# The Use of Monte Carlo Simulation Techniques for Risk Assessment: Study of a Municipal Waste Incinerator

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**Introduction**

In recent years, risk assessment has been used to evaluate stack emissions from municipal solid waste incinerators (MSWI). To perform risk assessment, both model uncertainty and data uncertainty can be considered. Date uncertainty includes variability and uncertainty. An important part of probabilistic risk assessment is to determine the relative influence of the input parameters in the magnitude of the variance in the output distribution. Since in MSWI risk assessment PCDD/Fs are of great concern, these compounds are the subject of the current study.

We present here the development of a methodology for estimating the distribution of general PCDD/Fs risk for the population living near to a MSWI (Montcada, Catalonia, Spain). This method compares the risk due to direct exposure pathways with indirect pathways. By means of Monte Carlo simulation, we evaluated the total human risk (cancer and non-cancer), and compared direct risk due to PCDD/F exposure from the incinerator with indirect PCDD/F exposure through diet.

**Method**

Risk assessment requires identification of the pathways via which people will be exposed to the potential chemicals of concern. The quantitative estimation of health risk due to PCDD/F exposure was considered a combination of six ways. These ways were classified depending on if they were due to a direct deposition of the MSWI emissions or to indirect exposure. Soil intake, ingestion of vegetables from the area, dermal absorption of soil, inhalation of resuspended particles, and air inhalation were considered as direct exposure, while ingestion through diet was considered as indirect exposure (1). The addition of the PCDD/F amount from the different pathways gives the total dose.

Risks for adverse human health effects are estimated assuming to be carcinogens or non-carcinogens. Non-carcinogenic risks were estimated comparing the calculated daily intake with the non-cancer potency factor for chronic exposure. Carcinogenic risks were calculated by multiplying the estimated daily dose by the cancer potency factor for PCDD/Fs. Monte Carlo simulation was carried out to obtain variability and uncertainty propagation.

In the scenario of this study (Montcada, Barcelona), only adult population was considered. Table 1 shows a description of the Monte Carlo parameter distribution for risk assessment evaluation for people living in the vicinity of the MSWI. The commercial software package Crystal Ball (Version 4.0) was used. Crystal Ball uses a Monte Carlo simulation in order to propagate the distributions. The end result was a distribution of the risk with corresponding probabilities.

Table 1: Monte Carlo parameter distributions for direct exposure for the population living in the vicinity of the MSWI

