Cost Effectiveness of Reducing Dioxin Emissions from Municipal Solid Waste Incinerators in Japan

ATSUO KISHIMOTO,*,†,‡
TOSIHIRO OKA,‡,§
KIKUO YOSHIDA,†,‡ AND
JUNKO NAKANISHI‡,||

Research Center for Chemical Risk Management, National Institute of Advanced Industrial Science and Technology, Onogawa 16-1, Tsukuba, 305-8569 Japan, Fukui Prefectural University, 4-1-1 Kenjojima, Matsuoka-cho, Fukui, 910-1195 Japan, Institute of Environmental Science and Technology, Yokohama National University, 79-7 Tokiwadai, Hodogaya-ku, Yokohama, 240-8501 Japan, and CREST, Japan Science and Technology Corporation, Japan

The main sources of dioxin emissions are municipal solid waste incinerators. The Japanese national government has set an emission standard for dioxins to reduce dioxin exposure levels. In this study, cost-effectiveness analyses are carried out regarding countermeasures that were recently taken and are being taken at municipal solid waste incinerators in Japan. Annual costs were estimated by telephone survey and model calculations. Annual decrease in the incidence of cancer was estimated in three steps. First, the annual decrease in the volume of dioxin emissions was estimated. Next, using a mathematical model, the annual decrease in human exposure was estimated. Finally, the annual decrease in the incidence of cancer was estimated by applying the cancer slope factor. When annual costs are divided by the annual number of life-years saved, cost per life-year saved (CPLYS) was obtained. CPLYS was estimated to be 7.9 million yen for emergency countermeasures and 150 million yen for long-term countermeasures. However, it must be noted that these obtained CPLYSs are highly dependent on the cancer slope factor and should be considered as an upper limit since there may be a cancer effect threshold.

Introduction

Since 1990, dioxins have attracted much attention in Japan, and a new regulation for controlling dioxin emissions 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 of reducing health risks from dioxins; rather, it is driven by strong public opinion. In this paper, we present an assessment of the cost-effectiveness of this regulation. The reduction of cancer incidence resulting from these countermeasures and the costs incurred are estimated.

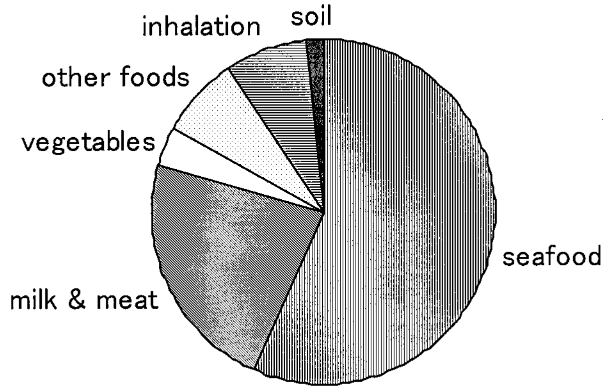

FIGURE 1. Routes of human exposure.

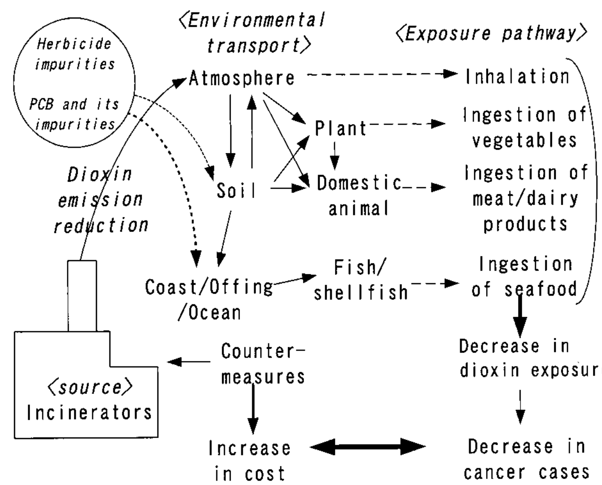

FIGURE 2. Schematic illustration of this study.

One reason this regulation regarding MSWIs may not be efficient is that MSWIs are not major contributors to human dioxin exposure, although they are the largest source of newly emitted dioxins. The breakdown of human exposure pathways is shown in Figure 1 (*1*). One-half of the total exposure is derived from coplanar PCBs, which come mainly from PCB products used in the past.

