# Estimation of Air Emission for Dioxin using a Mathematical Model in Two Large Cities of Korea

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## Introduction

Chlorinated hydrocarbons, such as PCBs and PCDDs/PCDFs are ubiquitous contaminants in the global environment. There is cause to dioxin emission to atmosphere from industrial and non-industrial sources in Korea.

The approach used in this study to estimate emissions is based on the emission factors. We estimate the dioxin emissions to air used to emission factor in Korea, and predict the concentration of dioxin in ambient air by ISCLT3 model in Seoul and Inchon cities of Korea, based on estimated emissions in air from industrial process and combustion sources. As the results, we estimate the amount of uptake via inhalation of particulates in the cities through by the deterministic and probabilistic method.

## Material and Methods

We searched and collected the annual quantities of waste generation and incineration disposal in Korea using statistical yearbook, report of waste management and recycling bureau, and statistical yearbook for environment. Also, the number and types of manufacturing or metallurgical processes with their annual quantities of products were searched using to statistical yearbook, report on mining and manufacturing survey, and report in industrial census. The general characterization of the study cities was shown table 1.

The emission factors were applied to the proposed values suggested in dioxin draft report of the US EPA(1994). Using collected data, we estimated dioxin emissions to air from industrial processes and combustion sources in Korea.

In Seoul(the metropolitan) and Inchon(the industrial harbor city), the concentration of dioxin in ambient air were predicted by ISCLT3 model. The modeling parameters such as emission type, emission coordinate(x,y,z), emission concentration, stack hight, stack exit velocity, stack inner diameter and stack exit temperature were searched and determinated. The meteorological inputs for ISCLT3 model program used hourly data of 10 years(1987~1996) by meteorological observation in the cities, respectively. Dispersion model option is decided to be urban mode of sigma function(Briggs, 1973). Receptor option was applied to an 500m interval-regularly-spaced Cartesian receptor grid system and annually average concentration was predicted.

Therefore, we estimated the uptake via inhalation of particulates in the cities by the deterministic and probabilistic method. The equation used to estimate uptake via inhalation of particulates was :

$$LADD = (C_{air} \times IR \times FR \times EF \times ED) / (BW \times AT)$$

where LADD=lifetime average daily dose of dioxin (pg/kg-day)
$C_{air}$=concentration of dioxin in air (pg/m³)
IR=inhalation rate (m³/day)
FR=fraction of inspired particulate absorbed in lower respiratory tract
EF=exposure frequency (fraction of year)
ED=exposure duration (years)
BW=body weight (kg)
AT=averaging time (years)

The value used to estimate uptake via inhalation are presented in Table 7. The range of body weights in the population of Korea is known to be log-normally distribution(mean=68kg)(Chung Y, 1997). The Exposure duration(ED) and averaging time(AT) were applied as 70 years which was the expected lifetime of Korean(IERY, 1996). The inhalation rate(IR) was 20m³/day(US EPA, 1994) and fraction of inspired particulate absorbed in lower respiratory tract(FR) was 0.33(Copeland et al., 1993).

## Result and Discussion

The annual products of manufacturing by industry of the study cities was shown table 2. The estimated annual quantities of wastes generated and incineration disposal was shown table 3. Total dioxin emission was annually 422 gTEQ/yr in Korea which was calculated by emission factor, and it was estimated that dioxin was emitted as much as 15.5 gTEQ/yr in Seoul and 12.8 gTEQ/yr in Inchon(Table 4). Table 5 was shown the comparison of several countries for air emission.

From the results of ISCLT3 modeling, dioxin concentration in air was predicted to be $0.00032\pm0.0048$pg/m³ (waste incineration 62%, industrial manufacturing 38%) in Seoul and $0.0062\pm0.0054$pg/m³ (waste incineration 2.5%, industrial manufacturing 97.5%)(Table 6). The predicted results of this air diffusion modeling was similar to the dioxin concentration in air of other countries(Fig. 1).

