worse operational characteristics would contribute higher inhalation risks; moreover, the sources located at the major agricultural districts in central Taiwan contributed higher ingestion risks. In conclusion, four sinter plants accounted for more than 24% of total PCDD/Fs exit rates in steel and iron industry, and the incremental risks of these were lower than those of other electric arc furnaces investigated in this study. Furthermore, comparing background cancer mortality for incremental PCDD/Fs risks of steel and iron industry, the total PCDD/Fs population risks contributed from steel and iron industry are low but still cannot be ignored.

Keywords: Sinter plant; Electric arc furnace; Steel and iron industry; PCDD/Fs risk assessment; Population risk.

INTRODUCTION

Polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzo furans (PCDFs), commonly known as dioxins, are toxic chemicals with numerous negative impacts including effects on the immune, nervous, endocrine, and reproductive systems of human and their carcinogenic potential (USEPA, 1994). They are considered as persistent organic pollutants (POPs) due to their ability to resist degradation and accumulate in ecosystems and human tissues through the food chain, thus becoming serious environmental problems. Within the present 21 POPs in the list of the Stockholm Convention, PCDD/Fs were the only one hard to be well-controlled through prohibiting from production and restricting the usage directly. PCDD/Fs are not products for specific purpose but unintentionally formed and released from anthropogenic activities including combustion processes and other thermal processes involving organic matter and chlorine. Reducing emissions is therefore the only way to decrease the damage of PCDD/Fs (Cleverly *et al*., 1998). At first, most studies focused on the municipal solid waste incinerators. With the installation of advanced pollution control systems and enactment of stricter regulations on incinerators, emission rates of PCDD/Fs from incinerators decreased gradually. Many attentions are currently directed towards other emissions sources. In fact, it was recognized that the stacks in industry with combustion procedure were the predominant sources of dioxin release based on investigations of the emission inventory.

The European Commission has indicated electric arc furnaces as the major sources with increasing emissions to the air over the incinerators in Europe (Quass *et al*., 1997). A previous study conducted in highly industrialized areas of Italy found that the reduction levels of PCDD/Fs from other steel production sources emissions were nearly zero, but that of the incinerators were 80–98% (Caserini *et al*., 2002), suggesting that the major interest and concern regarding PCDD/Fs emissions has been focused at metallurgical industry sources. The tendency is similar in Taiwan as PCDD/Fs emissions from the other sources such as stacks of metallurgical industry (Wang *et al*., 2003; Lee

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et al., 2004; Kao *et al*., 2006; Li *et al*., 2008; Wang *et al*., 2008; Hu *et al*., 2009; Lin *et al*., 2010; Wang *et al*., 2010b), coal-fired power plants (Lin *et al*., 2007) and vehicles (Chuang *et al*., 2010a; Chuang *et al*., 2010b) are still higher even those from waste combustion plants, PCDD/Fs emissions from the other sources, such as stacks of metallurgical industry (Wang *et al*., 2003; Wang *et al*., 2008; Wang *et al*., 2010b; Lee *et al*., 2004; Li *et al*., 2008; Chiu *et al*., 2011), coal-fired power plants (Lin *et al*., 2007) and vehicles (Chuang *et al*., 2010a; Chuang *et al*., 2010b), were still higher and became more important. Sinter plants (45 g I-TEQ/yr) are accounted for 40–44% of total PCDD/Fs emissions in Taiwan (Wang *et al*., 2003), and the total PCDD/Fs emissions from electric arc furnaces (20 g I-TEQ/yr) are 27 and 53 times higher than those from municipal solid waste incinerators and medical waste incinerators, respectively (Lee *et al*., 2005). A previous study regarding PCDD/Fs risks in an highly industrial city showed that the sinter plant and the electric arc furnace represent the top two sources due to higher concentration and larger exit flows compared with other stacks (Kao *et al*., 2005). A later report focused on the same region also revealed that the metallurgical industries contributed 98.1% of the total annual emissions in 2009 (remaining 1.9% from waste incinerators as shown by Wang *et al*. (2009))

Quantitative risk assessment that provides prediction of impacts on health by various emission sources and exposure scenario of receptors in a systematic way has been suggested as the best tool to evaluate health impact. Moreover, it is capable of distinguishing the incremental health impact of existing emission sources from background risk as well as predicting the possible influence of new factories. Accordingly, human health risk assessment has been recognized as a tool for addressing health consequences by contact with chemical hazard properties, environmental conditions and exposure scenario, which might be the basis for developing risk management measures (Crawford-Brown, 1999; Choosong *et al*., 2010; Yeh *et al*., 2011).

In past years, the PCDD/Fs carcinogenic and non-carcinogenic health risks associated with pollution sources have been assessed especially the issues involving municipal waste incinerators (Meneses *et al*., 2004; Cangialosi *et al*., 2008). In addition, numerous investigations have indicating the human carcinogenic risk of dioxins result from dietary exposure through food stuffs (Hu *et al*., 2003; Wang *et al*., 2009) or samples of biological surveillances (Chen *et al*., 2004; Hsu *et al*., 2009; Lee *et al*., 2009; Lin *et al*., 2010). However, the past risk assessments focused primarily on the effects of single source or exposure route with only few research considering the interactive effects of multiple sources (Ma *et al*., 2002; Kao *et al*., 2005).

Sinter plant and crude steel produced by electric arc furnace are not only the upstream parts in production line of steel and iron industry but also the most predominant emission sources of PCDD/Fs. Taiwan is ranking 13th supplier of crude steel worldwide, with four sinter plants and thirty-one electric arc furnaces where 20 million tons crude steel (1.7% of global production) are produced annually. Taiwan is an island nation with 23 million people, more than 90% population living in the highly urbanized and industrialized western plain, and these regions are also the main parts of various economic activities. In spite of delimiting the specific areas as ”Industrial Park” on land use, it is inevitable that there are some cultivated land and animal husbandry right close to the industrial park and enhancing serious environment problems. In the current study the characteristics of all sinter plants and electric arc furnaces were directly assessed from national emission data system, and the exit conditions of PCDD/Fs were estimated by analyzing samples of local stack flue gases. Also, assessment of the site-specific health risk from local dioxin emissions such as stacks of steel and iron industry has been made. The main goals of this study are as follows:

- to understand and to compare the contribution and distribution of the human health risk of PCDD/Fs from steel and iron industry emission.
- to identify differences of the impact degree on location of emission sources.
- to evaluate the overall health impact of steel and iron industry.

MATERIALS AND METHODS

Steel and Iron Industry in Taiwan

Crude steel manufactured by sinter plants and electric arc furnaces are the upstream product in production line of steel and iron industries. According to the data from the Economic Statistics Database of Taiwan Ministry of Economic Affairs, the production amount of crude steel whose leading product is steel millet and steel ingot was increasing from 12.62 million to 20.78 million tons during the past ten years (1996 to 2007) in Taiwan. The percentage of the annual amount of crude steel in Taiwan produced from sinter plants and electric arc furnaces is about 53% and 47%, respectively. However, virtually all companies (N = 21) employ the electric arc furnaces as refining steel with a sole exception (N = 1) where steel-making relies on sintering technique. Companies adopting electric arc furnaces can be classified into three types by their products: carbon steel, stainless steel and cast steel. The locations of these crude steel-producing 22 companies were shown in Fig. 1, and all the emission sources are located in seven different districts of western Taiwan.

Characterization of Emission Sources

From 2007 dioxin inventory of Taiwan Environmental Protection Agency, electric arc furnaces and sinter plants are still attributable to more than 50% of the total PCDD/Fs emissions in Taiwan. To characterize the amounts of PCDD/Fs emissions from the electric arc furnaces and sinter plants of steel and iron industry in Taiwan, it is necessary to identify the individual emission conditions of each fixed pollution source (i.e. the stack) including operational parameters and characteristics of fuel gas. The operational parameters of these 35 stacks belonging to 22 companies were collected from Taiwan Emission Data System (TEDS) of the Taiwan Environmental Protection Agency.