Our study involves two types of policy analysis. One is the prospective analysis, and the other is the retrospective analysis. We also modeled the transport pathway of dioxins from their sources to humans and predicted the time course of exposure levels. The schematic illustration of our study is shown in Figure 2.

The term dioxins in this study refers to a family of polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). We also incorporate coplanar PCBs in our calculations. PCDDs consist of 75 congeners, and PCDFs consist of 135 congeners. Although there are 209 PCB congeners, only 12 of them have dioxin-like toxicity, which are referred to as coplanar PCBs. The relative toxicity of each is weighted by means of toxic equivalency factors (TEFs). WHO-TEF is adopted in this study. The toxic equivalent (TEQ) of a mixture of dioxin-like compounds is obtained when the TEF of each congener is multiplied by its amount, and the products are then summed.

* Corresponding author e-mail: kishimoto-atsuo@aist.go.jp; telephone: +81-298-61-8297; fax: +81-298-61-8796.
† National Institute of Advanced Industrial Science and Technology.
‡ Japan Science and Technology Corporation.
§ Fukui Prefectural University.
|| Yokohama National University.

10.1021/es001782z CCC: $20.00
Published on Web 05/23/2001

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

type of incinerator	category	std ng TEQ/Nm^3
continuous-operation	newly installed	0.1
	existing (subject to old guidelines)	0.5
	existing (not subject to old guidelines)	1
others	existing (continuous operation)	1
	existing (intermittent operation)	5

[a] Source: Ministry of Health and Welfare.

New Regulations

In 1990, the national government of Japan published a set of guidelines on ways to reduce dioxin emissions from MSWIs and set the target value of dioxins at 0.5 ng TEQ/Nm^3 in the exhaust gas from the new MSWIs. However, these guidelines failed to promote the reduction of dioxin emissions because of a lack of enforcement. The Ministry of Health and Welfare (MHW), who established the value of tolerable daily intake (TDI) at 10 pg TEQ (kg of body weight)$^{-1}$ day^{-1} in 1996, published a new set of guidelines in 1997 (*2*). In this set of guidelines, MHW set a target value for existing incinerators and decreased the target value of new incinerators. Those target values were transformed into mandatory emission standards based on law by the amendment of the "Waste Disposal and Public Cleansing Law". Those MSWIs that 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. A total of 114 MSWIs undertook emergency countermeasures. 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. We undertook quantitative assessment of the cost and effectiveness of both the emergency countermeasures and the long-term countermeasures.

The standard of 80 ng TEQ/Nm^3 is the concentration level by which the intake of dioxins could not exceed the TDI at the maximum ground-level concentration near the MSWIs. Since TDI means "the amount of intake per kilogram of body weight per day that is judged to be safe even if one is exposed continuously during his/her lifetime", the temporary emission standard is a health-based or risk-based standard. On the other hand, long-term emission standards are technology-based ones because the objectives were established "to reduce dioxin emissions based on the best available control technology" (*2*).

In 1999, TDI was revised to 4 pg TEQ (kg of body weight)$^{-1}$ day^{-1} (including coplanar PCBs), as based on the proposal of the World Health Organization. Emergency countermeasures were completed, and long-term countermeasures are now being undertaken.

Cost of Reducing Dioxin Emissions

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. For two of those 114 plants, cost data were not available. For these plants, the unit cost of reducing 1 g of dioxin was assumed to be equal to the average cost of the other plants. The emergency countermeasures taken were divided into three types. The first is to decrease the formation of dioxins by maintaining appropriate temperature, residence time, and turbulence in the incineration process. Specifically, it includes improvement of nozzles for secondary air injection, auxiliary burners that must be switched automatically when the temperature falls below a predetermined point, feed preparation equipment that homogenizes the quality of garbage, installation of a carbon monoxide meter in order to achieve complete combustion, and expansion of furnace capacity. The second is the prevention of the new formation of dioxins in the cooling phase, which includes improvement of gas-cooling equipment and installation of a cooling tower. The third is the removal of dioxins from exhaust gas. It includes installation of a bag filter and injection of sprayed activated carbon.