We used the data that Korean adult average body weight is 68 kg, inhalation per day is 20m³/day, and the Korean average lifetime is 70 yr(Table 7). In this condition, 50th percentile value of lifetime uptake via inhalation of dioxin was estimated as $2.11\times10^{-4}$pg/kg-day in Seoul and $4.14\times10^{-4}$pg/kg-day(Fig. 2).

This study is the first research in Korea of which the estimation of dioxin emission in whole country and air diffusion modeling. The predicted results of this air diffusion modeling was similar to the dioxin concentration in air of other countries.

The limitation of this study is that applying emission factor of US EPA(1994). Because dioxin existed in ambient air as extremely small amount can not be measured easily, there is not enough measuring data in Korea. In this study, despite of many uncertainties, we predicted the dioxin in ambient air by using ISCLT3 model based on emission sources.

Although this first stage of dioxin study in Korea has many uncertainty and impractical assumption of estimating dioxin levels, this practice may give an opportunity of overviewing the dioxin-related researched in Korea and suggesting the further research interests to be pursued.

We are planning to develop and validate more reliable air dispersion modeling based on measurement data of Korea throughout further study.

## Acknowledgements

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**Table 1. Characterization of the study cities in Korea[1)]**

| | Whole country | Seoul | Inchon |
|---|---|---|---|
| Area (㎢) | 99,395 | 606 | 379[2)] |
| Population (persons) | 45,979,231 | 10,595,943 | 2,297,498[2)] |
| Incineration Plants : General wastes | | | |
| - Local government (No.) | 514 | 2 | 8 |
| - Self-treatment companies (No.) | 3,180 | - | 12 |
| - Treatment companies (No.) | 77 | | 6 |
| Incineration Plants : Specified wastes (No) | 310 | - | 8 |
| Manufacturing (No.) | 96,202 | 20,288 | 17,187 |

[1)]Source : Statistical Yearbook(1997); Based year=1995, [2)]Area and population of waste management area

**Table 2. Annual products of manufacturing by industry in Korea** (unit : ton/yr)

| Manufacturing | Whole country | Seoul | Inchon |
|---|---|---|---|
| Pulp & Paper mills | 2,370,311 | 243,686 | 86,338 |
| Secondary Copper smelting | 233,177 | 5,133 | 19,064 |
| Secondary Lead smelting | 10,256,142 | 239,292 | 844,861 |
| Total | 12,859,630 | 488,111 | 950,263 |

Source : Statistical Yearbook, Korea(1997) : Based year=1995

**Table 3. Estimated quantities of wastes generated and incinerated annually in Korea**

| Waste type | Whole country | | | Seoul | | | Inchon | | |
|---|---|---|---|---|---|---|---|---|---|
| | Products (ton/yr) | Incineration (ton/yr) | Rate of incine-ration(%) | Products (ton/yr) | Incineration (ton/yr) | Rate of incine-ration(%) | Products (ton/yr) | Incineration (ton/yr) | Rate of incine-ration(%) |
| **General wastes** | 54,034,965 | 3,030,595 | 5.6 | 8,517,567 | 102,938 | 1.2 | 1,846,900 | 33,215 | 1.8 |
| Domestic | (17,437,510) | ( 976,501) | | (5,147,230) | (26,306) | | (744,965) | (4,380) | |
| Industrial | (34,975,395) | (1,958,622) | | (3,370,410) | (76,632) | | (1,101,935) | (28,835) | |
| **Specified wastes** | 1,622,000 | 251,410 | 15.5 | 42,795 | 1,095 | 2.6 | 174,721 | 27,082 | 15.5 |
| **Total** | 55,656,965 | 3,282,005 | 5.9 | 8,560,362 | 104,033 | 1.2 | 2,021,621 | 60,297 | 3.0 |