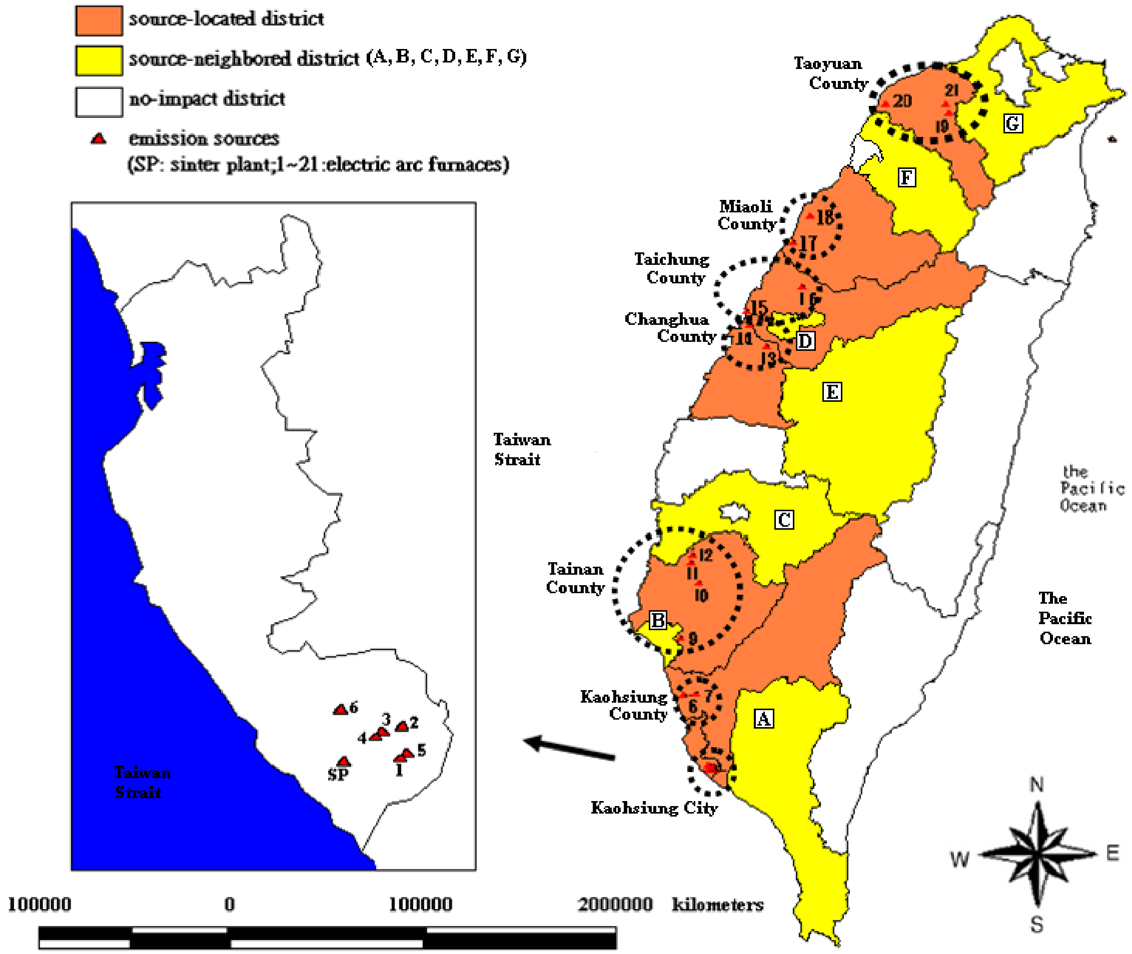

Fig. 1. The locations of 22 companies of steel and iron industry in Taiwan.

The emission concentrations of PCDD/Fs in fuel gas are the sum of 17 dioxin congeners. Among these 35 stacks, no actual values sampled and analyzed from the fuel gas are available except for four sinter plants and five electric arc furnaces located within Kaohsiung city in previous study during 2004 (Kao *et al*., 2005). Table 1 was the average ratio of the 17 dioxin congeners in fuel gas resulted from sinter plant and electric arc furnace in previous investigations and was used to assume the emission characteristics of the other stacks without monitoring data. This assumption is established on "chemical fingerprints" of 17 congeners of PCDD/Fs in stack gas. In sinter plant, 21 samples from four stacks, 1,2,3,4,6,7,8-HpCDF was the most abundant congener, followed by 1,2,3,4,7,8-HxCDF and OCDD. However, in electric arc furnace, the results from more than 30 samples of five electric arc furnaces, 2,3,4,7,8-PeCDF, 2,3,7,8-TeCD, 1,2,3,7,8-PeCDF were the most plentiful congener. As to the emission concentrations of these stacks, the present PCDD/Fs control regulations of sinter plant and electric arc furnace were used to figure out the exit rates of every emission source. The national regulations for electric arc furnaces and sinter plants are 0.5 ng-TEQ/Nm^3 and 1.0 ng-TEQ/Nm^3, respectively. Additionally, there is regional stricter regulation (0.5 ng-TEQ/Nm^3) on sinter plant in Kaohsiung City.

The operation parameters, location and characteristics of 1 sinter plant (SP) and 21 electric arc furnaces (EAF) were shown in Table 2. Except for the exit flows were the sum of the individual stack gas, other parameters, such as height and exit temperature were the average of stack of the emission sources. The exit rates were the sum of exit rates of individual dioxin congeners, which is obtained from the emission concentrations and gas characteristics of each emission source showed in Table 1.

Multimedia and Multiple-pathway Exposure Assessment Modeling

Multimedia and multiple pathway exposure models are aimed to estimate the concentrations of environmental media in impact areas and the exposure dose of the residents associated with all the identified emitting dioxins sources. The air deposition fluxes and ambient concentration of dioxins of these 22 emission sources in Taiwan were estimated by using an advanced plume air dispersion model, AREMOD, formally proposed by USEPA as a replacement for the ISCST3 (Industrial Source Complex-Short Term, Version 3) model. Results of the air dispersion model depend on three basic data sets: (1) meteorological conditions (wind speed, flow vector, ambient air temperature and so on); (2) individual stacks characteristics of emission source (Table 3); and (3) cartographic data (length, latitude, and height). The potential impact range of PCDD/Fs emissions was assumed as the area of 25 km × 25 km surrounding each emission source. Land territory, river and ocean were treated as the possible impact environmental media. The AREMOD model estimated the concentration

Table 1. The ratio of the 17 dioxin congeners in different type emission sources in steel and iron industry.

Type of emission sources	Sinter plants	Electric Arc Furnace		
		Stainless steel	Carbon Steel	Ave (Cast Steel)
2,3,7,8-TeCDD	0.00%	0.79%	0.67%	0.72%
1,2,3,7,8-PeCDD	0.25%	1.85%	1.57%	1.64%
1,2,3,4,7,8-HxCDD	1.61%	0.86%	0.82%	0.82%
1,2,3,6,7,8-HxCDD	0.22%	2.31%	2.11%	2.04%
1,2,3,7,8,9-HxCDD	0.38%	1.24%	1.41%	1.34%
1.2.3.4.6.7.8-HpCDD	2.70%	4.23%	7.35%	5.99%
OCDD	16.46%	3.02%	11.03%	7.81%
2,3,7,8-TeCDF	0.03%	15.43%	13.74%	15.69%
1,2,3,7,8-PeCDF	8.12%	11.37%	8.04%	9.53%
2,3,4,7,8-PeCDF	0.31%	16.37%	12.98%	13.36%
1,2,3,4,7,8-HxCDF	23.26%	8.78%	5.39%	6.73%
1,2,3,6,7,8-HxCDF	3.01%	8.39%	5.67%	6.82%
1,2,3,7,8,9-HxCDF	2.69%	0.59%	0.56%	0.74%
2,3,4,6,7,8-HxCDF	0.28%	7.23%	7.22%	7.21%
1,2,3,4,6,7,8-HpCDF	27.93%	9.67%	9.43%	9.64%
1,2,3,4,7,8,9-HpCDF	4.73%	1.81%	2.21%	2.08%
OCDF	8.02%	6.05%	9.80%	7.81%
	100.00%	100.00%	100.00%	100.00%

Table 2. The operational parameters and the emission characteristics of the 22 sources of steel and iron industry in Taiwan.

Region	Southern Taiwan									
Site City	Kaohsiung City							Kaohsiung County		Tainan County
Sources	SP	EAF1	EAF2	EAF3	EAF4	EAF5	EAF6	EAF7	EAF8	EAF9
Number of Stacks	4	3	2	2	1	1	1	2	1	1
Steel product types*	A,B	A	B	B	B	B	C	A	C	A
Total Exit Flow (dscm/min)	51009.1	8686.3	14671.9	11939.5	9600.0	9531.6	83.4	20778.2	607.9	2576.0
Height (m)	74.8	27.7	29.3	20.7	30.0	23.3	7.0	25.0	9.5	26.5
Exit temperature (°C)	177.3	78.0	78.0	76.0	43.0	84.0	24.0	83.5	39.0	69.0
Exit Rates (g-TEQ/s)	4.25E-07	7.24E-08	1.22E-07	9.95E-08	8.00E-08	7.94E-08	6.95E-10	1.73E-07	7.00E-09	2.15E-08

*Type of Steel product: A- Stainless steel; B- Carbon Steel; C- Cast Steel.