Although cost data regarding capital investment were obtained from almost all plants, many plants did not have information describing the incremental cost of operation and maintenance. We estimated the average cost based on data of some plants and applied it to all other plants. Some plants were not repaired but were shut down because they were timeworn or were difficult to repair. In such cases, costs were defined as the additional costs of building new plants before finishing their expected lifetimes. In the case of closure in 1998, the cost is as follows:

$$50 \text{ million} \times Q[1 - (1 + r)^{1998 - (Y + 21)}] \text{ (yen)}$$

where Q is the capacity of treatment per day (t/day), r is the discount rate whose value is determined to be 3% obtained from the interest rate in Japan, and Y is the year when the incinerator began operating. We assume the average operation period to be 21 yr on the basis of past data. Unit cost of plant construction per disposal capacity of 1 t/day is assumed to be 50 million yen based on past data from 1991 to 1998 (Table S1, Supporting Information). The sum of the capital investment cost spent on 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 is converted into an annualized value following

$$A = P\frac{r}{1 - (1 + r)^{-N}}$$

where A is the annualized value; P is the sum of initial investment and closure cost; r is the discount rate, whose value is 3%; and N is the time period of this study, whose value is 33 yr (from 1997 to 2030). The annualized value is calculated to be 710 million yen. When the increment of administrative and maintenance expense is added, the annualized value of emergency countermeasures turns out to be about 1460 million yen.

The quantity of dioxins reduced by the emergency countermeasures was calculated to be 780 g TEQ/yr according to MHW data. To incorporate coplanar PCBs and to replace I-TEF with WHO-TEF, 780 g TEQ needs to be multiplied by 1.157 (*3*), and this gives 900 g TEQ/yr, which corresponds to 18% of the baseline level in 1996. The average cost per gram of dioxin reduced is 1.63 million yen (Tables S1 and S2, Supporting Information). Since the contents of countermeasures were various, the distribution of unit cost is very wide, as shown in Figure 3.

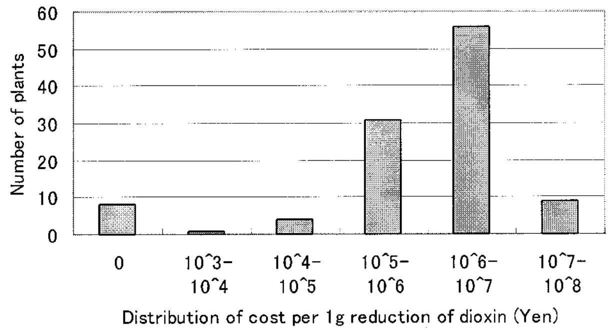

FIGURE 3. Distribution of unit cost of emergency countermeasures.

Long-Term Countermeasures. Since the long-term countermeasures have not yet been completed, 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 the plant's remaining lifetime and to estimate their costs by extrapolating the actual cost data in the emergency countermeasures. A detailed account of the calculation is given below.

(i) If the initial level of dioxin emission satisfies the 2002 standard (long-term emission standard), no countermeasures will be undertaken; otherwise some countermeasure will be undertaken.

(ii) Among the plants that do not satisfy the 2002 standard, those that will be more than 16 yr of age in 2002 and those that have not recently undertaken large-scale repairs will be abolished in 2002. We assume the cost of such termination before finishing their lifetime as follows:

$$50 \text{ million} \times Q[(1 + r)^{1998-2002} - (1 + r)^{1998 - (Y + 21)}] \text{ (yen)}$$

where Q is the treatment capacity (t/day); r is the discount rate, whose value is determined to be 3%; and Y is the year when the incinerator began operating. The term 50 million $\times\, Q(1+r)^{1998-2002}$ indicates the actual construction cost, and 50 million $\times\, Q(1 + r)^{1998 - (Y + 21)}$ indicates the hypothetical construction cost without regulations. This equation indicates the increase of the present value of construction cost, which is caused by earlier termination as in emergency countermeasures.

