Socio-Economic Analysis of Dioxin Reduction Measures in Japan

KISHIMOTO, Atsuo [1)4)], OKA, Tosihiro [2)4)], YOSHIDA, Kikuo[1)4)] and NAKANISHI, Junko[3)4)]

[1)] National Institute for Resources and Environment, Onogawa 16-3, Tsukuba, 305-8569, Japan (e-mail: atsuo@nire.go.jp)
[2)] Fukui Prefectural University, 4-1-1 Kenjojima, Matsuoka-cho, Fukui 910-1195, Japan
[3)] Yokohama National University, Tokiwadai 79-7, Hodogaya-ku, Yokohama-shi, Kanagawa 240-8501, Japan
[4)] CREST, Japan Science and Technology Corporation

Key Words: cost effectiveness analysis, dioxins, municipal solid waste incinerators, cost per life-year saved

Abstract

The national government has set an emission standard for dioxins to reduce dioxin exposure levels. In this study, cost effectiveness analyses are carried out for countermeasures that were recently taken and are being taken at municipal solid waste incinerators in Japan. Annual costs are estimated by telephone survey and model calculations. Annual decrease in the incidence of cancer is estimated in three steps. First, the annual decrease in the volume of dioxin emissions is estimated. Next, using a mathematical model, the annual decrease in human exposure is estimated. Finally, the annual decrease in the incidence of cancer is estimated by applying the cancer slope factor. When annual costs are divided by the annual number of life-year gained, cost per life-year saved (CPLYS) is obtained. CPLYS is estimated to be 9.5 million yen for emergency countermeasures and 125 million yen for long-term countermeasures.

1. Introduction

Since 1990, dioxins have attracted much attention in Japan, and a new regulation for the emission of dioxins was introduced in 1997. This regulation is targeted at the major sources of dioxin emissions, of which municipal solid waste incinerators (MSWIs) have been regarded as the largest contributor. This regulation, however, is not based on any systematic assessment of the effectiveness or the efficiency in reducing health risks from dioxins; rather, it is pushed by strong public opinion. In this presentation, we present an assessment of the cost effectiveness of this regulation.

One reason why the regulation on MSWIs may not be efficient is that they are not major contributors to human exposure to dioxins, although they are the largest source of newly emitted dioxins. As shown in FIGURE 1, 90% of dioxin intake comes from food, of which more than half is via seafood (MHW 1999). Dioxin contamination in seafood depends strongly on the accumulation from past discharge, since a large quantity of dioxins were included as impurities in some herbicides and released into paddy fields during the 1960s and 1970s (Masunaga 1999). Those dioxins continue to flow out from the paddy fields and largely influence dioxin levels in fish and shellfish. The schematic illustration of our study is shown in Figure 2.