Table 2. *(continued).*

Region	Southern Taiwan			Middle Taiwan						Northern Taiwan		
Site City	Tainan County			Changhua County		Taichung County		Miaoli County		Taoyuan County		
Sources	EAF9	EAF9	EAF9	EAF13	EAF14	EAF15	EAF16	EAF17	EAF18	EAF19	EAF20	EAF21
Number of Stacks	1	1	1	1	1	1	3	3	1	2	1	1
Steel product types*	A	A	A	C	B	B	B	B	B	B	B	B
Total Exit Flow (dscm/min)	2576.0	2576.0	2576.0	839.6	8410.0	25547.2	9543.9	8905.7	6571.6	5723.0	15.0	7.7
Height (m)	26.5	26.5	26.5	9.0	19.8	50.0	25.6	35.0	21.2	21.3	16.0	15.0
Exit temperature (°C)	69.0	69.0	69.0	29.0	79.0	66.0	59.0	79.7	94.0	121.0	76.0	52.0
Exit Rates (g-TEQ/s)	2.15E-08	2.15E-08	2.15E-08	5.07E-09	7.01E-08	2.13E-07	7.95E-08	7.42E-08	5.48E-08	4.77E-08	1.25E-10	6.42E-11

Table 3. The site-specific transfer factors of 12 agricultural products in the districts of no-sources, source-located and source-neighbored impacted by steel and iron industry.

Type of Agricultiral product	Source-located Distinct							Ssource-neighbered Distinct							Other District
	Kaohsiung City	Kaohsiung County	Tainan County	Changhua County	Taichung County	Miaoli County	Taoyuan County	Pingtung County	Tainan City	Chiayi County	Taichung City	Nantou County	Hsinchu County	Taipei County	with no-sources
Rice	4.69E-04	2.27E-02	9.03E-02	1.88E-01	1.02E-01	4.05E-02	3.49E-02	2.93E-02	2.00E-03	1.21E-01	7.94E-03	1.87E-02	2.28E-02	1.01E-03	3.19E-01
Aboveground vegetable	3.04E-04	4.83E-02	4.37E-02	1.66E-01	3.68E-02	1.43E-02	2.51E-02	7.92E-02	9.61E-03	5.97E-02	6.94E-04	5.27E-02	1.44E-02	2.11E-02	4.28E-01
Belowground vegetable	6.27E-05	3.32E-02	1.23E-01	1.19E-01	5.12E-02	2.21E-02	9.84E-03	5.73E-02	7.30E-03	8.44E-02	5.22E-03	7.83E-02	1.00E-02	2.67E-02	3.72E-01
Skin-Protected vegetable	9.36E-04	1.02E-01	1.63E-01	5.57E-02	9.18E-02	3.71E-02	5.38E-03	1.60E-01	2.96E-03	8.06E-02	1.76E-03	8.22E-02	1.87E-02	5.58E-03	1.92E-01
Poultry	4.26E-05	6.66E-02	1.33E-01	2.12E-01	3.27E-02	2.58E-02	3.02E-02	1.73E-01	5.25E-03	8.41E-02	1.99E-04	4.36E-02	2.42E-02	2.17E-03	1.68E-01
Beef and Sheep	2.88E-03	1.09E-01	1.73E-01	1.50E-01	3.02E-02	3.06E-02	2.83E-02	1.51E-01	5.52E-03	6.54E-02	2.78E-03	2.07E-02	9.32E-03	9.80E-03	2.13E-01
Pork	1.55E-04	6.75E-02	1.17E-01	1.31E-01	2.66E-02	1.42E-02	2.89E-02	2.41E-01	1.72E-03	6.02E-02	1.92E-03	1.81E-02	1.39E-02	1.91E-02	2.59E-01
Milk	5.78E-04	7.00E-02	1.95E-01	1.93E-01	2.11E-02	2.52E-02	4.91E-02	1.66E-01	6.60E-03	6.88E-02	1.44E-03	1.27E-02	1.90E-02	1.39E-02	1.57E-01
Egg	-	9.06E-02	1.05E-01	4.36E-01	1.82E-02	1.13E-02	8.23E-03	2.07E-01	2.64E-04	7.53E-02	2.27E-04	2.22E-02	3.31E-03	1.33E-05	2.21E-02
Marine Fish	1.87E-03	2.07E-02	3.29E-02	1.47E-02	1.80E-04	1.30E-03	3.09E-04	1.53E-02	7.13E-03	2.83E-02	-	-	7.72E-04	7.21E-03	6.83E-02
Freshwater Fish	-	1.63E-01	1.83E-01	9.51E-02	8.02E-04	8.06E-04	4.10E-02	1.44E-01	6.10E-03	1.85E-01	1.84E-05	2.69E-03	1.12E-02	1.04E-03	1.67E-01
Shellfish	4.54E-03	1.66E-02	1.27E-01	1.54E-01	3.86E-04	2.82E-04	6.44E-04	1.23E-01	3.34E-02	1.63E-01	-	2.74E-05	3.25E-04	1.94E-02	3.57E-01
Total	1.18E-02	8.10E-01	1.49E+00	1.91E+00	4.12E-01	2.24E-01	2.62E-01	1.55E+00	8.79E-02	1.08E+00	2.22E-02	3.52E-01	1.48E-01	1.27E-01	2.72E+00

of dioxin in both vapor and particle phases, and it was performed on a grid domain with resolution of 200 meters. The dispersion of 17 dioxin congeners in the vapor and particle phase was simulated separately, and vapor-particle partition was incorporated to obtain average air concentration and deposition. Air concentration and deposition in each sector was modeled followed by estimation of concentrations in the other environmental media.

There are two connected parts in the multimedia exposure assessment process: (1) multimedia transport and transformation modeling are used to calculate the temporal and spatial distribution in various environmental media as a result of air concentration and deposition of dioxins, (2) the other involves multiple-pathway exposure model that predicts the exposure dose a resident would receive through various pathways of contact. Risks of PCDD/Fs caused by stack emissions were considered from both direct (e.g., inhalation) and indirect (e.g., ingesting) exposures because the bioaccumulation tends to concentrate dioxins as they migrate through the environment (Fradkin *et al*., 1998; USEPA., 1998). The following direct and indirect pathways were considered: (1) Inhalation of airborne gases and particles; (2) Drinking water; (3) Incidental ingestion of contaminated soil; (4) Ingestion of food produced from the impact area near the emission sources. Except using fish concentration to figure out environmental concentration by bioaccumulation factor and biota-sediment accumulation factor, the concentrations of food items about animal tissues were calculated by biotransfer factors (Ba) and the animal intake of dioxin through the ingesting of daily diet and soil. Rsults of the multiple-pathway exposure model were the estimated averaged daily intakes (ADIs) of 17 dioxin congeners. Eq. (1) below was used to calculate the average daily intake of dioxins where ADIij (mg-TEQ/kg/day) means the exposure from an environmental medium i (such as air and soil) and an exposure medium j (such as milk and meats)

$$ADI_{ij} = \sum_{k} (C_{ijk} \times TEF_k) \times \frac{IU_j}{BW} \times \frac{EF \times ED}{AT} \quad (1)$$

where Cijk is the concentration of the dioxin congener k in the exposure medium j from environmental medium i; TEFk is the international toxicity equivalency factor (I-TEF) of congener k based on its relative toxicity to 2,3,7,8-TCDD (NATO/CCMS, 1988); IU_j is the site-specific contact rate of exposure medium j; EF and ED are the exposure frequency and exposure duration, respectively; AT is the average lifetime; and BW is the body weights of risk receptors.

The Assumption of Site-specific Exposure Scenario

For simulating the exposure processes as close to the actual situations as possible, this study not only used site-specific environmental and exposure parameters but also assumed an exposure scenario matching the real lifestyle in Taiwan. From previous studies, the main exposure pathway of the dioxin risk were dietary intake, normally accounting for more than 90% of the total risk (Ma 2002; Schuhmacher *et al*., 2001)., suggesting the importance of the assumption of intake exposure. In Taiwan, land use for industry and agriculture was not divided clearly so that the industrial park is generally surrounded by cultivated land producing agricultural products. In addition, the food supply chain and distribution system were complicated due to the supply-consumption network of various food items from all cities and counties. For food ingestion, the site specific fraction of product locally is also taken into account on constituting the site-specific exposure scenario (Kao *et al*., 2005; Cangialosi *et al*., 2008). In the study, we separated the impact land around each emission source as "located district" and "neighbored district". The site-specific transfer factors were the local parameters to determine the possibility of food items with dioxin risk. The basis of these parameters is the statistics data from 2002 to 2009 obtained over several years and presented in Food Supply and Utilization Yearbook of Taiwan Council of Agriculture, which provided information about total annual yields of agricultural production throughout the city and country. The site-specific transfer factor was calculated as follows:

$$\text{site-specific transfer factor} = \frac{\text{local yields}}{\text{national total yields}} \quad (2)$$

From the Eq. (2), we obtained the site-specific transfer factors of various food groups in different districts (Table 3). These values represent the fraction of 12 food items produced from the impact region of source -located or source -neighbored. From the sum of the individual site-specific transfer factor of different food groups, it found that Tainan, Pingtung, Chiayi and Changhua County are the regions with the larger agricultural yields. Based on site-specific transfer factors, we obtained the probability of ingesting contaminated food from impact districts. Furthermore, when calculating the risks of ingesting food items, areas of districts in the impact range of every emission sources (we called" the impact ratio" in the article) were taken into account to estimate the ratio of polluted agricultural product in target district because the boundary of impact range differed from the land division in administration.