(iii) If the current dioxin level in exhaust gas is 10 times higher than the 2002 standard, it is assumed that its furnace will be expanded, a bag filter will be installed (including installation of a cooling tower), and activated carbon will be injected. The unit cost of such countermeasures is assumed to be 170 million yen/(t/h), which is the weighted average cost derived from the actual data of six plants. The incremental cost of operation and maintenance is assumed to be 2980 yen/t for semi-continuous and batch type incinerators and 540 yen/t (injection of activated carbon) for continuous type incinerators. These estimates are based on the average value of the emergency countermeasures (Tables S3 and S4, Supporting Information).

(iv) If the initial dioxin level in exhaust gas is higher than the 2002 standard but is not 10 times higher, it is assumed that a bag filter will be installed (including installation of a cooling tower) and activated carbon will be injected. In the case wherein a bag filter has already been installed, only activated carbon will be injected. In the first case, the initial cost is estimated to be 130 million yen/(t/h). In the latter case, the initial cost of activated carbon injection equipment is estimated to be 2.7 million yen/(t/h). The incremental cost of operation and maintenance (for activated carbon) is also estimated to be 540 yen/t. Those values are all based on data from emergency countermeasures (Tables S3 and S4, Supporting Information).

(v) It is assumed that all of the construction except closure was carried out in 2000. The construction cost is converted into annualized cost for the time period of 33 yr (from 1997 to 2030), and the discount rate is 3%. Another assumption is that plants in which some construction other than closure was undertaken must utilize the equipment for at least 7 yr because their funding comes from a national subsidy. The annualized total cost is obtained by adding the annual cost of operation and maintenance to the annualized cost of construction.

(vi) The volume of dioxin emission reduction is calculated from the difference between the initial emission concentrations and the predicted emission concentrations that are assumed to be half of the 2002 standard, since they are designed to have some margin of safety.

We applied this procedure to 1655 plants. The results show that it is necessary to invest 358 billion yen by 2002 and that its annualized cost will be 17.2 billion yen. Adding the incremental cost of operation and maintenance (24.0 billion yen) to this, the annualized total cost is 41.2 billion yen. These estimates are called baseline case estimates. The quantity of dioxins reduced by the emergency countermeasures was calculated to be 1910 g TEQ/yr, which corresponds to 44% of the baseline level in 1996. To incorporate coplanar PCBs and to replace I-TEF with WHO-TEF, 1910 g TEQ needs to be multiplied by 1.157, and this gives 2210 g TEQ/yr, which corresponds to 44% of the baseline level in 1996. The average cost per gram of dioxin reduced is 18.6 million yen.

We also calculate the cost of long-term countermeasures under some alternative assumptions in order to confirm the robustness of the result. First, the terms of the third and fourth stage of the calculation are changed from "if the dioxin level in exhaust gas is 10 times higher than the 2002 standard" and "if the initial dioxin level in exhaust gas is higher than the 2002 standard but is not 10 times higher" to "if the long-term dioxin standard for dioxins in exhaust gas is no more than 1 ng TEQ/Nm^3" and "if the long-term dioxin standard for dioxins in exhaust gas is more than 1 ng TEQ/Nm^3", respectively. The annualized total cost is 41.6 billion yen, which is almost the same as the baseline case estimate. Second, the unit cost of investment in the third stage (170 million yen/(t/h)) and the fourth stage (130 million yen/(t/h)) is assumed to be 150 million yen/(t/h). The annualized total cost is 41.7 billion yen, which is almost same as the baseline case estimate. Therefore, we adopt the result of the baseline case.

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 coplanar PCBs) before the introduction of those regulations was about 2.60 pg TEQ (kg of body weight)$^{-1}$ day^{-1} (*1*). 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 the implementation of the regulations.

