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Occupational health risk assessment of municipal solid waste incinerator workers

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ABSTRACT

Occupational health risk assessment is a tool for evaluating health hazards associated with different levels of exposure to workplace hazards. This study evaluated the health risk from municipal solid waste incinerators (MSWIs) for workers in Phra Nakhon Si Ayutthaya and Rayong provinces. Hazardous pollutants released from MSWIs included arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), nickel (Ni), lead (Pb), mono- to tri-chlorinated dibenzodioxins (CDDs) and dibenzofurans (CDFs). Concentration over 8-h workday was estimated by the air quality model. The finding of 8-h concentration of contaminants in working environment did not exceed standards. Carcinogenic and non-carcinogenic risk assessment was calculated by direct inhalation pathway. The results showed that worker contaminant exposure concentration was found to be Pb, Cd, Cr, Ni, Hg, As, CDD, and CDF, in decreasing order of magnitude. Carcinogenic risk quantification showed that Cr and total contaminants exceeded the reference level. However, non-carcinogenic hazard quotient risk was below the acceptable limit, representing an absence of non-carcinogenic risk to workers. These findings may be helpful in identifying health risks and providing appropriate preventive measure to ensure worker safety.

Keywords: municipal solid waste incinerators; heavy metals; dioxins and furans; occupational health risk assessment; workers

1. INTRODUCTION

Because of the numerous serious problems that result from improper disposal, municipal solid waste (MSW) management has now become a vital challenge in Thailand. Waste management has been recognized as a national priority that requires immediate attention. Mixed wastes, including hazardous compounds such as heavy metals, chlorinated organic chemicals, and other toxic chemicals, are often put into municipal solid waste incinerators (MSWIs). According to the compilation of air pollutant emission factors (AP-42) by the United States (U.S.) Environmental Protection Agency (U.S. Environmental Protection Agency, 1995), the hazardous air contaminants emitted in significant concentrations by waste combustors are arsenic (As), nickel (Ni), lead (Pb), cadmium (Cd), chromium (Cr), and mercury (Hg) in the form of heavy metals; mono- to tri-chlorinated dibenzodioxin (CDD) and dibenzofuran (CDF) in the form of chlorinated organic chemicals. The dioxin group, in particular, has been found in systems with insufficient controls (Ravindra et al., 2008). In China, the carcinogenic and non-carcinogenic risks of heavy metals in the soil found around the MSWIs were not acceptable, suggesting that the MSWIs had a noticeable effect on human health (Ma et al., 2018). Further, it was reported that modern incinerators had fewer recorded health effects, possibly because of a lack of time for adverse effect to manifest, together with the need to remain aware (Tait et al., 2020). In Thailand, heavy metals and chlorinated organic chemical groups were found to be at unacceptable levels (via inhalation and breast milk mostly), ranging from 1.35×10^{-6} to 2.51×10^{-6}, thus involving carcinogenic agents, especially in people who lived near the MSWIs (Srivieng et al., 2021a).

A human health risk assessment (HHRA) has been proposed as a tool for addressing health impacts associated with interactions with multi-risk contaminants and as a guideline for assessing risk management approaches. The risk assessment paradigm is aided by the following major steps: 1. hazard identification to evaluate the contaminants in the working environment that have an adverse health effect; 2. dose response as the magnitude of contaminants that cause an adverse health effect; 3. exposure assessment to evaluate the receptors; employees working in MSWIs, exposed the contaminants via 3 major routes; and 4. risk characteristics to quantify the risk as carcinogens and non-carcinogens (U.S. Environmental Protection Agency, 2021). Two of the HHRAs were included in this study. Carcinogenic risk, as a cancer risk (CR), has been defined as the probability of developing cancer throughout the duration of a person's lifetime as a result of being exposed to a potential carcinogen" (U.S. Environmental Protection Agency, 1991). Non-carcinogenic risk, as a hazard quotient (HQ), has been defined as the level of a potential substance exposure at a threshold at which no harmful effects are expected to be chosen in study (U.S. Environmental Protection Agency, 1989).

