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비교 위험도 평가 방법의 대기 오염에 대한 적용 연구

Comparative Risk Assessment Methodology: An Application to Air Pollution

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Abstract

The research in this paper centers on a comparative risk assessment for nearby air pollution by carcinogenic metal emission from municipal solid waste incinerators. If a substance is identified as a potential human carcinogen, the carcinogenicity may be related to the chemical form of a substance and the route of exposure.This type of information with regard to carcinogenic uncertainty is incorporated into hazard quantification.

In addition to the dioxin emission, the metal emission from municipal solid waste incineration is found to be a major contributor to human cancer risk via the inhalation route. The magnitude of risk by metals is about 5 times greater than that of risk by dioxins. Hexavalent form of chromium and cadmium compounds are major contributors to cancer risk from metal emission. In addition, hexavalent chromium is known to be human carcinogen while 2,3,7,8-TCDD is known to be only probable human carcinogen.

1. INTRODUCTION

In addition to the emission of dioxins, toxic metal emissions in particular may be a major contributor to human cancer risk from municipal solid waste(MSW) incineration. The several reasons for this statement are as follows:(a)metals are more likely present in municipal solid wastes;(b)unlike organics metals do not thermally destruct during combustion;and(c)metals are persistent in the environment. Thus, a comparative risk assessment methodology is applied to nearby atmospheric pollution by MSW incinerator emissions to compare risk from toxic metals with that from dioxins. The metal compounds containing arsenic(As), beryllium(Be),cadmium(Cd), chromium(Cr) and nickel (Ni) are of concern in this study because of their carcinogenicity.

The risk assessment method presented in this paper consists of hazard identification and hazard quantification. If a substance is identified as a potential human carcinogen,the carcinogenicity may be related to the chemical form of a substance and the route of exposure (Friberg, 1981). Regarding the carcinogenic potency of a pollutant, the chemical form of a substance and the route of exposure is investigated. This type of information is incorporated into hazard quantification. In order to quantify carcinogenic risks from the metal and dioxin emissions via the inhalation route, the following are determined: emission factor; air dispersion model; population data; and unit risk. These are combined to estimate comparative risks from metal and dioxin emissions imposed by a proposed MSW incinerator in the Los Angeles area.

2. MATERIALS AND METHOD

2.1 Risk Assessment Method

Health risks to human populations from toxic pollutants are a function of two factors: hazard and exposure. Health risk assessment is a process by which these two factors are interpreted, judging whether adverse health effects will or will not occur in exposed humans,and then evaluating the extent of these effects. A health risk assessment can be defined as a two-step process, i.e., hazard identification and hazard quantification. Hazard identification involves evaluating existing biomedical evidence to determine whether the pollutants will cause or contribute to adverse health effects. Hazard quantification for the route of inhalation involves several distinct tasks: emission estimation, air dispersion modeling, and risk characterization with uncertainty analysis.

As far as carcinogenic substances are concerned,the end-point of concern is a likelihood of cancer caused by these substances since this is by far the most sensitive end-point when using non-threshold extrapolation models. In the case of potential carcinogens, the objective of hazard identification is to establish how likely a substance is to be a human carcinogen. Whenever a compound is classified as a carcinogen, such a statement should only apply to specific forms of the compound (Friberg, 1981). For example, the hexavalent form of chromium is the most significant form with respect to carcinogenicity while the other form is of minor importance (Basu,1984). Furthermore, the importance of the route of exposure regarding metal carcinogenesis is identified. There has been no evidence that cadmium compounds are carcinogenic via ingestion (U.S. EPA, 1984a). Therefore, these two factors should be considered as far as information is available when quantifying carcinogenic risks from pollutant emissions.

The first step of hazard quantification, estimation of pollutant emissions, calculates emission rates of metals and dioxins from MSW incinerator stacks using the emission factors in units of kilograms of pollutant per ton of waste incinerated. The emission factors are developed from measured data for comparable incinerator facilities. The second step, air dispersion simulation, estimates pollutant transport by using the ISCLT(Industrial Source Complex Long Term) model. This model is used to predict annual average ground-level concentrations(GLCs) of contaminants at specifically identified receptors. The final step, risk characterization, quantifies the expected value of cancer risk and addresses uncertainties in the analysis. The two important measures for describing the impact are the maximum individual and the population average cancer risk.