| Parameter | Units | Type | Distribution * |
|---|---|---|---|
| Soil Ingestion Rate (2) | mg/day | log-normal | 3.44 ± 0.80 |
| Fraction absorption ingestion of soils (3) | unitless | point | 40 |
| Vegetables ingestion rate [a] | g/day | log-normal | 203 ± 80 |
| Fraction absorption ingest. of veg. (3) | unitless | point | 60 |
| Fraction vegetables from the area [a] | unitless | uniform | 1 – 10 |
| Resuspended part. from the soil (4) | unitless | point | 50 |
| Ventilation rate (5) | $m^3$/day | log-normal | 20 – 2 |
| Fraction retained in the lungs (3) | unitless | uniform | 60 |
| Particles concentration [a] | $\mu g/m^3$ | point | 133 |
| Fraction absorption inhalation (3) | unitless | point | 100 |
| Contact time soil-skin (1) | hr/day | uniform | 1 – 2 |
| Exposed skin surface area (1) | $cm^2$ | triangular | 1980 (910–2940) |
| Dermal absorption factor (6) | unitless | triangular | 0.003 (0-0.03) |
| Soil to skin adherence factor (1) | $mg/cm^2$ | uniform | 0.75 - 1.25 |
| PCDD/Fs conc. in soils from the area (7) | ng/kg | triangular | 4.8 (0.06-127) |
| PCDD/Fs conc.in veget. from the area (7) | ng/kg | triangular | 0.79 (0.32-1.94) |
| PCDD/Fs conc. in air from the area [b] | $pg/m^3$ | triangular | 0.55 (0.15-0.95) |
| Intake of meat [a] | g/day | log-normal | 40 ± 84 |
| Intake of eggs [a] | g/day | log-normal | 26 ± 28 |
| Intake of fish [a] | g/day | log-normal | 80 ± 53 |
| Intake of milk [a] | g/day | log-normal | 188 ± 177 |
| Intake of dairy products [a] | g/day | log-normal | 69 ± 60 |
| Intake of oil [a] | g/day | log-normal | 31 ± 18 |
| Intake of cereals [a] | g/day | log-normal | 175 ± 90 |
| Intake of pulses [a] | g/day | log-normal | 22 ± 21 |
| Intake of vegetables [a] | g/day | log-normal | 203 ± 80 |
| Intake of fruits [a] | g/day | log-normal | 296 ± 174 |
| PCDD/F conc. in meat (8) | ng/kg | point | 0.12 |
| PCDD/F conc. in eggs (8) | ng/kg | point | 0.13 |
| PCDD/F conc. in fish (8) | ng/kg | point | 0.42 |
| PCDD/F conc. in milk (8) | ng/kg | point | 0.12 |
| PCDD/F conc. in dairy products (8) | ng/kg | point | 0.04 |
| PCDD/F conc. in oils (8) | ng/kg | point | 0.56 |
| PCDD/F conc. in cereals (8) | ng/kg | point | 0.25 |
| PCDD/F conc. in pulses (8) | ng/kg | point | 0.19 |
| PCDD/F conc. in veget. (8) | ng/kg | point | 0.14 |
| PCDD/F conc. in fruit (8) | ng/kg | point | 0.09 |
| Fraction absorption ingestion of food (3) | unitless | point | 60 |
| Body weight [c] | kg | log-normal | 67.52 ± 12.22 |
| Non-cancer potency factor (9) | pg /kg day | uniform | 1 – 4 |
| Cancer potency factor (6) | kg day/mg | uniform | 34000-56000 |

*To describe the distribution, mean and standard deviation are used for log-normal distributions, low and high values for uniform distributions, and the mean, low and high values for triangular distributions.

[a] Generalitat of Catalonia, Statistics Department, personal communication.

[b] Generalitat of Catalonia, Environment Department, personal communication.

[c] Salas et al., personal communication.

**Results and Discussion**

Figure 1 shows the sensitivity analysis for total direct exposure from the different pathways due to MSWI emissions. The mean and standard deviation of direct exposure of PCDD/Fs

were 1.33E-2 and 5.39E-3 ng/day, respectively. The percentiles 10th, 50th and 90th were 7.64E-3, 1.23E-2 and 2.03E-2 ng/day, respectively.

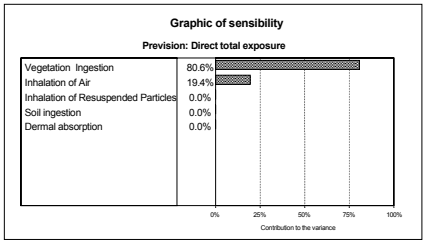


Figure 1: Results of sensitivity analysis for a direct exposure

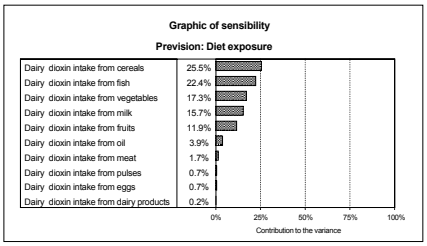


Figure 2: Results of sensitivity analysisfor diet exposure

The sensitivity analysis for diet exposure (Figure 2) shows the contribution of each food group to the total diet variance. Daily intake of PCDD/Fs through the diet was 122.17 pg I-TEQ/day (standard deviation, 28.86). The percentiles 10th, 50th and 90th were 89.66, 118.54 and 159.20 pg I-TEQ/day.