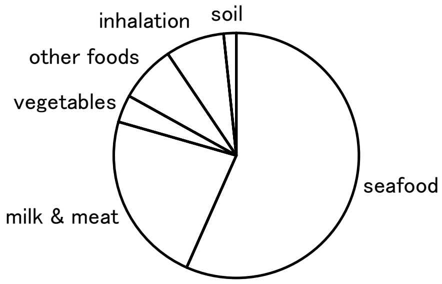

FIGURE 1. Routes of Human Exposure

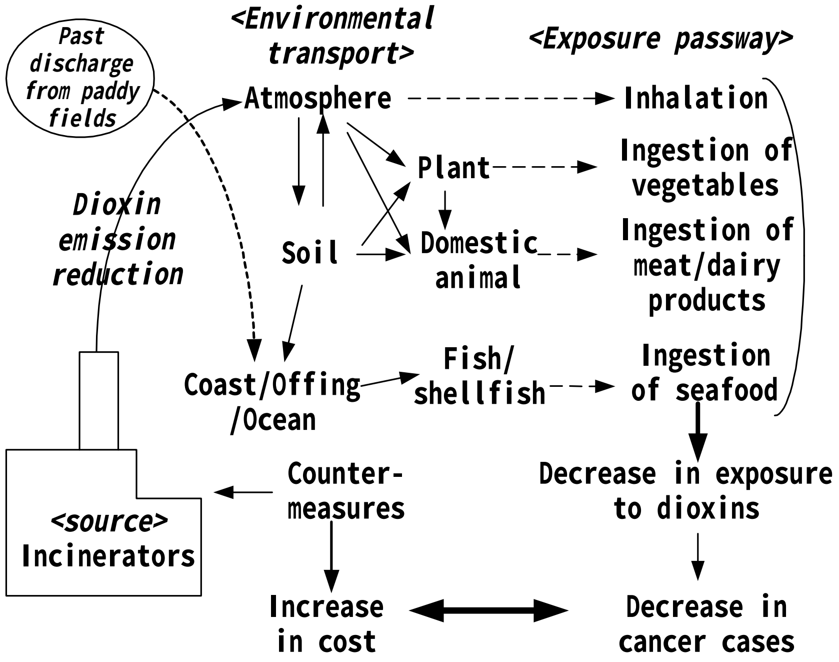

FIGURE 2. Schematic illustration of this study

The term ‘dioxins’ in this study refers to a family of polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). We also incorporate coplanar PCB (co-PCB) in our calculation. The relative toxicity of each is weighted by means of toxic equivalence factors (TEFs). WHO-TEF is adopted in this study. Toxic equivalence (TEQ) of a mixture of dioxin-like compounds is obtained when TEF of each congener is multiplied by its volume and the products are summed.

2. New Regulation

The Ministry of Health and Welfare (MHW), who set the value of tolerable daily intake (TDI) at 10 pg-TEQ/kg-bw/day in 1996, published a new set of guidelines in 1997 (MHW 1997a). In this set of guidelines, MHW set a target figure for existing incinerators and decreased the target figure of new incinerators. Those target figures were transformed into mandatory emission standards based on law by the amendment of the "Waste Disposal and Public Cleansing Law". Those MSWIs which did not satisfy the temporary emission standard of 80 ng-TEQ/Nm^3 in 1997 were forced to take countermeasures to reduce dioxin emissions to satisfy that level by December 1998. Emergency countermeasures were undertaken by 114 MSWIs. The long-term emission standards shown in Table 1 will take effect in December 2002 and MSWIs that do not satisfy these standards have to take countermeasures.

TABLE 1. Long-Term Emission Standards for Dioxins in Exhaust Gas from MSWIs

Type of incinerator	Category		Standard ng-TEQ/Nm^3
Continuous-operation incinerators	Newly installed incinerators		0.1
	Existing incinerators	Subject to old guidelines	0.5
		Not subject to old guidelines	1
Others	Existing incinerators	Continuous operation	1
		Intermittent operation	5

Source: Ministry of Health and Welfare

In 1999, TDI was revised to 4 pg-TEQ/kg-bw/day (including co-PCB), following the proposal of the World Health Organization. Emergency countermeasures were completed and long-term countermeasures are now being undertaken.

3. Cost of Reducing Dioxin Emissions

3.1. Emergency countermeasures

There were 114 MSWIs that did not satisfy the temporary emission standard in 1997. At those plants, emergency countermeasures were taken. Data on the cost of emergency countermeasures were collected by visiting two plants and carrying out detailed interviews, and by conducting a telephone survey of 112 plants. The emergency countermeasures taken were divided into three types. The first one is to ensure adequate burning temperature and burning time and achieve complete combustion. The second one is to cool down exhaust gas as soon as possible. The third one is to treat exhaust gas.

Some plants were not repaired, but were shut down because they were timeworn or had difficulty in repairing. The sum of the capital investment cost which was spent for repair is estimated to be 10.12 billion yen and the sum of the cost generated by closure of incinerators which is calculated using the above equation is 4.64 billion yen. The investment cost for each plant was converted into an annualized value, which is calculated to be 0.70 billion. When the increment of administrative and maintenance expense is added, the annualized value of emergency countermeasures was calculated to be about 1.74 billion yen.

The quantity of dioxins reduced by the emergency countermeasures was calculated to be 780 g-TEQ / year according to MHW data. In order to incorporate co-PCB and to replace I-TEF with WHO-TEF, ‘780 g-TEQ’ needs to be multiplied by 1.157, and this gives 900 g-TEQ / year, which corresponds to 18% of the baseline level in 1996. The average cost per gram of dioxin reduced is 1.94 million yen.