These concepts are being described in order to achieve a full understanding of the potential health impacts of the MSWI emissions, but only in terms of the regional-scale effects of the contaminants. The MSWI worker should also be taken into consideration when it came to adverse health effects. The few studies examined showed that some workers were exposed to high levels of organic chemicals and metals (such as dioxins, furans, and Pb) that caused toxic concentrations in the tissues of the body. However, the health effects of the exposures have not been assessed thus far through systematic monitoring of these workers (National Research Council, 2000). Furthermore, a biomonitoring of the MSWI workers found that there were concentrations of 18 metals (e.g., As, beryllium, Cd, Cr, Hg, Ni, platinum, and zinc, etc.) in their urinary systems, and that certain levels of Pb were quantified in their blood (Bena et al., 2020). One of a cohort study of people who live near the Italian incinerators found that it was associated with cancer mortality among women, in particular for all cancer target organs (Ranzi et al., 2011). The other health impact on the mother who live over 10 years near MSWIs, also found higher body burden of polychlorinated dibenzo-p-dioxins (PCDD)/ furans (Fs) and PCBs. It could affect their children because of breast milk feeding (Xu et al., 2019).

The purpose of this research was to estimate both carcinogenic and non-carcinogenic risks from the proposed MSWIs in the provinces of Phra Nakhon Si Ayutthaya and Rayong, as well as the distribution of those risks along the direct exposure pathway and their significantly negative health effects on MSWI workers as the receptors, as already known the impact for people who live near MSWIs (Srivieng et al., 2021a). It would be one of the sources of evidence used to convince the government and the MSWI authorities to take the appropriate action to protect the workers.

2. MATERIALS AND METHODS

2.1 Study area

In the present study, two locations situated in the central region of Thailand were selected, where there is a particularly large cluster of waste, with a capacity of over 500 tons per day, according to Buranasingh (2015). The first site selection was located in Phra Nakhon Si Ayutthaya and was designated as Ayutthaya MSWI. The Ayutthaya MSWI was placed in the Bang Ban district, with coordinates 14° 20' 28.8" N and 100° 29' 51.3" E. The second site was located in the Rayong and was designated as Rayong MSWI. The Rayong MSWI was placed in Mueang Rayong district with coordinates 12° 44' 58.9" N and 101° 14' 17.4" E, as shown in Figure 1.

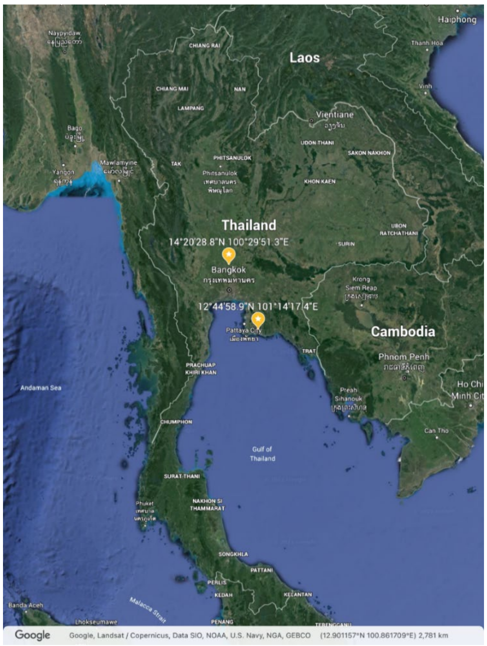

Figure 1. Locations of municipal solid waste incinerators in Phra Nakhon Si Ayutthaya and Rayong

Note: The map was retrieved from https://earth.google.com/web/ search/12.74969614,+101.2381581/@12.15904162,102.12178549,-2.97969938a,1965721.21338129d,35y,-0h,0t,0r/data=CigiJgokCbCcGqkehClAETq4LU4oeylAGVpapgS2T1lAIaZgi5EHT1lA

2.2 Occupational health risk assessment

Health risk assessment (HRA) was adapted to the method established by the U.S. Environmental Protection Agency (1991). By use of this assessment, it was estimated that the emitted contaminants of the MSWIs were coming from the stack, with a potentially serious impact on public health. The emitted contaminants were identified through the compilation of air pollutant emission factors (AP-42) from the U.S. Environmental Protection Agency (1995) as both criteria air pollutants and hazardous air pollutants (HAPs).

