Scenario analysis of PCB emission reduction effects of countermeasures in Japan

Koshiba J.[1], Hirai Y.[1], Sakai S.[2]

[1] Kyoto University, Kyoto, Japan, 606-8501, j-koshiba@eprc.kyoto-u.ac.jp; [2] Advanced Science, Technology & Management Research Institute of KYOTO, Kyoto, Japan, 600-8813

Introduction

In Japan, production and use of PCB (Polychlorinated Biphenyls) were banned in 1972. After that, the product and waste containing PCB were stored and not disposed of inappropriately. Moreover, the destruction of waste containing PCBs had been conducted since 2004. However, PCB have been still widely detected in Japanese environment in recent years[1]. Some studies reported the decreasing trends of PCB concentrations in air, water, and sediment[1]. It was also suggested that destruction of PCB waste caused these decreasing trends by the previous study estimating PCB emission trends in Japan[2]. It is essential to understand the effects of countermeasures for considering not only further PCB countermeasures but also countermeasures for other new POPs. Koshiba, et al., 2021 estimated the amount of emissions reduced by each countermeasure[3].
The objective of this study is to estimate the emission and concentration reduction effects for each PCB countermeasures conducted in Japan. The environmental PCB emission from 1950 to 2050 was estimated for each scenarios according to existence of each countermeasures.

Materials and Methods

Emission Estimation

This study estimated the whole life cycle emissions of products containing PCBs by the method of our previous studies (Fig.1)[2,3]. The emissions were divided into five categories: (i) wastewater during production of PCB mixtures and products containing PCB, (ii) volatilization from products containing PCB, (iii) leakage from products containing PCB, (iv) incineration of waste containing PCB, and (v) volatilization and leachate from landfill site.

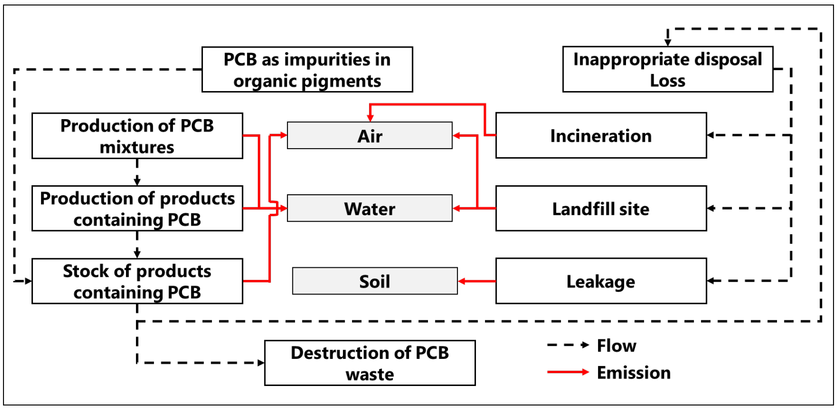

Fig.1 Material flow and emission of PCB considered in this study

Emissions from each processes were calculated by multiplying emission factor and stock or flow. Stock of PCB contained in products was estimated using Eq.1. This study assumed that the stock of PCB contained products would be increased by production of products containing PCB and decreased by volatilization, inappropriate disposal and loss, and destruction. The stock and emission were estimated for each year (*t in* Eq.1*)* and for each homologue (*i* in Eq.1). In addition, PCB containing products were divided into six categories: electrical equipment, heat medium, carbonless copy paper, joint sealant, organic pigment, and other open use product. They were assumed to be set life time distribution, volatilization factors, and disposal distribution when disposed of inappropriately individually. These parameters for estimation were obtained from Koshiba et al., 2021.

$$Stock_{i,t+1,k} = Stock_{i,t,k} + Prod_{i,t,k} - Volat_{i,t,k} - Disp_{i,t,k} - Dest_{i,t,k} \quad \text{... Eq.1}$$

where *Stock* is the stock of PCB contained products, *Prod* is the amount of PCB used for production of products, *Volat* is the volatilization amount, *Disp* is the amount of inappropriate and loss, *Dest* is the amount of PCB destructed.

Scenario Analysis

This study considered four kind of countermeasures conducted in Japan.

(1) "Ban of production and use" ... assuming that there were no production and use of PCB after 1972

(2) "Storing of waste containing PCB" ... stored PCB waste was assumed not to be disposed of inappropriately but lost in a constant proportion

(3) "Strict storing" ... reducing loss rate of stored PCB waste

(4) "Destruction of waste containing PCB" ... proper destruction of waste containing PCB

According to existence of these countermeasures, five scenarios were assumed (Table.1). In scenario (I), it was assumed to continue production and use of PCB at the peak level, which was the value of 1970. In scenario (I) and (II), the products containing PCB would be disposed of inappropriately after the end of life time. In scenario (III), a part of electrical equipment, heat medium, and carbonless copy paper would be stored but a part of were assumed to be lost and inappropriately disposed of. In scenario (IV), the lost rate of stored products would be reduced after 2001. This scenario assumed the effects of "PCB special measures law" in 2001. Scenario (V) assumed that stored PCB waste would be destructed, and this study considered incinerating destruction on the sea during 1977-1979, incinerating destruction during 1987-1989, and chemical destruction since 2004.