Eq. (3) was used to calculate the impact ratio (IR), where IR_{mn} (unitless) means the proportion of land areas of district m (such as Kaohsiung City) in the impact range of emission sources n (such as SP and EAF) and the total land areas of district. The impact ratio (IR_{mn}) can be written as

$$IR_{mn} = \frac{\textit{Land areas} \text{ of distirct m in the i}\textit{mpact} \text{ range of sources n}}{\text{Total areas of district m}} \quad (3)$$

The impact ratios were also considered when calculating the regional inhalation risk of every impact district and showed in Table 4. The values of impact ratio showed that source-located district was not the area with largest impact. To the emission sources located in the boundary of two districts, the impact ratios of source-neighbered district would be even higher than the located district of emission sources. Besides, the area size of these districts would also affect the impact ratio.

The multi-pathway intake factors were mainly the intake rate of various exposure routes. To calculate the incremental ingestion risk of each emission source, it is assumed that incidental risks of soil are considered with cultivated land

Table 4. The impact ratios of source-located districts and source-neighbored district with regard to 22emission sources.

Region	Source-located Distinct							Source-neighbered Distinct						
	Kaohsiung City	Kaohsiung County	Tainan County	Changhua County	Taichung County	Miaoli County	Taoyuan County	A	B	C	D	E	F	G
SP	67.86%	5.33%	-	-	-	-	-	3.72%	-	-	-	-	-	-
EAF1	65.84%	5.18%	-	-	-	-	-	5.29%	-	-	-	-	-	-
EAF2	71.69%	5.63%	-	-	-	-	-	5.61%	-	-	-	-	-	-
EAF3	69.87%	5.48%	-	-	-	-	-	4.85%	-	-	-	-	-	-
EAF4	70.81%	5.56%	-	-	-	-	-	5.05%	-	-	-	-	-	-
EAF5	65.49%	5.18%	-	-	-	-	-	6.60%	-	-	-	-	-	-
EAF6	67.86%	5.33%	-	-	-	-	-	3.72%	-	-	-	-	-	-
EAF7	13.71%	15.73%	3.86%	-	-	-	-	-	1.99%	-	-	-	-	-
EAF8	15.83%	11.84%	2.87%	-	-	-	-	-	1.55%	-	-	-	-	-
EAF9	-	0.10%	21.44%	-	-	-	-	-	82.85%	-	-	-	-	-
EAF10	-	-	29.75%	-	-	-	-	-	-	1.38%	-	-	-	-
EAF11	-	-	21.72%	-	-	-	-	-	-	9.72%	-	-	-	-
EAF12	-	-	17.13%	-	-	-	-	-	-	12.52%	-	-	-	-
EAF13	-	-	-	33.25%	7.06%	-	-	-	-	-	60.67%	0.45%	-	-
EAF14	-	-	-	17.26%	9.94%	-	-	-	-	-	24.70%	-	-	-
EAF15	-	-	-	6.98%	11.10%	-	-	-	-	-	17.21%	-	-	-
EAF16	-	-	-	-	21.70%	8.96%	-	-	-	-	13.72%	-	-	-
EAF17	-	-	-	-	15.56%	3.61%	-	-	-	-	-	-	-	-
EAF18	-	-	-	-	-	21.79%	-	-	-	-	-	-	-	-
EAF19	-	-	-	-	-	-	38.94%	-	-	-	-	-	0.02%	7.61%
EAF20	-	-	-	-	-	-	20.96%	-	-	-	-	-	7.73%	-
EAF21	-	-	-	-	-	-	40.03%	-	-	-	-	-	-	6.91%

from the impact region. Except for the ingestion rate of soil (50 mg/day suggested by the USEPA was adopted), the multi-pathway intake factors were determined from the statistical results of the Nutrition and Health Survey in Taiwan, including the inhalation rate (1 m^3 per hour for adult), intake of drinking water (1.4 Liter per day for adult and all from tap-water) and dietary ingestion rates of various food items. Three food groups are classified by the intake rates of food items as follows: territory animals (beef and sheep, pork, chicken, eggs and dairy), aquatic animals (freshwater fish, marine fish and shellfish) and vegetables (aboveground, root and skin-protected).

Except for the daily dietary ingestion rate, the degree of food self-sufficiency (i.e. the ratio of the domestic food supply over the total food demand) in Taiwan for the various food items was also considered for the site-specific exposure scenario. From information above we obtained the exposure scenario of site-specific dietary intake of individual sources in specific-regions. Table 5 presented the daily intake rates and degree of food self-sufficiency using the site-specific exposure scenario on ingestion of food items, the product value of site-specific transfer factor and the two items obtained the site-specific contact rate of ingestion food.

Risk Characterization

The carcinogenic risk of PCDD/Fs was calculated by multiplying the estimated dose by the cancer potency factor for dioxins. The carcinogenic potency factor used in the model was 150,000 1/(mg/kg/day) (NATO/CCMS, 1988). According to the comment of USEPA, the risk of carcinogenic chemicals falls below 10^{-6} (i.e., one occurrence over 1 million people) may be neglected (USEPA, 1990). An individual risk from 22 emission sources of steel and iron industry was calculated by accumulating the carcinogenic risk of the PCDD/Fs to each exposure pathway (Sedman *et al*., 1994). Besides, the total risks contributed from steel and iron industry of the residents in different regions were also evaluated.

In the study, we not only calculated the risk of direct exposures and indirect exposures pathway contributed from 22 emission sources but also considered the local risks and transferred risks of all the districts in Taiwan. The transferred risk was defined as the risk of ingesting food items from the other polluted areas. The exposure scenario was established on the following assumptions: (1) risk from inhalation and drinking water were not transferred; (2) the residents' daily intake of food produced from the impacted districts might be contaminated through environmental transport and transformation following the considered emissions, while the food from other non-impacted region contained no dioxin; (3) agricultural products in source-impacted areas were stable and could meet all residents' consumption needs; (4) the probability of getting contaminated food from the impacted districts is the same regardless of whether the subject was living in the study area. Thus, the total PCDD/Fs risks of the resident in each district were calculated as Eq. (4):

$$\begin{aligned} &Total\ Risk \\ &= Local\ Risk + Neighbor\ Risk + Tansfer\ Risk \\ &= \left[Inhaltion\ Risk + Drinkingwater\ Risk\right. \\ &\left.+ Ingestion\ Risk\right](by\ local\ sources) + \left[Inhaltion\ Risk\right. \\ &\left.+ Ingestion\ Risk\right](by\ sourcese\ in\ neighborhood\ ) \\ &+ Ingestion\ Risk(transfer\ food) \end{aligned} \qquad (4)$$

The predicted carcinogenic risk is an estimated value of potential risk associated with the assumption of exposure scenarios. Population risk for PCDD/Fs was obtained as the sum of products between the total risk and population living in the districts within impact range of emission sources and other no-impact region in steel an iron industry. It indicate the number of expected additional cancer occurrences of population from PCDD/Fs emissions in steel and iron industry in the study. Finally, this value was compared with background levels recorded by local Sanitary Agencies to perform the health impact in steel and iron industry.

Table 5. The daily intake rates and Degree of food self-sufficiency used to assume the site-specific exposure scenario.

Food groups	Daily dietary ingestion rate (gDW/day)	Degree of food self-sufficiency (unitless)
Rice	248.60	0.1757
Aboveground vegetable	485.59	0.9586
Belowground vegetable	107.52	0.8347
Skin-Protected vegetable	197.40	0.8416
Poultry	51.18	0.8704
Beef and Sheep	5.49	0.1711
Pork	107.20	0.9058
Milk	57.18	0.9612
Egg	30.49	0.9977
Marine Fish	27.74	0.6577
Freshwater Fish	24.17	0.6577
Shellfish	33.60	0.4936

RESULTS AND DISCUSSION

Comparison of Emission Rates

Table 2 shows the average PCDD/Fs exit rates estimated by the control levels on regulations of stack gas and the patterns of different type of emission sources. The exit rates range from 6.42E-11 to 4.25E-07 for these twenty-two emission sources in steel and iron industry once the unit of grams TEQ per second is considered. The source possessing the highest exit rates was the sinter plant (SP), while the lowest one was the electric arc furnace 21(EAF21). Since the limitation of obtaining actual fuel gas, the exit rate of these sources is proportional to the exit flow but didn't reflect the real PCDD/Fs emission.