Source : Statistical Yearbook, Korea(1997) : Based year=1995

**Table 4. Estimated dioxin emissions to air from combustion sources in Korea**

| Source type | Emission factor[1)] (μgTEQ/kg) | Annual emission (gTEQ/yr) | | |
|---|---|---|---|---|
| | | Whole country | Seoul | Inchon |
| **Waste Incineration** | | | | |
| General waste | 0.1[1)] | 303.1 | 10.3 | 3.30 |
| Specified waste | 0.002[2)] | 0.5 | - | 0.05 |
| Medical waste | 2 | | 2.2 | - |
| **Industrial manufacturing** | | | | |
| Pulp & paper mills | 0.002 | 4.7 | 0.49 | 0.17 |
| Secondary copper smelting | 0.4 | 93.3 | 2.05 | 7.63 |
| Secondary lead smelting | 0.002 | 20.5 | 0.48 | 1.69 |
| **Total** | | 422.1 | 15.52 | 12.83 |

[1)]Source : US EPA(1997), [2)]Using to emission factor of municipal waste incineration
[3)]Using to emission factor of hazardous waste incineration

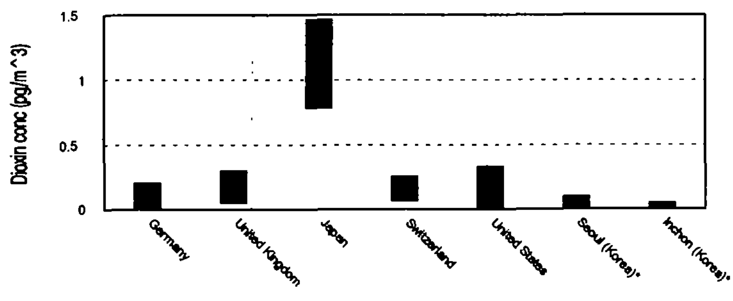
**Table 5. Air emission for several countries** (unit : gTEQ/yr)

| Emission Source | West Germany[a] | Austria[a] | United Kindom[a] | Netherland[a] | Switzerland[a] | United States[a] | Japan[b] | Korea[c] |
|---|---|---|---|---|---|---|---|---|
| **Incineration Source** | | | | | | | | |
| Municipal waste incineration(MSW) | 5.4-432 | 3 | 1,150 | 382 | 90-150 | 3,000 | 3,100-7,400 | 303.1 |
| Sewage waste incineration | 0.01-1.1 | < 1 | - | 0.3 | - | 23 | 5 | - |
| Hazardous waste incineration | 0.5-72 | 6 | 11 | 16 | < 1 | 35 | 490 | 0.5 |
| Hospital waste incineration | 5.4 | 4 | 32 | 2.1 | 2-3 | 5,100 | 80-240 | |
| **Industrial/Municipal Process** | | | | | | | | |
| Pulp and paper mills | | 4 | | | 1-5 | 2.7 | 47 | 4.7 |
| **Chemical Manufacturing sources** | | | | | | | | |
| Organic chemical manufacture | | | | 0.5 | | | | |
| **Metallurgical Processes** | | | | | | | | |
| Tire Combustion | | | | | | 0.3 | | |
| Ferrous metal smelting/refining | 1.3-18.9 | 19[d] | | 30[d] | 6-16[d] | | | |
| Nonferrous metal smelting/refining | 38-380 | | | | | 230 | 250 | 113.8 |
| Scrap electric wire recovery | | | | 1.5 | | | | |
| Drum and barrel reclamation | | | | | 2-14[e] | 1.7 | | |
| **Power/Energy Generation** | | | | | | | | |
| Vehicle fuel combustion -leaded | 7.2 | <1[e] | 613[e] | 7.0[e] | | | | |
| -unleaded | 0.8 | | | | | 1.3 | 0.07 | |
| -diesel | 4.6 | | | | | 85 | | |
| Wood burning | | 70 | 16 | 12 | | 40[f] 320[g] | 0.2 | |
| Coal combustion - residential | 1.1 | <1[h] | 989 | 3.7[h] | | | | |
| - industrial | | | 301 | | | | | |
| - utility | | | 199 | | | | | |
| Oil combustion - residential | 1.2 | | 2[i] | | | | | |
| Charcoal briquette combustion (residential) | 1.8 | | | | | | | |
| **Total** | 67-926 | <109 | 3,870 | 484 | 100-200 | 9,200 | 3972-8432 | 422.1 |

a) Source : US EPA (1994) ; Based year=1987-1990, b) Source : Masaru T (1997); Based year=1990
c) Estimated generated in this study, based year=1995, d) Total for all metal industries including sintering process, e) Total for all fuel types, f) Estimate for residential wood burning, g) Estimate for industrial wood burning, h) Total of all coal combustion of from all sources, i) Total of 2gTEQ/yr from "oil burning"