Table.1 Scenario settings

Numbers and names for each scenario	Countermeasures			
	Ban of production and use	Storing of waste containing PCB	Strict storing	Destruction of waste containing PCB
(I) No countermeasures	—	—	—	—
(II) Ban of production and use	✓	—	—	—
(III) Storing of waste containing PCB	✓	✓	—	
(IV) Strict storing	✓	✓	✓	—
(V) Destruction of waste containing PCB	✓	✓	✓	✓

Concentration Estimation

The PCB concentration for each homologue was estimated using Mackay level IV environmental fate model. This study considered the compartment of air, water, soil, and sediment in whole Japan. The detailed estimating method and parameters were shown in previous study[2].

Results and Discussions

Fig.2 showed the total-PCB (sum of all homologues) emission trends of scenario (I), (II), and (III). Emission of scenario (I) had continuous increasing trend because of assumption of continuous production and use of PCB after 1972. Largest emission sources would be leakage from electrical equipment, but the contributions of volatilization from products and wastewater during production were also large. In the case of scenario (II), the emission after 1972 had decreased rapidly due to ban of production and use. There was also increasing trend of emission around 1980, that was because the disposal and leakage of electrical equipment had increased during this period. On the other hand, scenario (III) had no increasing trends around 1980 shown in scenario (II). This suggests that the storing of PCB waste could reduce the inappropriate disposal and loss of electrical equipment, followed by reducing PCB emission immediately. After 2000, scenario (IV) could decrease PCB emission immediately, however, strict storing of waste did not have larger effect compared to other countermeasures (Fig.3).

Fig.3 also showed scenario (V) had smallest emission during whole estimation period. However, there would be still 0.58 tons/year in 2050; the main emission sources were volatilization from open use products and leakage from electrical equipment. These were because some of open use products such as joint sealant and organic pigment were assumed to be not destructed and a part of electrical equipment were also assumed to be not destructed.

One more important thing was that the emission of scenario (III) and (IV) would be larger than scenario (II) after around 2005. The reason was that the storing of PCB waste would have kept up stock of PCB, therefore emission from stored PCB would be also kept up. This suggested that future risk of PCB emission could remain if PCB waste would be stored for a long time, even though storing of waste had immediate effect of emission reduction.

Fig.4 shows the estimated concentrations in air and sediment for each scenario. It suggests that the