To predict the exposure level, we modeled the transport pathways of PCDD/Fs and coplanar PCB congeners from the main sources to the human body and estimated the time course of exposure levels of the congeners in the Japanese population from the past to the future in terms of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin toxic equivalents (TEQs). As emission sources, we considered not only incinerators but also impurities in herbicides used in the past, and PCB and

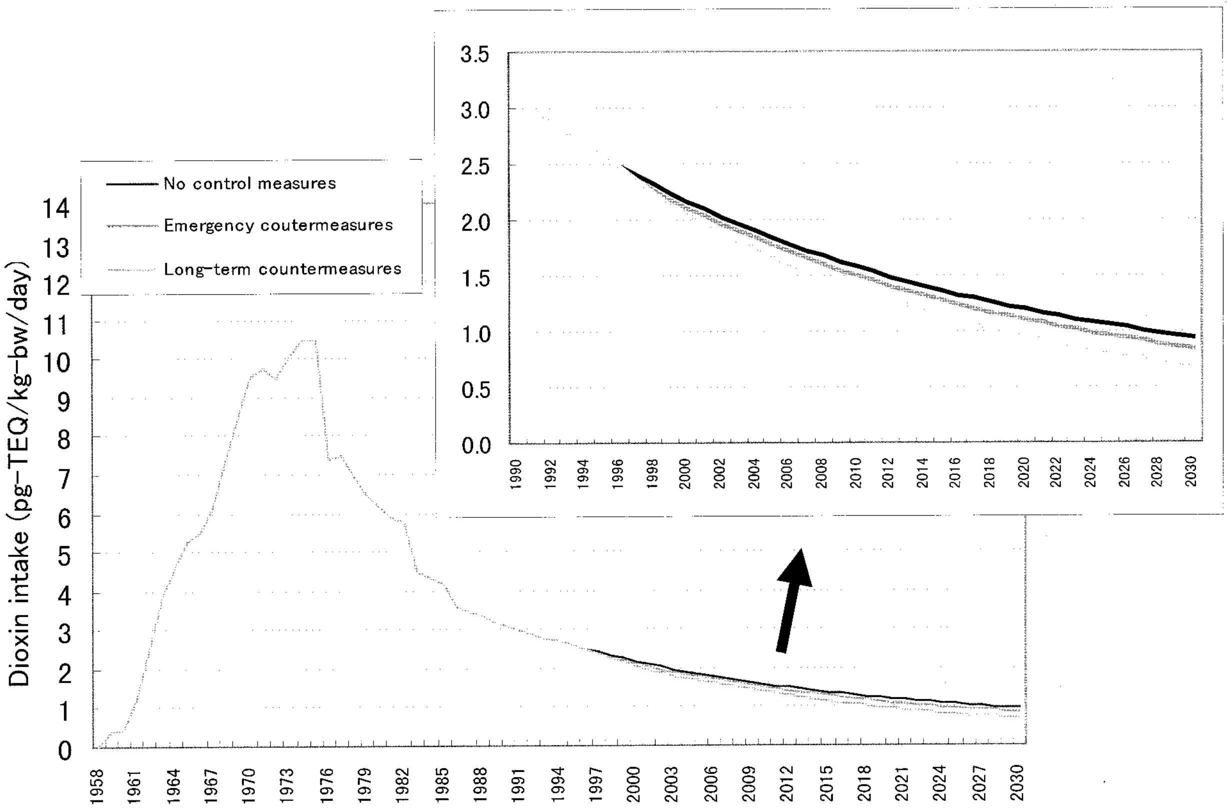

FIGURE 4. Change in the volume of dioxin intake.

its impurities (details of mathematical models are illustrated in Appendix S1, Supporting Information). The air/soil two-compartment model was applied to estimate the environmental concentrations of PCDD/Fs and coplanar PCBs from incinerators in the air and soil other than that in paddy fields (*4*). The concentrations of PCDD/Fs as herbicide impurities in paddy fields were estimated using the one-compartment model. The concentrations of PCDD/Fs and coplanar PCBs in the coastal environment were estimated using the water/sediment two-compartment model. Average daily intakes via various pathways were individually calculated as products of concentrations of PCDD/Fs and coplanar PCBs in each medium and its ingestion or inhalation rate, assuming that the ingestion rates of various foods were constant. The concentration in coastal fish was calculated based on the assumed equilibrium between the concentrations in water and fish. The concentrations in offshore and oceanic fish were assumed to be half of that in coastal fish (*5*). The concentrations in crops, meat, and dairy products were estimated according to the methods described by the U.S. Environmental Protection Agency (U.S. EPA) (*6*). We assumed that the epidermis of rice plants was contaminated by PCDD/Fs and that the residual culms and blades after threshing rice were fed to domestic animals as fodder.