The sum of exit rates from 31 stacks from 21 electric arc furnaces was 1.37E-06 g-TEQ/s, comprising of more than 76% of total exit rates (1.79E-06 g-TEQ/s) in steel and iron industry. Fig. 2 showed the exit rates contribution of four different sources types in steel and iron industry with 1.03E-06 g-TEQ/s from carbon-steel electric arc furnaces, which

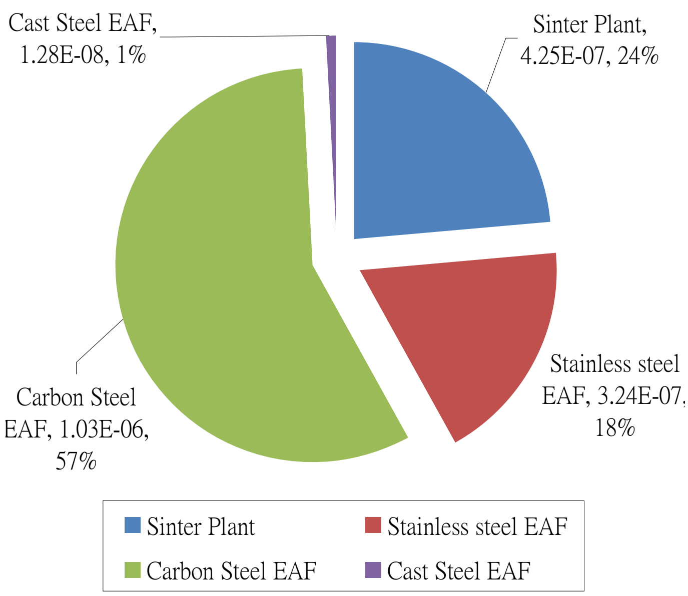

Fig. 2. Distributions of Emission Rates of 4 Different Types of Sources that Classified by the Techniques of Steel-refining and the Types of Steel Product.

is higher than other types of sources and responsible for more than 57% of total exit rates in steel and iron industry. The exit rates contribution of the sinter plant, stainless steel electric arc furnaces and cast steel electric arc furnaces were 23.7%, 18.1% and 0.71%, respectively.

All these 22 emission sources in steel and iron industry were located at particular district zone in coastal plain of western Taiwan, resulting in a total of seven districts with emission sources (sinter plant or electric arc furnace) of steel and iron industry among 25 districts in Taiwan. The contributions of the PCDD/Fs exit rates from seven districts ranged from 4.79E-08 g-TEQ/s (Taoyuan County) to 8.79E-07 g-TEQ/s (Kaohsiung City).

Comparisons of the PCDD/Fs Risks from 22 Emission Sources

Table 6 shows the estimated dioxin risks for the 22 emission sources in steel and iron industry through four exposure pathways under the site-specific exposure scenario. The incremental PCDD/Fs health risk of emission sources ranged from 3.10E-10 (EAF20) to 5.73E-06 (EAF14). Generally speaking, the safe level of carcinogenic risk ranges from 1E-04 to 1E-06, and the health risk less than 1E-06 would be regarded as acceptable. Among the 22 emission sources, except for four electric arc furnaces (EAF13, EAF14, EAF15, EAF16), the estimated risks of other 18 emission sources were less than 1E-06. However, the health risk assessment results are quite different from the estimations of emission rates. Among these 4 high-risk emission sources, there is only electric arc furnaces 15 (EAF15) with the higher emission rates (2.13E-07 g-TEQ/s, about 11.88% of total emission rates), compared to other emission sources. EAF13, EAF14, EAF16 have higher cancer risks but lower PCDD/Fs exits. The exit rate of electric arc furnaces 13 (EAF13) was even less than 1%.

The sinter plant (SP) in Kaohsiung City is the emission source with highest PCDD/Fs exit rates, however, the estimated dioxin risks to the resident living in impact area are lower than other emission sources with smaller exit rates. It might be due to two possible reasons: (1) air dispersion of PCDD/Fs is affected by the operational parameters; and (2) the difference of the land use among emission sources. The results of inhalation risks revealed the influence of emission conditions of stack by air dispersion. Inhalation risks of these 22 emission sources ranged from 1.55E-11 (EAF20, EAF21) to 4.09E-08 (EAF3). Because of the promoting conditions of air dispersion such as higher temperature of exit gas and taller stacks, most PCDD/Fs emitted from stacks were diluted so that the inhalation risks contributed from sinter plant is lower than other 13 electric arc furnaces (EAF1, EAF2, EAF3, EAF4, EAF5, EAF7, EAF10, EAF12, EAF14, EAF15, EAF16, EAF17, and EAF18).

In the study, we attempted to formulate the incremental contribution of PCDD/Fs risks from emission sources in impact area and assumed site-specific exposure scenarios, leading us to effect of these 22 emission sources represented by site-specific health risks. For the emission sources located at the important agricultural districts, risks of ingesting food would be likely much higher. Considering the impact ratio, the ingestion risks of all food items attributed from these sources ranged from 2.95E-10 (EAF20) to 5.71E-06 (EAF14). There are four emission sources located in Changhua County and Taichung County of central Taiwan (EAF13, EAF14, EAF15, and EAF16) with ingestion risks higher than 1E-06, respectively. We also found that these two districts are very important agricultural region (Table 4). More than 10% of terrestrial animals, aquatic animals or vegetables nation-wide are produced form Changhua County Thus, the ingestion risk of food items from EAF13, EAF14, EAF15 and EAF16 are all much higher than that contributed from the other emission sources.

Table 6. The estimated dioxin risks for the 22 emission sources of steel and iron industry through four exposure pathways under the site-specific exposure scenario.

Exposure Route		Soil	Food	Drinking water	Inhalatiom	Total Risk
1	SP	2.92E-12	7.62E-07	4.13E-09	1.03E-08	7.77E-07
2	EAF1	4.46E-12	5.76E-07	7.10E-09	2.64E-08	6.10E-07
3	EAF2	5.25E-12	5.11E-07	6.12E-10	2.15E-08	5.33E-07
4	EAF3	6.62E-12	5.85E-07	7.89E-10	4.09E-08	6.26E-07
5	EAF4	3.28E-12	3.16E-07	8.75E-10	2.08E-08	3.38E-07
6	EAF5	3.15E-12	3.51E-07	5.37E-10	1.53E-08	3.67E-07
7	EAF6	5.32E-14	8.37E-09	4.01E-11	4.51E-09	1.29E-08
8	EAF7	9.24E-12	1.59E-07	1.54E-10	2.15E-08	1.81E-07
9	EAF8	5.81E-13	1.73E-08	2.08E-11	7.70E-09	2.51E-08
10	EAF9	5.12E-13	6.97E-09	3.13E-14	1.91E-09	8.88E-09
11	EAF10	5.95E-12	1.10E-07	2.59E-11	7.96E-09	1.18E-07
12	EAF11	1.74E-12	3.18E-08	8.75E-12	3.14E-09	3.49E-08
13	EAF12	4.39E-12	3.56E-08	1.62E-11	8.83E-09	4.44E-08
14	EAF13	6.22E-12	1.67E-06	0	6.59E-09	1.68E-06
15	EAF14	2.26E-11	5.71E-06	0	1.21E-08	5.73E-06
16	EAF15	1.88E-11	5.32E-06	0	2.37E-08	5.35E-06
17	EAF16	7.90E-12	2.76E-06	0	2.79E-08	2.79E-06
18	EAF17	2.39E-12	8.14E-07	1.65E-11	2.15E-08	8.35E-07
19	EAF18	1.66E-12	3.33E-07	1.57E-13	1.20E-08	3.45E-07
20	EAF19	1.02E-12	7.52E-08	1.85E-11	8.84E-09	8.41E-08
21	EAF20	5.98E-15	2.95E-10	0	1.55E-11	3.10E-10
22	EAF21	5.80E-15	1.30E-09	1.83E-13	1.55E-11	1.32E-09

Previous studies of the health risk assessment of PCDD/Fs indicated that food ingestion was the major exposure route of dioxin carcinogenic risk. In fact, ingestion risk transfer due to the wholesale-marketing of agricultural products was considered, and the risk of food items aside from 25 km× 25 km impact range was ignored in such an exposure scenario. In general, people received less than 10% of dioxin risk contributed from inhalation. Results of the study showed that the fraction of cancer risk via ingestion is different from emission sources. Fig. 3 shows the risk distributions of the 22 emission sources in site-specific exposure scenarios to the resident living in impact areas. Six out of 22 emission sources (EAF6, EAF7, EAF8, EAF9, EAF12 and EAF19) possess more than 10% of total risks via inhalation. Besides, three electric arc furnaces (EAF13, EAF14 and EAF15) possess less than 1% inhalation risks, and exposure through food ingestion accounted for more than 99% of total dioxin risks. In fact, the broad assumption of dietary intake would decrease the total incremental risk from each emission source in steel and iron industry, and the magnitude and distribution of total risks vary with regional properties and the characteristics of emission sources. Moreover, it would change the contribution of ingestion routes to another. However, the assessment results still reflect that the ingestion exposure was the major route no matter how strict the assumptions on food ingestion are.