3.2. Long-term countermeasures

Since the long-term countermeasures have not been completed yet, we cannot obtain actual cost data and actual risk reduction data. The methodology adopted here is to predict the measures taken by classifying the plants according to initial dioxin level in emission gas, plant type and capacity, and plant’s remaining lifetime, and to estimate their costs by extrapolating the actual cost data in the emergency countermeasures. Although a detailed account of the calculation is not given in this paper, we applied this procedure to 1655 plants. The result is that it is necessary to invest 349 billion yen by 2002 and its annualized cost is 16.8 billion yen. Adding the incremental cost of operation and maintenance to this, the annualized total cost is 37.2 billion yen. The quantity of dioxins reduced by the long-term countermeasures was calculated to be 1910 g-TEQ / year, which corresponds to 44% of the baseline level in 1996. In order to incorporate co-PCB and to replace I-TEF with WHO-TEF, ‘1910 g-TEQ’ needs to be multiplied by 1.157, and this gives 2210 g-TEQ / year. The average cost per gram of dioxin reduced is 16.8 million yen.

4. Estimation of Reduced Daily Intakes

In this section, we estimate the decrease in the daily intake of dioxins due to emergency and long-term countermeasures. According to MHW, the average daily intake of dioxins (including co-PCB) before the introduction of those regulations was about 2.60 pg-TEQ/kg-bw/day (MHW 1999). The exposure to dioxins via inhalation, leafy vegetables, milk and meat will decrease in proportion to the reduction of dioxin emissions. On the other hand, the decrease in the exposure via ingestion of seafood and root vegetables will take some time after implementation of regulations. Since there is much regional difference with regard to the exposure via inhalation, the entire population in Japan is divided into three groups, as shown in Figure 3. Sixty-seven percent of dioxins emitted into the air is attributable to MSWIs (Environment Agency 2000).

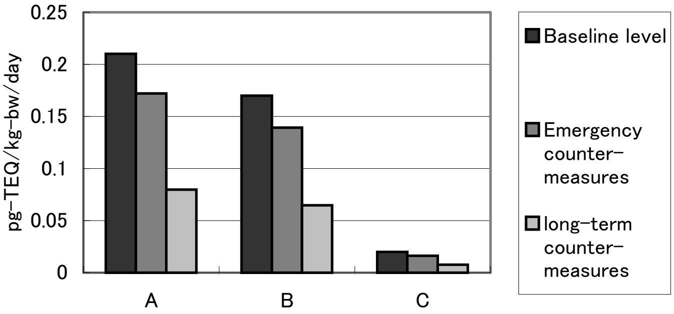

FIGURE 3. Decrease in Exposure via Inhalation

* 'A' indicates 'metropolitan areas' which have 25 million population; 'B' indicates 'midsize and small cities' which have 73 million population; and 'C' indicates 'background areas' which have 22 million population. These figures are our original estimates.

**Baseline levels were cited from Dioxin Risk Assessment Study Group (MHW 1997b) multiplied by 1.157 to incorporate co-PCB and to replace I-TEF with WHO-TEF.