In this study, HAPs were the main focus of our HRA. The pollutants of interest included As, Cd, Cr, Hg, Ni, Pb, mono- to tri-CDD and CDF. The concentration of these pol-lutants was simulated by the air quality model (AERMOD version 16216). All eight of the aforementioned pollutants were capable of inflicting adverse health effects onto the people, who were residing in the area around the MSWIs. They were assessed for their non-carcinogenic and carci-nogenic effects.

The risk assessment paradigm was aided by the following steps; hazard identification, dose-response assessment, exposure assessment by AERMOD, and risk characterization. For carcinogenic risk, CR can be referred to the probability of developing cancer while exposed to the contaminants. For non-carcinogenic risk, HQ for a single chemical and the hazard index (HI) for a multi-contaminants were the potential exposure to the contaminants.

2.2.1 Hazard identification and dose-response assessment

As, Cd, Cr, Hg, Ni, Pb, CDD and CDF were classified as contaminants having an adverse impact toward health. Only through the inhalation route was acute exposure likely to occur for an on-site worker. Such exposure was analyzed under the assumption that the worker was exposed at the location of maximum estimated onsite effects across the entire exposure event, as required by our HRA.

The stack technical parameters, stack feature, terrain processor as AERMAP and local weather conditions as meteorology pathway (AERMET) were used to calculate an 8-h average of contaminated ground-level air concentra-tions from the MSWIs stack emissions by air quality model: AERMOD. Table 1 presents the rate of emission released from the MSWIs. The data were used to simulate the ground level concentration (GLC) of contaminants.

One of the four steps involved in evaluating the HRA was the determination of dose response, defined as an estimate of daily inhalation caused by the exposure of the workers to the contaminants. The values of unit risk of contaminants are shown in Table 2. The inhalation unit risk (IUR) was determined by a comparison to the rate of intake by inhalation to estimate CR. IUR is an estimate of the increased CR from inhalation exposure to a concen-tration of 1 μg/m^3 for a lifetime CR. For the purpose of estimating potential carcinogenic effects, on the other hand, the reference concentration (R*f*C) evaluation was conducted to determine the HQ, which was useful for estimating possible non-carcinogenic effects. R*f*C estimated a continuous inhalation exposure to the receptors that is likely to be without an appreciable risk of deleterious effects during a lifetime. It is noticed that IUR and R*f*C data came from different sources and different years (Table 2).

Table 1. Rate of emission released from the municipal solid waste incinerators stacks in Phra Nakhon Si Ayutthaya and Rayong

Emission rate (g/s)	Site	
	Phra Nakhon Si Ayutthaya	Rayong
Arsenic	6.62E-04	1.14E-03
Cadmium	1.69E-03	2.91E-03
Chromium	1.39E-03	2.39E-03
Mercury	8.66E-04	1.49E-03
Nickel	1.22E-03	2.10E-03
Lead	3.31E-02	5.71E-02
Mono to tri-chlorinated dibenzodioxin	2.58E-07	4.45E-07
Mono to tri-chlorinated dibenzofuran	2.58E-07	4.45E-07

Note: Adapted from to the compilation of air pollutant emission factors (U.S. Environmental Protection Agency, 1995)

Table 2. Summary of unit risk of contaminants in terms of both carcinogenic and non-carcinogenic effects

Contaminants	Inhalation unit risk (per μg/m^3)	Reference concentration (mg/m^3)
Arsenic	4.30E-03[a]	1.50E-05[b]
Cadmium	1.80E-03[a]	1.00E-05[d]
Chromium	1.20E-02[a]	2.86E-05[a]
Mercury	n/a	3.00E-04[a]
Nickel	2.40E-04[a]	9.00E-05[d]
Lead	1.20E-05[b]	n/a
Mono to tri-chlorinated dibenzodioxin	3.30E-01[c]	2.0E-09[e]
Mono to tri-chlorinated dibenzofuran	3.80E-01[b]	3.5E-03[e]

Note: Data is from [a]integrated risk information system (U.S. Environmental Protection Agency, 2021), [b1,b2]office of the U.S. Environmental Protection Agency (1989), [d]Agency for Toxic Substances and Disease Registry (2005), [e]Michigan Department of Environmental Quality (2015).