Although inhalation is the minor route of PCDD/Fs risks, inhalation risk still has the most direct effect compared to other emissions sources. There are 22 emission sources in steel and iron industry with large PCDD/Fs exit flows and emission rates in the impact areas so that the air concentration, wet and dry deposition of dioxin are higher. The inhalation risk of twelve emission sources (one sinter plant and eleven electric arc furnaces) is higher than 1E-08. The incremental inhalation risk in the impact area is much greater than the total risks in other regions in Taiwan (Ma 2002; Lee *et al.*, 2004) and other kinds of emission sources (Llobet *et al.*, 2003; Cangialosi *et al.*, 2008). Thus, the results above suggest that the resident living in the impact range would experience higher dioxin risks from inhalation and ingestion.

PCDD/Fs Regional Risks Contributed from Steel and Iron Industry

PCDD/Fs are persistent organic pollutants that could transport long distance through air dispersion. In order to realize the influence of local emission sources in steel and iron industry, it assumed that the PCDD/Fs health risks were the combination of the emission of the local sources and those in the neighborhood, and sources far away from evaluated sites were ignored. The site-specific exposure scenario of the study assumed that the PCDD/Fs risks of ingesting food items would transfer randomly though wholesale-marketing. Thus, the ingestion risks of food contributed from emission sources in steel and iron industry would influence not only the resident living in the impact area but also the people far away from the emission sources. Actually, intake PCDD/Fs from ingested food was regarded as background exposure because it was very difficult to precisely track the sources of dioxin in food items and thus to avoid slight but long lasting accumulation from daily dietary.

The total ingestion risks of the residents were calculated in Table 7. In such an exposure scenario, it would be no regional variation to calculate individual risks on exposure

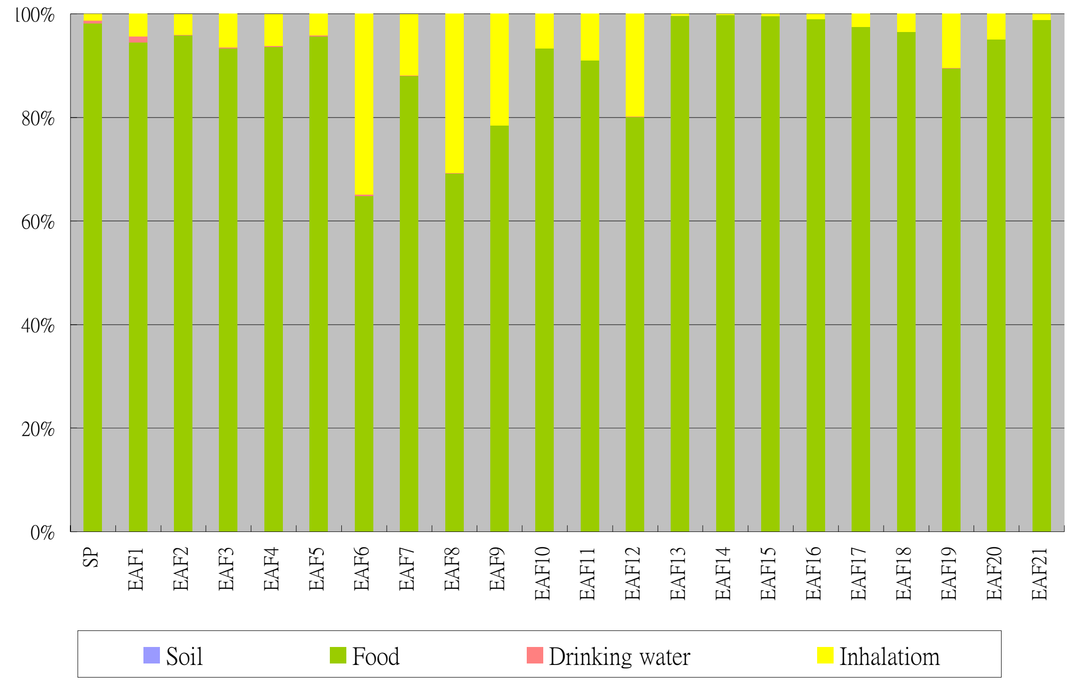

Fig. 3. Distributions of 4 Exposure Routes from 22 Emission Sources of Steel and Iron Industry.

Table 7. The ingestion risk of PCDD/Fs resulting from the 22 emission sources in steel and iron industry under the site-specific exposure scenario.

	Emission Sources	Soil	Vegetable	Beef/ Sheep	Milk	Egg	Poultry	Pork	Freshwater Fish	Shellfish	Marine Fish
1	SP	2.92E-12	6.16E-09	5.85E-09	2.26E-08	5.06E-12	9.64E-12	4.20E-08	3.23E-09	1.06E-07	2.45E-10
2	EAF1	4.46E-12	1.01E-08	9.00E-09	3.61E-08	8.03E-12	1.54E-11	6.82E-08	1.90E-08	4.32E-07	1.75E-09
3	EAF2	5.25E-12	1.14E-08	1.03E-08	4.12E-08	9.40E-12	1.80E-11	7.89E-08	1.84E-09	8.37E-10	3.66E-07
4	EAF3	6.62E-12	1.52E-08	1.65E-08	6.25E-08	1.15E-11	2.20E-11	1.06E-07	5.04E-09	1.44E-09	3.78E-07
5	EAF4	3.28E-12	7.93E-09	8.90E-09	3.32E-08	5.89E-12	1.13E-11	5.63E-08	7.78E-09	1.25E-09	2.00E-07
6	EAF5	3.15E-12	7.20E-09	5.98E-09	2.45E-08	5.88E-12	1.13E-11	4.99E-08	1.09E-09	4.92E-10	2.61E-07
7	EAF6	5.32E-14	2.97E-10	2.88E-10	1.09E-09	8.12E-14	1.54E-13	1.03E-09	1.13E-10	6.78E-10	4.88E-09
8	EAF7	9.24E-12	2.07E-08	3.18E-09	2.44E-08	1.52E-11	2.89E-11	5.27E-08	2.81E-09	1.27E-09	5.40E-08
9	EAF8	5.81E-13	1.90E-09	3.45E-10	2.68E-09	9.54E-13	1.76E-12	3.98E-09	1.18E-09	2.23E-10	7.02E-09
10	EAF9	5.12E-13	1.17E-09	5.44E-11	8.14E-10	4.62E-13	1.72E-12	1.42E-10	7.65E-10	7.02E-10	3.32E-09
11	EAF10	5.95E-12	1.72E-08	1.09E-09	1.61E-08	1.23E-11	3.76E-11	2.81E-09	1.52E-08	4.16E-09	5.37E-08
12	EAF11	1.74E-12	5.33E-09	3.55E-10	5.22E-09	3.35E-12	1.01E-11	7.50E-10	4.15E-09	1.64E-09	1.43E-08
13	EAF12	4.39E-12	1.31E-08	8.40E-10	1.23E-08	8.07E-12	2.40E-11	1.76E-09	2.37E-09	2.27E-10	4.90E-09
14	EAF13	6.22E-12	1.23E-08	2.67E-08	4.77E-07	1.39E-11	1.65E-11	1.12E-06	1.80E-10	1.11E-10	3.38E-08
15	EAF14	2.26E-11	4.10E-08	9.23E-08	1.60E-06	4.87E-11	5.92E-11	3.95E-06	3.85E-10	1.20E-10	2.88E-08
16	EAF15	1.88E-11	3.59E-08	8.91E-08	1.31E-06	3.13E-11	4.50E-11	3.82E-06	2.91E-10	1.03E-10	6.69E-08
17	EAF16	7.90E-12	2.44E-08	4.91E-08	4.88E-07	3.53E-12	1.56E-11	2.05E-06	1.13E-10	1.19E-11	1.46E-07
18	EAF17	2.39E-12	7.62E-09	1.55E-08	1.57E-07	1.13E-12	5.19E-12	6.22E-07	2.26E-11	3.98E-12	1.19E-08
19	EAF18	1.66E-12	5.43E-09	8.37E-09	9.74E-08	1.14E-12	6.25E-12	1.84E-07	7.30E-11	1.46E-11	3.81E-08
20	EAF19	1.02E-12	1.89E-09	4.25E-10	9.66E-09	2.57E-13	2.28E-12	1.82E-10	5.42E-09	3.37E-11	5.76E-08
21	EAF20	5.98E-15	1.07E-11	2.44E-12	6.88E-11	1.66E-15	1.53E-14	1.58E-10	4.52E-12	5.28E-14	5.00E-11
22	EAF21	5.80E-15	1.04E-11	1.12E-11	2.25E-10	1.57E-15	1.39E-14	1.02E-09	1.55E-12	2.41E-13	3.08E-11
Total Risk		1.09E-10	2.46E-07	3.44E-07	4.43E-06	1.86E-10	3.42E-10	1.22E-05	7.10E-08	5.51E-07	1.73E-06

routes of ingesting food and ingesting contaminated soil incidentally.