2.2 Assessment of Emission Factor

Unlike uncontrolled metal emissions relatively more data exists for controlled metal emissions by air pollution control device (APCD). In addition, the U.S. Environmental Protection Agency (EPA) has recently compiled a data base of stack emissions for MSW incinerators including toxic metals (U.S. EPA, 1987). This data base is also largely for controlled emissions, regardless of the type of APCD. The data from mass-burn incinerators are relatively better characterized than the data from other type of MSW incinerators, e.g.,modular or refuse-derive-fuel incinerators. Unlike the modular incinerators which are specifically designed for a small combustion demand, the data indicate that mass-burn incinerators are designed to meet a variety of capacity requirements up to more than 1,000 tons per day. Most new, large mass-burn incinerators have waterwall furnaces for energy recovery. Because of the reasons stated above; e.g.,more data, larger design capacity and energy recovery for the new type mass-burn incinerator, an emission factor for each metal and dioxin is estimated using the data from mass-burn, heat recovery incinerators. Data was obtained from 9 facilities (that is, Baltimore, Braintree, Hampton, Malmo, Marion, Munich, Tulsa, Westchester, and Wurzburg), which were operated under near-steady-state conditions (U.S.EPA,1987; Jerry and Mills, 1988).

The metal emission factor for the Hampton facility is the largest one while the emission factor for the Marion facility is the smallest one. The reason is that the Hampton facility has been notable for several design and operational problems while the Marion facility is new facility using a Martin GmBH stoker combustion system. In addition, the Hampton incinerator is equipped with only electrostatic precipitator (ESP) as its APCD. But, the APCD for the Marion incinerator consists of a spray dryer and a fabric filter. A metal emission factor for this study is estimated as the mean emission factor, which is the average of values from all facilities excluding the Hampton and Marion facilities.

An emission factor for the mixture of dioxins and furans emitted from a MSW incinerator is determined by employing an approach suggested by the EPA (U.S. EPA, 1985). The approach is that assessing the potential health effects of the mixture is made by converting the mixture into a measure of toxic equivalent 2,3,7,8-TCDD (tetrachlorodibenzo-dioxin). Like the derivation of the emission factor for metals, an emission factor for toxic equivalent dioxin is derived from previous data sets. All of emission factors are presented in Table 1.

2.3 Carcinogenic Forms and Inhalation Route

The EPA has specified chemical species and routes of exposure for some metals regarding their carcinogenic evidence to humans in its Health Assessment Documents. The Documents have concluded that the metals of interest to this study and 2,3,7,8-TCDD cause carcinogenic effects via the inhalation route. In addition, the EPA has provided the estimate of carcinogenic potency of each pollutant in terms of a unit risk for the inhaltion route. A "unit risk" is defined as excess lifetime cancer risk associated with breathing 1 μg of a chemical per m^3 of air over a 70-year life span for a 70-kg human. "Excess" means that the risk is in addition to the risk of cancer caused by background sources.

The unit risk for each pollutant is estimated by the linear risk model in the case of human data or by the linearized multistage model in the case of animal data, respectively. With regard to carcinogenesis of chromium and nickel compounds, Health Assessment Documents appear to have concluded that the unit risk values for chromium and nickel compounds be applied to only hexavalent form of chromium and subsulfide form of nickel, respec-tively. The unit risk for each chemical is sum-merized in Table 2.

Table 1. Emission factors (kg/ton of MSW)

Pollutant	Hampton	Mean	Marion
As	1.0×10^{-3}	3.0×10^{-5}	1.9×10^{-8}
Be	8.2×10^{-8}	1.1×10^{-7}	9.5×10^{-9}
Cd	2.1×10^{-3}	2.7×10^{-4}	3.3×10^{-10}
Cr	1.2×10^{-3}	9.1×10^{-4}	1.4×10^{-11}
Ni	9.5×10^{-4}	6.4×10^{-4}	3.3×10^{-12}
2,3,7,8-TCDD (toxic equivalent)	1.4×10^{-6}	9.1×10^{-9}	1.7×10^{-10}

Table 2. Unit risk

Pollutant	Unit risk $(\mu g/m^3)^{-1}$
As	4.29×10^{-3}
Be	2.4×10^{-3}
Cd	1.8×10^{-3}
Cr(VI)	1.2×10^{-2}
Ni(subsulfide)	4.8×10^{-4}
2,3,7,8-TCDD	3.3×10^{-5} $(pg/m^3)^{-1}$

3. RESULTS AND DISCUSSIONS

Based on the emission factor, the maximum individual cancer risk-individual lifetime cancer risk of the maximally exposed person-from metal emission is estimated as 7.4 x 10^{-7}, while that from dioxin emission is estimated as 1.3 x 10^{-7}. The population average individual risk is also computed by using population weighted GLC.