Using this model, the secular variation of average daily intake under the following three scenarios was 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 second scenario subtracted by the baseline scenario obtains the net effect of emergency countermeasures, and the third scenario subtracted by the second scenario obtains the net effect of long-term countermeasures. Figure 4 shows the decrease in dioxin caused by both countermeasures from 1958 to 2030 (Table S5, Supporting Information).

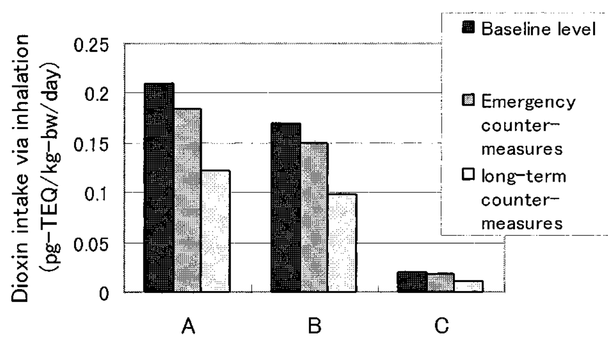

FIGURE 5. Decrease in exposure via inhalation. A indicates metropolitan areas that have a population of 25 million, B indicates midsize and small cities that have a population of 73 million, and C indicates background areas that have a population of 22 million. These figures are our original estimates. Baseline levels were cited from the Dioxin Risk Assessment Study Group (*5*) multiplied by 1.157 to incorporate coplanar PCBs and to replace I-TEF with WHO-TEF.

Among these exposure pathways, inhalation is dealt with differently from others, since there exists much regional difference. The entire population in Japan is divided into three groups as shown in Figure 5, and the exposure decreases in proportion to the reduction of dioxin emissions. Sixty-seven percent of dioxins emitted into the air are attributable to MSWIs (*3*).

Estimation of Reduced Risk

To estimate the number of cancer cases reduced due to the emergency and long-term countermeasures, we use a dose–response function. We adopt the linear dose–response model proposed by the U.S. EPA, although the 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. The U.S. EPA assumed

TABLE 2. Summary of the Data Used

countermeasures	annualized capital cost (million yen)	annualized maintenance cost (million yen)	annualized total cost (million yen)	dioxin reduction (g-TEQ/yr)	cost per 1 g of dioxin reduced (million yen)	annualized life-years saved (yr)	cost per life-year saved (million yen)
emergency	710	750	1460	900	1.63	184	7.9
long-term	17200	24000	41200	2210	18.6	282	150

dioxins to be activators mediated by an Ah receptor and proposed in a draft report a tentative cancer slope factor of 1.0×10^{-4} (pg (kg of boday weight)$^{-1}$ day^{-1}) for the oral intake of 2,3,7,8-TCDD (*6*). This factor is also 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 (*4*). The number of cancer cases reduced due to the decrease in lifetime exposure to dioxins is obtained from the following equation:

$$\text{cancer cases avoided} = \triangle\text{dioxins} \times \text{POP} \times (1.0 \times 10^{-4})$$

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-years saved due to the decrease in 1-yr 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 1-yr exposure to the level that will cause one cancer death if exposed during one's lifetime was estimated to be about 0.16 (*7*). The number of life-years gained each year from 1997 to 2030 is discounted at 3% per year, yielding a present value. The emergency countermeasures save 3941 life-years and the long-term countermeasures save 6041 life-years from 1997 to 2030. When they are converted into the annualized value, we find that the emergency countermeasures save 184 life-years and the long-term countermeasures save 282 life-years annually (Table S6, Supporting Information).

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 1460 million yen, and the number of life-years gained is 184. Therefore, the CPLYS is about 7.9 million yen. As for long-term countermeasures, the annual cost is estimated to be 41.2 billion yen, and the number of life-years gained is 282. Therefore, the CPLYS is about 150 million yen. Table 2 shows the data used for the calculation of the CPLYS.