Cancer risks from ingestion poultry, eggs and freshwater fish were less than 1%. The results showed that pork (62.36%) was the main pathway of dioxin ingestion exposure from the emission in steel and iron industry. In addition, pork had high degree of food self-sufficiency and was the most important source to the resident in Taiwan. It accounted for more than 50% producing from the major impact region (i.e. source-located districts) so that the individual risks is higher than the other exposure routes in dietary. The pathways with less ingestion exposure were milk (22.59%), marine

Fish (8.85%) and shellfish (2.81%). The distributions of risk in food groups was correlated with the intake rates of Taiwanese adults and the agricultural production yields in the impact range around the emission sources under the site-specific exposure scenario. Fig. 4 is the pie chart of the risk distributions and the total risks of nine ingestion food pathways from the PCDD/Fs emissions. The results of the nine pathways of risk distributions are similar to another study about site-specific dioxin risk from emission sources in Taiwan (Wang *et al*., 2009).

Table 8 shows the drinking water risks in the impact districts of these 22 emission sources in steel and iron industry. Compared to the food ingestion risks, the risks of drinking water is lower possibly due to high tap-water supply served in Taiwan. The influence of PCDD/Fs emission from steel and iron industry on drinking water were only focused on the water quality and water volume protectorate located at the impact range of emission sources. In the current study, the PCDD/Fs risk from drinking water was assumed that it would only influence the resident living in the source-located district. The risks of drinking water from a single emission source ranged from 0 (EAF13, EAF14, EAF15, EAF16, EAF20) to 7.10E-09 (EAF2). The impact range of five electric arc furnaces (EAF13, EAF14, EAF15, EAF16, EAF20) did not locate at water quality water volume protectorate so that there were no PCDD/Fs health risks via drinking water. Among seven source-located districts, the total risk of drinking water to the resident in Kaohsiung City was 1.41E-08, which was much higher than that in other districts.

Table 9 shows the inhalation risks of the source-located districts and the source-neighbored districts when considering the ratio of impact area. For the resident living in these 14 impact districts, the inhalation risks from emission sources ranged from 5.35E-08 (Kaohsiung City) to 3.62E-13 (District F), indicating Kaohsiung City is the district with the highest inhalation risk. The Taichung County ranks second in term of the inhalation risk (7.06E-09) as mainly contributed by the five electric arc furnaces. As a whole, the inhalation risks to the residents living in the neighboring districts were lower than that in source-located districts, except for the inhalation risk (2.85E-09) of Taichung City. It might be that Taichung City was located between Changhua County and Taichung County. For the no-impact districts, transferred risk of food items was the only source in calculating the contribution of the PCDD/Fs risk.

From the data of Taiwan Department of Health in 2009, the basic mortality level for cancer diseases was 173 lifetime cancer risk referred to 100,000 people, in comparing the mortality level for cancer, the incremental population risks of PCDD/Fs contributed from the emission sources was estimated in the study. Population risk for PCDD/Fs showed higher level in urbanized districts. As a whole, the total population risks from the PCDD/Fs emissions in steel and iron industry are 1030.1 people as shown in Table 10, and carcinogenic population risks for the people living in the source-located districts, source-neighbored districts and non-direct impact districts are 417, 365 and 248 people, respectively. Furthermore, considering 50% cancer mortality of IARC suggestion and standardized as rates for additional

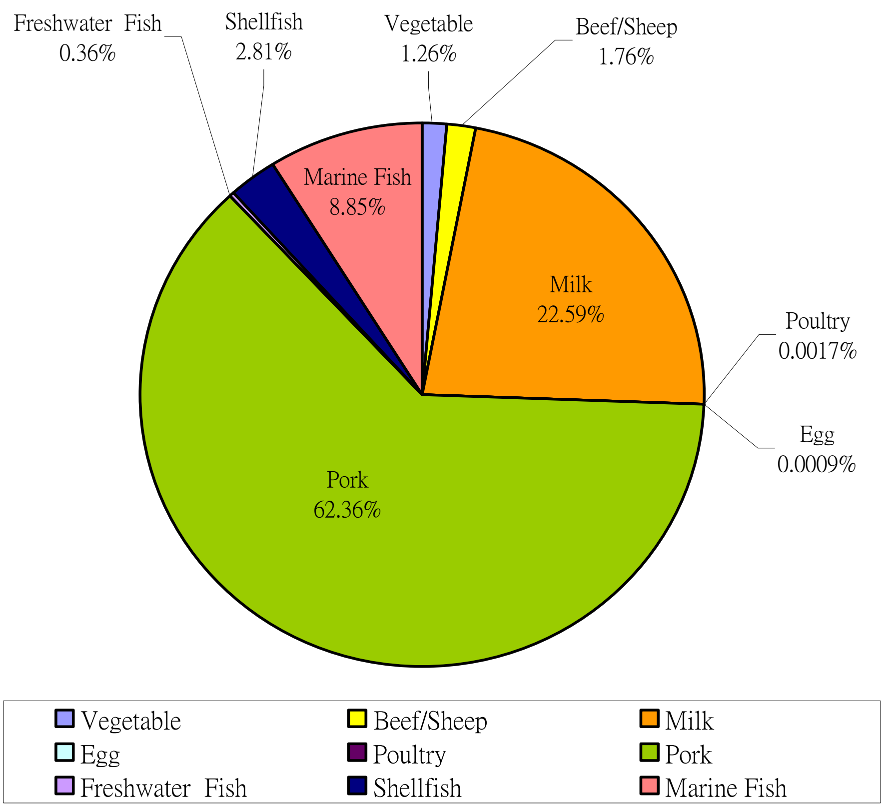

Fig. 4. Distributions of Risk from the 11 Ingestion Pathways Contributed by PCDD/Fs emissions of Steel and Iron Industry.

Table 8. The PCDD/Fs risk of drinking water resulting from the 22 emission sources in steel and iron industry.

Region		Kaohsiung City	Kaohsiung County	Tainan County	Changhua County	Taichung County	Miaoli County	Taoyuan County
1	SP	4.13E-09	-	-	-	-	-	-
2	EAF1	7.10E-09	-	-	-	-	-	-
3	EAF2	6.12E-10	-	-	-	-	-	-
4	EAF3	7.89E-10	-	-	-	-	-	-
5	EAF4	8.75E-10	-	-	-	-	-	-
6	EAF5	5.37E-10	-	-	-	-	-	-
7	EAF6	4.01E-11	-	-	-	-	-	-
8	EAF7	-	1.54E-10	-	-	-	-	-
9	EAF8	-	2.08E-11	-	-	-	-	-
10	EAF9	-	-	3.13E-14	-	-	-	-
11	EAF10	-	-	2.59E-11	-	-	-	-
12	EAF11	-	-	8.75E-12	-	-	-	-
13	EAF12	-	-	1.62E-11	-	-	-	-
14	EAF13	-	-	-	0.00E+00	-	-	-
15	EAF14	-	-	-	0.00E+00	-	-	-
16	EAF15	-	-	-	-	0.00E+00	-	-
17	EAF16	-	-	-	-	0.00E+00	-	-
18	EAF17	-	-	-	-	-	1.65E-11	-
19	EAF18	-	-	-	-	-	1.57E-13	-
20	EAF19	-	-	-	-	-	-	1.85E-11
21	EAF20	-	-	-	-	-	-	0.00E+00
22	EAF21	-	-	-	-	-	-	1.83E-13
Total Risk of Drinking water		1.41E-08	1.75E-10	5.09E-11	0.00E+00	0.00E+00	1.66E-11	1.87E-11

Table 9. The inhalation risk of PCDD/Fs resulting from the 22 emission sources in steel and iron industry.