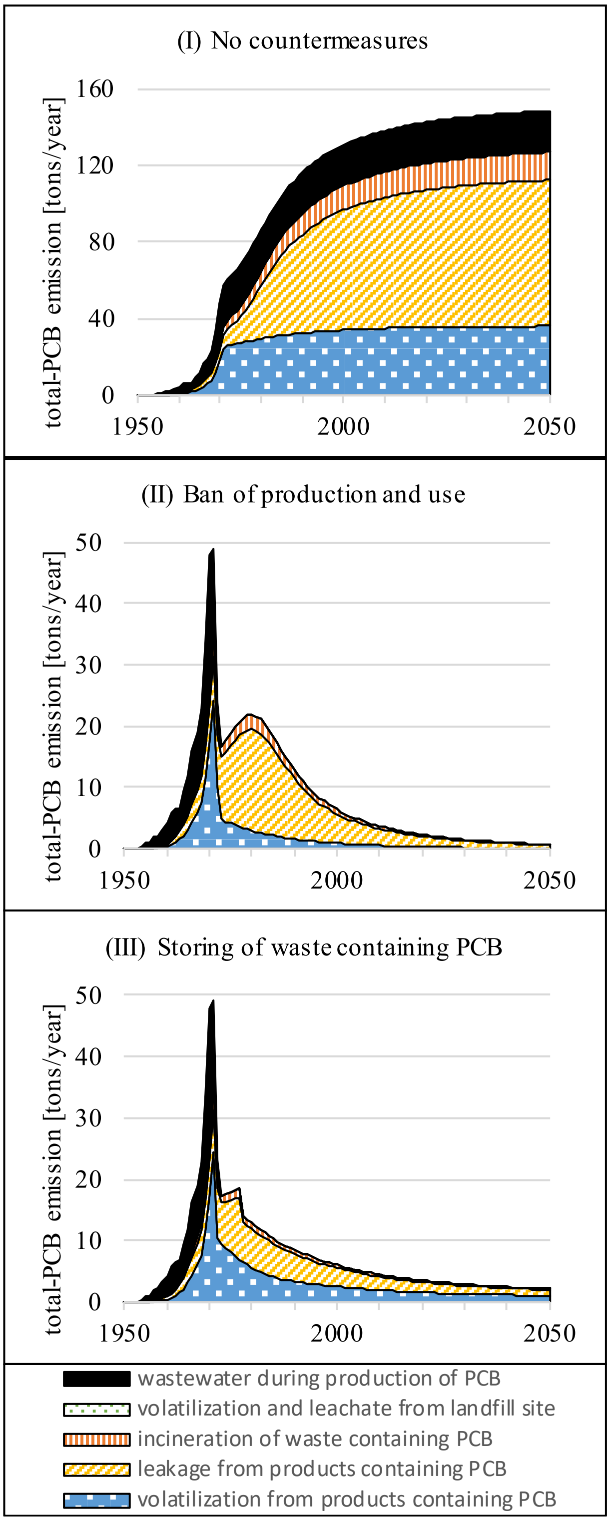

Fig.2 Estimated emission trends of scenario (I), (II), and (III)

atmospheric total-PCB concentration would be decreased approximately 20 pg/m^3 due to destruction of PCB waste in 2050. On the other hand, the air concentration of scenario (III) and (IV) would to be higher than scenario (II). This also suggests the storing of PCB waste may keep up the emission. The sediment concentration of scenario (II) was significantly higher than other scenarios around 2000. This implied that the emission before 2000 was much higher in scenario (II) and persisted in sediment even though the emission became same level compared to other scenarios.

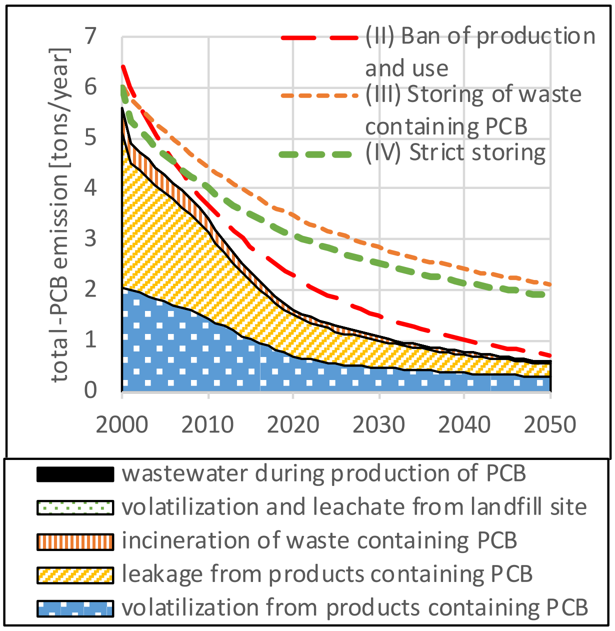

Fig.3 Estimated emission trends of scenario (II) to (V)

note: area graph showed emission of scenario (V) for each emission process and line graphs showed emissions of scenario (II), (III), and (IV)

Conclusions

This study estimated the emission reduction and concentration reduction by countermeasures conducted in Japan. The results suggested all of countermeasures had the emission reduction effects. However, it was also supposed that storing of PCB waste could keep up stock and emission even though it could reduce the emission immediately. Therefore, it was effective to destruct the PCB waste and not to store PCB waste for a long time.

Acknowledgements

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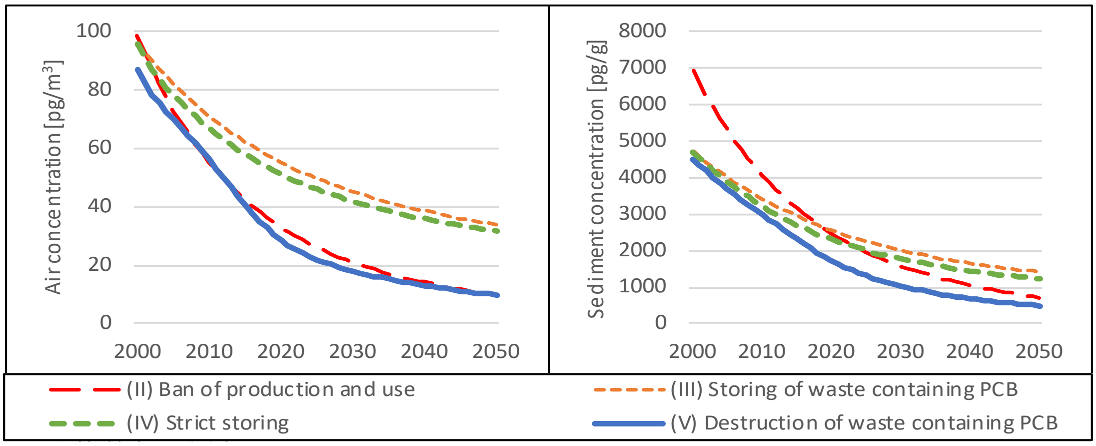

Fig.4 Estimated air concentration trends of total-PCB