Using our cost estimation model, we examine the effect of changes in long-term emission standards. In place of the actual case shown in Table 1, two hypothetical cases are compared to the actual case. The results are shown in Table 3. When the emission standard for all incinerators is relaxed to be 5 ng TEQ/Nm^3, cost per gram of dioxin reduced is decreased by 35%, which means that cost per life-year saved is about 100 million yen. On the other hand, when the emission standard for all plants is tightened to be 0.1 ng TEQ/Nm^3, cost per gram of dioxin reduced is increased by 35%, which means that cost per life-year saved is about 200 million yen. The actual judgment was that although 150 million yen was spent to save 1 life-year, the option that could have saved 1 life-year by spending 200 million yen was not adopted. This current regulatory policy offers a reference point for future regulatory policies.

We also examined the sensitivity of changing the discount rate. When the discount rate is 1%, the annual cost is 34.8 billion yen and the number of life-years gained is 296. Therefore, CPLYS is about 120 million yen. When the discount rate is 5%, the annual cost is 48.8 billion yen and the number of life-years gained is 269. Therefore, the CPLYS is about 180 million yen. These results are shown in Table 3.

TABLE 3. Cost Per Life-Year Saved Resulting from Long-Term Countermeasures under Hypothetical Standards and Various Discount Rates and Previous Case Studies[a]

	cost per life-year saved (million yen)
Baseline Case	
long-term countermeasures	150
Hypothetical Cases (Emission Standards)	
5 ng TEQ/Nm^3 (all incinerators)	100
0.1 ng TEQ/Nm^3 (all incinerators)	200
Sensitivity Analysis (Discount Rates)	
1%	120
5%	180
Case Studies	
prohibition of chlordane	45
prohibition of mercury electrode process in caustic soda production	570
control of benzene in gasoline	230
dioxin control by emergency countermeasures in municipal incinerators (in this study)	7.9

[a] Note: $1 roughly equaled ¥131 in 1998.

Finally, it is helpful to compare our results with those of previous studies shown in Table 3 (*8*−*10*). It is easily found that emergency countermeasures are cost-effective on average and that long-term countermeasures are located in the middle.

Discussion

Much greater uncertainty exists in the choice of dose−response function than in the cost estimation and exposure estimation process. In this study, only cancer risk was estimated and quantified. However, it is reported that dioxins may cause various noncancerous adverse health effects, such as reproductive dysfunction, endometriosis, and neurobehavioral effects. 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. (*4*) calculated the MOE values for noncancer end points 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" (*1*).

We performed cost-effectiveness analysis by 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. (*4*) calculated the 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. The 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 epidemiological data are adopted (*6*). 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 0.46 million yen for emergency countermeasures, and 8.8 million yen for long-term countermeasures. In the case of 2.8×10^{-3}, CPLYS is about 0.28 million yen for emergency countermeasures and 5.4 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 value of CPLYS.

Acknowledgments

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

Supporting Information Available

Tables S1−S6 and Appendix S1 (details of mathematical models used in estimating dioxin levels in Japan). This material is available free of charge via the Internet at http://pubs.acs.org.

Literature Cited

(1) Ministry of Health and Welfare. *On the Tolerable Daily Intake of Dioxins*; 1999 (in Japanese).
(2) Ministry of Health and Welfare. *Guideline for Preventing the Generation of Dioxins in the Waste Treatment Process*; 1997 (in Japanese).
(3) Environment Agency. *On the Emission Inventory of Dioxins*; 2000 (in Japanese).
(4) Yoshida, K.; Ikeda, S.; Nakanishi, J. *Chemosphere* **2000**, *40*, 177−185.
(5) Ministry of Health and Welfare. *Report of Research Group on Risk Assessment of Dioxins*; 1997 (in Japanese).
(6) 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); U.S. Government Printing Office: Washington, DC, 1997.
(7) Oka, T.; Gamo, M.; Nakanishi, J. *Jpn. J. Risk Anal.* **1997**, *8* (2), 174−186.
(8) Gamo, M.; Oka, T.; Nakanishi, J. *Reg. Toxicol. Pharmacol.* **1995**, *21*, 151−157.
(9) Nakanishi, J.; Oka, T.; Gamo, *M. Environ. Eng. Policy* **1998**, *1*, 3−9.
(10) 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; pp 62−70.

Received for review October 17, 2000. Revised manuscript received March 7, 2001. Accepted April 6, 2001.

ES001782Z