The population average individual risks from metal and dioxin emissions are 1.1 x 10^{-7} and 1.9 x 10^{-8} within 16 km of a proposed source, respectively. These magnitudes are about 1/7 of the maximum individual cancer risks. The total population individual risk of 1.3 x 10^{-7} from both emissions means 0.4 excess cancer burdens in a population of 2.97 x 10^{6} persons by nearby air pollution of the

Table 3. Carcinogenic inhalation risk

Pollutant	Maximum individual cancer risk	Population average individual risk
Total risk	8.7×10^{-7}	1.3×10^{-7}
Metal risk	7.4×10^{-7}	1.1×10^{-7}
Dioxin risk	1.3×10^{-7}	1.9×10^{-8}
Major metal compounds	Cr(VI), Cd	Cr(VI), Cd

proposed incinerator. The risk from metal emission is 85% of the total risk, which is greater than the risk from dioxin emission by more than a factor of 5. Major metal contributions come from hexavalent chromium and cadmium emissions. It should be noted that hexavalent chromium is human carcinogen {EPA Group A} while cadmium {Group B1} and 2,3,7,8-TCDD{Group B2} are only probable human carcinogens. These results are summerized in Table 3.

Several uncertainties are associated with this comparative risk assessment. The first one comes from the estimated emission factor for each pollutant. The range of the emission factors for each metal are many orders of magnitude. For example, it is 7 orders of magnitude for chromium. Therefore, the mean emission factor was developed excluding those from the Hampton and Marion incinerators. There are still as many as 2 or 3 orders of magnitude difference between the emission factors which were used to develop the mean emission factor. However, with the limited available data the mean emission factor seems to be representative for a proposed MSW incinerator. If a proposed incinerator has a new updated combustion system and it has not undergone severe operational problems,the maximum individual cancer risk can be less than 10^{-7}, which well meet the risk standard of 10^{-5} (U.S.Federal Register, 1987) or even 10^{-6}. The second comes from the dispersion model. The range of this uncertainty has been generally estimated with a factor of 2 to even 4 (U.S. EPA, 1984b). The third one is associated with an estimation of the unit risk. The range of the uncertainty is as many as 3 to 5 orders of magnitude. However, the unit risks used in this study are considered the plausible upper bounds among many possible estimates. This would make the results presented, conservative.

The final uncertainty comes from the fraction of hexavalent chromium or nickel subsulfide in the chromium or nickel emission, respectively. One may assume that cadmium and nickel emissions from an incinerator are totally (100%) hexavalent chromium and nickel subsulfide. But,this appears to be very unlikely. From previous investigations approximately 10% of chromium (U.S. EPA, 1986; Jerry and Mills, 1988) and nickel emissions are assumed to be hexavalent and subsulfide for the reasonable case in this study. If one thinks about even the possible worst case, the associated uncertainty is a factor of 10 for these two metals.

4. CONCLUSIONS

A comparative risk assessment has been presented for nearby air pollution by MSW incinerators with an emphasis on carcinogenic metal emission. In addition to the dioxin emission, the metal emission from MSW incineration was found to be a major contributor to human cancer risk via the inhalation route. The risk from metal emission was estimated to be about 85% of the total risk imposed by both dioxin and metal emissions. This magnitude of risk from metals is about 5 times greater than that of risk from dioxins.

Hexavalent form of chromium and cadmium compounds are major contributors to cancer risk from metal emission. In addition, hexavalent chromium is known to be human carcinogen. On the other hand, toxic equivalent dioxin(2,3,7,8-TCDD) is known to be only probable human carcinogen.

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초록

본 연구는 비교 위험도 평가 기법을 사용하여, 도시 고형 폐기물의 소각에 따른 대기 오염 중 발암성 금속이 호흡기를 통해 소각로 주변 주민에게 미치는 암 위험도를 디옥신과 비교해 평가하였다. 어떤 물질이 인체에 암을 유발할 가능성이 있는 경우, 이 발암성은 물질의 화학적 형태 및 피폭경로에 관련될 지도 모른다. 물질의 발암성에 대한 이러한 사실이 조사되었고 위험도 정량화에 고려되었다. 본 연구 결과, 도시 고형 폐기물의 소각시 방출되는 발암성 금속으로 인한 위험도는 디옥신으로 인한 위험도의 약 5배 정도로 평가되었고, 위험도의 측면에서 가장 중요한 금속은 6가 크롬과 카드뮴인 것으로 판명되었다.