**Table 6. Estimated dioxin concentrations to ambient air in Seoul and Inchon of Korea using ISCLT3 modeling**

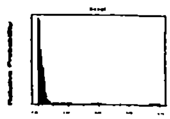
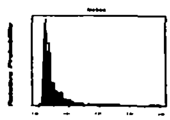
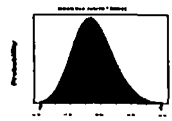
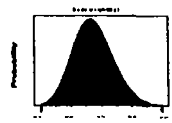
| Emission Source | Seoul ($pg/m^3$) Mean ± SD | Inchon ($pg/m^3$) Mean ± SD |
|---|---|---|
| Waste Incineration | 0.0020 ± 0.0042 | 0.0002 ± 0.0002 |
| Industrial Manufacturing | 0.0012 ± 0.0019 | 0.0061 ± 0.0054 |
| Total | 0.0032 ± 0.0048 | 0.0062 ± 0.0054 |



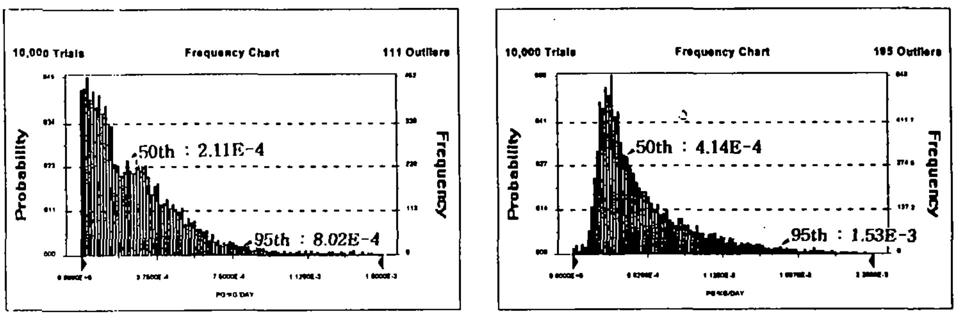

* Estimated dioxin concentration to ambient air using ISC modeling in this study

**Figure 1. Comparison to ambient air levels of dioxin emission for several countries**

Table 7. Parameters used in the probabilistic assessments to estimate the uptake of dioxin due to ambient air

| Parameters | Mean | SD | Distribution | |
|---|---|---|---|---|
| Concentration ($pg/m^3$)[1)] | | | | |
| Seoul | 0.0032 | 0.0048 | Empirical |  |
| Inchon | 0.0062 | 0.0054 | Empirical |  |
| Inhalation rate ($m^3$/day)[2)] | 20 | 2 | Log-normal |  |
| Body weight (kg)[3)] | 68 | 6.8 | Log-normal |  |
| Fraction to inspired particulates retained in lung[4)] | 0.33 | | Point value | |
| Exposure frequency (fraction of time exposed) | 1.0 | | Point value | |
| Exposure duration (yr)[3)] | 70 | | Point value | |
| Averaging time (yr)[3)] | 70 | | Point value | |

[1)]Estimated dioxin concentration to ambient air using ISC modeling in this study, [2)]Source : US EPA(1994)
[3)]Application to average body weight of adults and expected lifetime of Korean(IERY, 1995; Chung Y, 1997),
[4)]Source : Copeland et al.(1993)




(a) Seoul (b) Inchon

Figure 2. Distributions of dioxin-uptake due to inhalation of particulates in the cities of Korea