Region	Source-located Distinct						
	Kaohsiung City	Kaohsiung County	Tainan County	Changhua County	Taichung County	Miaoli County	Taoyuan County
SP	3.21E-09	1.68E-10	-	-	-	-	-
EAF1	9.67E-09	4.06E-10	-	-	-	-	-
EAF2	7.89E-09	3.88E-10	-	-	-	-	-
EAF3	1.52E-08	6.80E-10	-	-	-	-	-
EAF4	7.51E-09	3.82E-10	-	-	-	-	-
EAF5	6.27E-09	1.98E-10	-	-	-	-	-
EAF6	2.23E-09	4.53E-11	-	-	-	-	-
EAF7	9.95E-10	1.57E-09	1.28E-10	-	-	-	-
EAF8	5.35E-10	3.15E-10	2.53E-11	-	-	-	-
EAF9	-	9.42E-13	5.55E-11	-	-	-	-
EAF10	-	-	1.51E-09	-	-	-	-
EAF11	-	-	4.58E-10	-	-	-	-
EAF12	-	-	1.05E-09	-	-	-	-
EAF13	-	-	-	9.94E-10	1.19E-10	-	-
EAF14	-	-	-	1.02E-09	3.28E-10	-	-
EAF15	-	-	-	5.53E-10	1.08E-09	-	-
EAF16	-	-	-	-	4.82E-09	1.99E-10	-
EAF17	-	-	-	-	1.36E-09	4.62E-10	-
EAF18	-	-	-	-	-	2.61E-09	-
EAF19	-	-	-	-	-	-	2.71E-09
EAF20	-	-	-	-	-	-	2.41E-12
EAF21	-	-	-	-	-	-	4.77E-12
Total Risk	5.35E-08	4.16E-09	3.23E-09	2.57E-09	7.69E-09	3.28E-09	2.71E-09

Table 9. *(continued).*

Region	Source-neighbered Distinct						
	A	B	C	D	E	F	G
SP	8.82E-11	-	-	-	-	-	-
EAF1	2.02E-10	-	-	-	-	-	-
EAF2	2.00E-10	-	-	-	-	-	-
EAF3	3.28E-10	-	-	-	-	-	-
EAF4	1.70E-10	-	-	-	-	-	-
EAF5	1.28E-10	-	-	-	-	-	-
EAF6	1.41E-11	-	-	-	-	-	-
EAF7	-	1.75E-11	-	-	-	-	-
EAF8	-	1.21E-11	-	-	-	-	-
EAF9	-	5.72E-10	-	-	-	-	-
EAF10	-	-	3.95E-11	-	-	-	-
EAF11	-	-	1.00E-10	-	-	-	-
EAF12	-	-	3.38E-10	-	-	-	-
EAF13	-	-	-	6.07E-10	4.16E-12	-	-
EAF14	-	-	-	7.16E-10	-	-	-
EAF15	-	-	-	1.05E-09	-	-	-
EAF16	-	-	-	4.73E-10	-	-	-
EAF17	-	-	-	-	-	-	-
EAF18	-	-	-	-	-	-	-
EAF19	-	-	-	-	-	5.42E-14	1.19E-10
EAF20	-	-	-	-	-	3.07E-13	-
EAF21	-	-	-	-	-	-	2.48E-13
Total Risk	1.13E-09	6.02E-10	4.78E-10	2.85E-09	4.16E-12	3.62E-13	1.20E-10

Table 10. Populations and the population risk of the PCDD/Fs emissions from steel and iron industry.

Type of Agricultiral product		Source-located Distinct						
		Kaohsiung City	Kaohsiung County	Tainan County	Changhua County	Taichung County	Miaoli County	Taoyuan County
Population (person)		1515518	1240903	1105641	1314149	1537432	560580.3	1889612
Population Risk (person)	Inhalation	8.10E-02	5.16E-03	3.57E-03	3.38E-03	1.18E-02	1.84E-03	5.13E-03
	Drinking Water	2.13E-02	2.17E-04	5.63E-05	0.00E+00	0.00E+00	9.33E-06	3.54E-05
	Food Ingestion	6.90E+01	5.65E+01	5.03E+01	5.98E+01	7.00E+01	2.55E+01	8.60E+01
Total		69.06	56.47	50.31	59.8	69.96	25.51	85.98

Table 10. *(continued).*

Type of Agricultiral product		Source-neighbered Distinct							No-impact District	Total Population Risk
		A	B	C	D	E	F	G		
Population(person)		894309.4	758348.1	554654.4	1036540	535749.8	481321	3753924	5457444	22636126
Population Risk (person)	Inhalation	1.01E-03	4.57E-04	2.65E-04	2.95E-03	2.23E-06	1.74E-07	4.49E-04	-	0.117
	Drinking Water	-	-	-	-	-	-	-	-	0.022
	Food Ingestion	4.07E+01	3.45E+01	2.52E+01	4.72E+01	2.44E+01	2.19E+01	1.71E+02	2.48E+02	1029.944
Total		40.69	34.51	25.24	47.17	24.38	21.9	170.8	248.31	1030.082

cancer mortality over a lifetime referred to 100,000 people, the total PCDD/Fs population risks from steel and iron industry was corresponding to 2.28 incremental lifetime cancer risk referred to 100,000 people. Comparing background mortality level for cancer with incremental PCDD/Fs risks of steel and iron industry, the total PCDD/Fs population risks contributed by steel and iron industry are low but still higher than other kind of pollution sources (Cangialosi *et al*., 2008). For some emission sources with lower exit rates, the incremental risks are even much lower than 1E-06. Actually, the level of carcinogenic risk "1E-06" is also regarded as a proportion that how many people die in cancer per hundred thousand; thus, the amount of population would result in the value of mortality rates. Furthermore, such as the carcinogenic health impact of specific pollutant from single industry was notable.

CONCLUSION

The study has combined the multimedia, multiple pathway exposure modeling and site-specific exposure scenario to perform dioxins risk assessment of 22 emission sources in Taiwan. We found that the major health risk of dioxins exposure contribution were the electric arc furnaces in the middle Taiwan, especially indirect exposure from ingestion food items, although the emission sources in southern Taiwan possessing the most PCDD/Fs exits in steel and iron industry. Moreover, pork, milk and fish are proven as major exposure pathways. The assessment would not only reflect the realistic intake status of the Taiwanese but also show regional difference on agricultural yields, indicating how the location and operational parameters of emission sources influence the incremental risks. Finally, population risk was used to evaluate the impact of steel and iron industry by combing population and transfer risk that were ignored in the previous studies.

Limitations when interpreting the results of this study should be mentioned as follows: first, we determined the PCDD/Fs health risk from emission sources only within the districts in the impact range (25 km × 25 km) for all emission sources. Even though the assumption of impact range above was much larger than before, the actual impact areas of the large-scale emission sources (sinter plants and electronic arc furnaces) might be larger. As a result, the long-term transportation ability of PCDD/Fs was ignored. Second, average values were presented instead of detailed uncertainty and variability because this study focused on examination of the aggregate effects on PCDD/Fs emissions in steel and iron industry and provided directions and comments for future management. Third, we have not considered the real geographic distribution of agricultural yields in the impacted county or city, but used the impact ratio to evaluate the fraction of polluted agricultural yields. The ingestion risks of food items might therefore be overestimated or underestimated because of the different land usages. All the exposure parameters we used to estimate risks only considere average conditions of general population but ignored extreme scenario of sensitive population, such as farmers or fishers. Most importantly, the assumption of exposure scenario of ingestion and inhalation routes was too loose to ignore the local impact.

Despite these limitations, the results are still solid for making recommendations about future risk assessments and management of PCDD/Fs in steel and iron industry. According to the results, it is clear that the PCDD/Fs emissions from steel and iron industry could lead to significant risks, not only to the resident living around the emission sources but also the people in the neighbored.

In order to protect the resident living in the region of numerous PCDD/Fs emission sources or large-scale emission rates, only Kaohsiung City announced stricter regional standard on sinter plant. Under that control level, the total incremental PCDD/Fs risk to the resident living around the city is acceptable; however, this value is not enough to protect the resident living in Taichung County and Changhua County. Our results suggested that the local authority should adopt high priority on carrying out a management strategy of PCDD/Fs emission in these two regions as soon as possible. Expect for adopting the stricter control levels of PCDD/Fs emission sources, other strategies such as enforcement of a stricter local standard, the total control amount of dioxin emissions and replacement of the BACT (Best Achievable Control Technology) by MACT (Maximum Achievable Control Technology) in air pollution prevention facilities of dioxins should be considered. Additionally, persistent monitoring agricultural products and adjusting the land using purpose in the future are also quite important.

As a whole, the results indicate that even if all emission sources meet the regulatory standards, these sources may cause health risks after all, so it is important to consider the aggregate risk of steel and iron industry to realize the individual and the whole effects to the environment.

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