*Total exposure*

The result of the direct exposure was 2.10E-4 ng I-TEQ/kg/day (standard deviation 8.92E-5), while 1.88E-3 ng I-TEQ/kg/day was that from the diet (standard deviation 5.63E-4). Therefore, the total dose was 2.09E-3 ng I- TEQ/kg/day (standard deviation, 5.67E-4). The 2% of the total exposure was due to direct MSWI exposure, while the 98% was due to exposure from diet. The tolerable average intake of PCDD/Fs recently established by the World Health Organization (WHO) is between 1 and 4 pg I-TEQ/kg/day for lifetime exposure (9). Consequently, the current total exposure: 1.87 pg I-TEQ/day/kg is inside of this tolerable intake.

*Risk evaluation*

The non-cancer and cancer risk from direct, indirect (diet) and total exposure, are shown in Tables 2 and 3, respectively. The results reveal that the uncertainty of the estimated non-cancer risk defined as the ratio of the 90th to the 10th percentile is 3.6. With respect to total cancer risk, the ratio between the 90th percentile and 10th percentile is about 2.3.

Table 2: Non-cancer risk: mean, standard deviation and 10 th, 50 th and 90th percentiles

| | | | Percentiles | | |
|---|---|---|---|---|---|
| ***Non-cancer risk*** | **Mean** | **SD** | **10th** | **50th** | **90th** |
| **Direct Risk** | 9.78E-2 | 6.15E-2 | 4.15E-2 | 8.19E-2 | 1.75E-1 |
| **Diet Risk** | 8.61E-1 | 4.55E-1 | 4.20E-1 | 7.40E-1 | 1.48 |

Table 3: Cancer risk: mean, standard deviation and 10th, 50 th and 90th percentiles

| | | | Percentiles | | |
|---|---|---|---|---|---|
| ***Cancer risk*** | **Mean** | **SD** | **10th** | **50th** | **90th** |
| **Direct Risk** | 9.71E-6 | 4.61E-6 | 4.98E-6 | 8.74E-6 | 1.56E-5 |
| **Diet Risk** | 8.05E-5 | 2.77E-5 | 5.06E-5 | 7.57E-5 | 1.16E-4 |
| **Total Risk** | 9.02E-5 | 2.86E-5 | 5.56E-5 | 8.44E-5 | 1.26E-4 |

Non-cancer risk due to indirect exposure (diet) corresponds to 94.6 % of the total risk, while the cancer risk due to diet is 96.8% of the total risk.

An apportionment of the overall variance among key contributors to the non-cancer and cancer risk shows that uncertainty about the potency factors was the principal contributor to the uncertainty. The results of the structural decomposition analysis of the variable shows that the risk attributable to uncertainty about non-cancer potency was about 67.4% of the diet non-cancer risk variability, while for cancer risk the potency factor contributed with 20.6%. On the other hand, the contribution of the diet ranges between 32.6% and 79.4% of the diet risk in the cases of non-cancer and cancer risks, respectively. With respect to direct risk, the uncertainty in non-cancer potency factor is about 44.9% of the variability, while in cancer risk the potency factor contributed with 8.9%. In turn, the contribution of the direct dose was 55.1% and 91.1% of risk for cases of non-cancer and cancer risk, respectively.

**Conclusions**

1- In general, PCDD/F ingestion through diet contributed with more than 94% of the total risk, whereas exposition to PCDD/F emissions from the MSWI contributed less than 6%.
2- A big uncertainty was found in both non-cancer potency factor and in cancer potency factor.
3- According to the tolerable WHO daily intake of PCDD/Fs, neither the MSWI, nor the indirect exposure (diet) to PCDD/Fs in the Montcada would mean health risks for the general population.
4- It can be concluded that probabilistic analyses in which inter-individual variability and the uncertainty are analyzed can make easier considerations about their different sources and implications in a decision-make context.

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