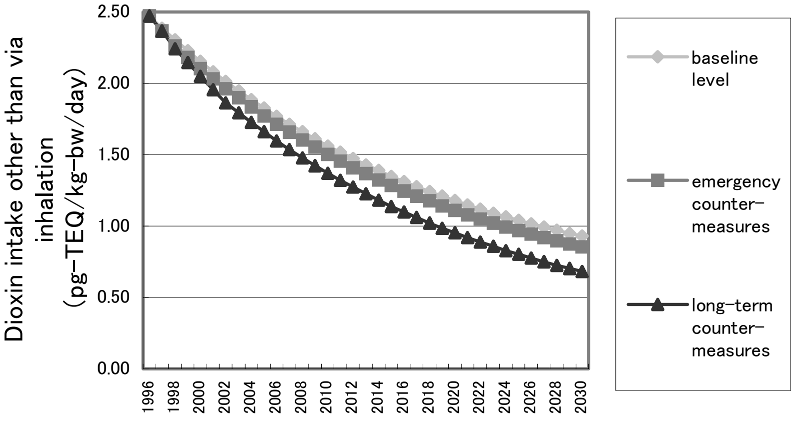

FIGURE 4. Prediction of dioxin intake

To estimate the exposure level other than that via inhalation, we modeled the transport pathways of dioxins from sources to the human body and estimated the time course of exposure levels of dioxins in Japanese from the past to the future (Yoshida et al. 2000). As emission sources, we considered not only incinerators but also impurities in herbicides used in the past, and PCB and its impurities. The secular variation of average daily intake under the following three scenarios is predicted and compared. The first one is the baseline case with no control measures. The second one is the hypothetical case that only emergency countermeasures are undertaken.

The third one is the actual case that both emergency and long-term countermeasures are completed. The net effect of emergency countermeasures is obtained by the second scenario subtracted by the baseline scenario and the net effect of long-term countermeasures is obtained by the third scenario subtracted by the second scenario. Figure 4 shows the decrease in dioxin intake (other than via inhalation) caused by both countermeasures from 1996 to 2030.

5. Estimation of Reduced Risk

To estimate the number of cancer cases reduced due to the emergency and long-term countermeasures, we use dose-response function. We adopt the linear dose-response model proposed by the U.S. Environmental Protection Agency (U.S.EPA) although WHO and the Japanese government take the position that there is a threshold since dioxins act not as initiators but as promoters in the process of carcinogenic action. U.S. EPA assumed dioxins to be activators mediated by an Ah receptor and proposed a tentative cancer slope factor of 1.0×10^{-4} $[\text{pg/kg-bw/day}]^{-1}$ for the oral intake of 2,3,7,8-TCDD in a draft report (U.S.EPA 1997). This factor was applied to other congeners and intake via inhalation. The cancer risk caused by dioxins is calculated from the lifetime average daily intake multiplied by the cancer slope factor (Yoshida et al. 2000b). The number of cancer cases reduced due to the decrease in lifetime exposure to dioxins is obtained from the following equation:

$$\text{Cancer case avoided} = \triangle\text{dioxins} \times \text{POP} \times (1.0 \times 10^{-4}),$$

where $\triangle$dioxins is the decrease in the daily intake of dioxins; and POP is the population exposed to $\triangle$dioxins. To estimate the number of life expectancies gained due to the decrease in one-year exposure to dioxins, the number of cancer cases reduced due to the decrease in lifetime exposure to dioxins is multiplied by 0.16 since the average loss of life expectancy due to one-year exposure to the level that will cause one cancer death if exposed during one's lifetime was estimated to be about 0.16 (Oka et al. 1997). The number of life-year gained each year from 1998 to 2030 is discounted at 3% per year, yielding a present value. When the sum of them is converted into the annualized value, we find that the emergency countermeasures save 180 life-years and the long-term countermeasures save 300 life-years annually.

6. Cost per Life-Year Saved

To estimate the cost per life-year saved (CPLYS), the annual cost must be divided by the number of life-years gained. As for emergency countermeasures, the annual cost is estimated to be 1.74 billion yen and the number of life-years gained is 180. Therefore, CPLYS is about 9.5 million yen. As for long-term countermeasures, the annual cost is estimated to be 37.2 billion yen and the number of life-years gained is

300. Therefore, CPLYS is about 125 million yen.

In order to discuss our results, it is helpful to compare our results with those of previous studies shown in Table 2 (Gamo et al. 1995, Nakanishi et al. 1998, Kajihara et al. 1999). It is easily found that although emergency countermeasures are cost-effective on average, long-term countermeasures are relatively cost-ineffective on average.

TABLE 2. Case Studies of Cost Effectiveness for Chemical Substances Control

case study	cost per life-year saved (million yen)	(million dollars
Prohibition of chlordane	45	0.4
Prohibition of mercury electrode process in caustic soda production	570	5.2
Control of benzene in gasoline	230	2.1
Dioxin control by emergency countermeasures in municipal incinerators	9.5	0.086
Dioxin control by long-term countermeasures in municipal incinerators	125	1.1

7.Discussion

In this study, only cancer risk was estimated and quantified. However, it was reported that dioxins may cause various noncancerous adverse health effects, such as reproductive dysfunction, endometriosis, and neurobehavioral effect. Those risks are described in terms of the margin of exposure (MOE). MOE is defined as the ratio of the lower 95% confidence limit of the dose associated with a 10% increase in effect (LED_{10}) to the dose associated with environmental exposure of a chemical. Yoshida et al. (8) calculated the MOE values for noncancer endpoints and concluded that the estimated MOE values for reproductive dysfunction and endometriosis were sufficiently high to guarantee safety; however, the estimated MOE value for neurobehavioral effects on infants and fetuses was low and worth paying attention to. Counting only cancer risk in this study may lead to underestimation of the effectiveness of countermeasures. However, as discussed below, assuming the existence of the threshold for these effects, even these potential adverse effects are “considered to be recoverable by the physical training (MHW 1999).

We performed cost effectiveness analysis applying the cancer slope factor of dioxins, which assumed no threshold for dioxin exposure. However, the Japanese government assumes a threshold, or TDI for human exposure. In this case, dioxin intake is described in terms of MOE. Yoshida et al. (2000b) calculated MOE of the Japanese population and concluded that the estimated MOE values were much higher than 10 and were sufficient to guarantee safety. Therefore, the method used in this study produces the upper limit of the number of life-years saved.

Although uncertainty exists in this type of calculation, the cancer slope factor seems to have the largest uncertainty. Therefore, we examined the sensitivity of the CPLYS to the choice of the cancer slope factor. U.S.EPA also estimated the slope factors to be 1.7×10^{-3} (relative risk model) and 2.8×10^{-3} (absolute risk model) for all cancer deaths if the slope factors based on human epidemiologic data are adopted (U.S.EPA 1997). The use of these slope factors leads to a marked increase in the number of cancers avoided and a marked decrease in the value of CPLYS. In the case of 1.7×10^{-3}, CPLYS is about 0.56 million yen for emergency countermeasures, and 7.4 million yen for long-term countermeasures. In the case of 2.8×10^{-3}, CPLYS is about 0.34 million yen for emergency countermeasures, and 4.5 million yen for long-term countermeasures. In those cases, both emergency and long-term countermeasures are considerably cost-effective and even stricter regulations may be worth considering. The cancer slope factor has much influence on the number of CPLYS.

Acknowledgment

This work was supported by CREST (Core Research for Evolutional Science and Technology) of the Japan Science and Technology Corporation (JST).

References

Environment Agency, *On the Emission Inventory of Dioxins*, 2000 (in Japanese)

Gamo, M.; Oka, T.; Nakanishi, J. *Reg. Toxicol. Pharmacol.* 1995, 21, 151-157.

Kajihara, H.; Ishizuka, S.; Fushimi, A; Masuda, A. *In Proceedings of the Second International Workshop on Risk Evaluation and Management of Chemicals*, Yokohama, Japan, 1999, 62-70.

Masunaga, S., *In Proceedings of the Second International Workshop on Risk Evaluation and Management of Chemicals*, Yokohama, Japan, 1999, 1-10.

Ministry of Health and Welfare, *Guideline for Preventing the Generation of Dioxins in the Waste Treatment Process*, 1997a (in Japanese)

Ministry of Health and Welfare, *Report of Research Group on Risk Assessment of Dioxins*, 1997b (in Japanese)

Ministry of Health and Welfare, *On the Tolerable Daily Intake of Dioxins*, 1999 (in Japanese)

Nakanishi, J.; Oka, T.; Gamo, *M. Environ. Engg. Policy*, 1998, 1, 3-9.

Oka, T,; Gamo, M.; Nakanishi, J. *Japanese Journal of Risk Analysis*, 1997, 8(2), 174-186.

U.S. Environmental Protection Agency, *Health Assessment Document for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds.* EPA560/5-90-14 (External Review Draft), 1997.

Yoshida, K.; Ikeda, S.; Nakanishi, J. *In Proceedings of the Third International Workshop on Risk Evaluation and Management of Chemicals*, Yokohama, Japan, 2000a, 94-102.

Yoshida, K.; Ikeda, S.; Nakanishi, J. *Chemosphere*, 2000b, 40, 177-185.