2.2.2 Exposure assessment

Workers were exposed to contaminants mostly by inhalation in accordance with the exposure pathways. Direct inhalation was the only pathway for the MSWI workers, as shown in Figure 2. The concentration of contaminants at the GLC level was indicated by the output of the AERMOD, in which the worker was placed at the location of maximal estimated worksite impacts (Table 2).

For occupational assessment, the workers normally worked 8 h per day. To evaluate the contamination in workplace, occupational exposure limits (OELs) were regulation values that determined exposure levels for contaminants in the workplace ambient. In Thailand, there was a regulation on permissible exposure limits of some hazardous chemicals issued by Notification of the Department of Labour Protection and Welfare (2017), Thailand for OELs, however, the other chemical standard would be taken from the U.S. occupational Safety and Health Administration (OSHA) OELs.

As a means of calculating exposure concentration (EC) values, the U.S. Environmental Protection Agency recom-mended dividing total exposure by average time (AT) to arrive at an average inhalation exposure per unit time and utilizing total-air concentrations. The AT for carcinogenic health effects would be life expectancy. The AT for carcinogenic health effects was the day that receptors have a life expectancy time. Based on a Thai life expectancy exposure of 75.3 years (The World Bank, 2019), for non-carcinogenic effects, the AT would be the time that the MSWIs could operate (30 years). When determining ECs, it is not necessary to consider inhalation rates or body weight (Office of Solid Waste and Emergency Response,, 2005; U.S. Environmental Protection Agency, 2011). Equation (1) presents the calculation used to determine direct inhalation exposure concentration.

$$\text{EC}\ (\mu\text{g/m}^3) = \frac{\text{C}_\text{a}*\text{EF}*\text{ED}}{\text{AT}*365\ \text{days/year}} \quad (1)$$

where C_a = maximum 8 h average concentration (μg/m^3)
EF = exposure frequency (5 days x 52 weeks = 260 days/year)
ED = exposure duration (year)
AT = average time (years).

2.2.3 Characterizing Risk

The incremental probability of an individual developing cancer over the course of his/her lifetime because of a specific exposure to a carcinogenic contaminant could be used to assess CR. The significant level of CR as recommended by the U.S. Environmental Protection Agency (1989; 1991) is 10^{-6}, which implies that the hazardous and damaging chemicals are likely to cause cancer (Cai et al., 2018). The inhalation pathway risk can be calculated from Equation (2) below:

$$\text{CR} = \text{EC} * \text{IUR} \quad (2)$$

where IUR = inhalation unit risk (per μg/m^3).

For each contaminant, the HQ could be calculated using Equation (3). The cumulative hazard associated with exposure to all contaminants via an inhalation pathway is referred to as a high risk factor. When the value of HQ is more than or equal to 1, the hazardous chemicals are more likely to constitute a true carcinogenic risk (Cai et al., 2018).

$$\text{HQ} = \frac{\text{EC}}{\text{R}f\text{C}} \quad (3)$$

where R*f*C = reference concentration (mg/m^3).

3. RESULTS AND DISCUSSION

3.1 Contaminant distribution in the workplace

The maximum 8-h GLC of each pollutant near the MSWIs was calculated using an air quality modeling called AERMOD. None of the GLC pollutants exceeded the OELs established by Thai law enforcement and the OSHA, according to the estimated concentrations listed in Table 3.

Even though the waste-incinerator plant was operating for 8 h per day, 365 days per year for 30 years, according to OSHA, a typical work shift was defined as a work time of no more than 8 h throughout the day, five days a week (The National Institute for Occupational Safety and Health, 1988). The calculation was performed in Equation (1), with results shown in Figure 3, which described the EC via inhalation pathway for both Phra Nakhon Si Ayutthaya and Rayong. The carcinogenic contaminants showed a smaller value than the non-carcinogenic contaminants, since the ATs were higher than for the non-carcinogenic case. The contaminant to which the workers were most exposed was Pb.

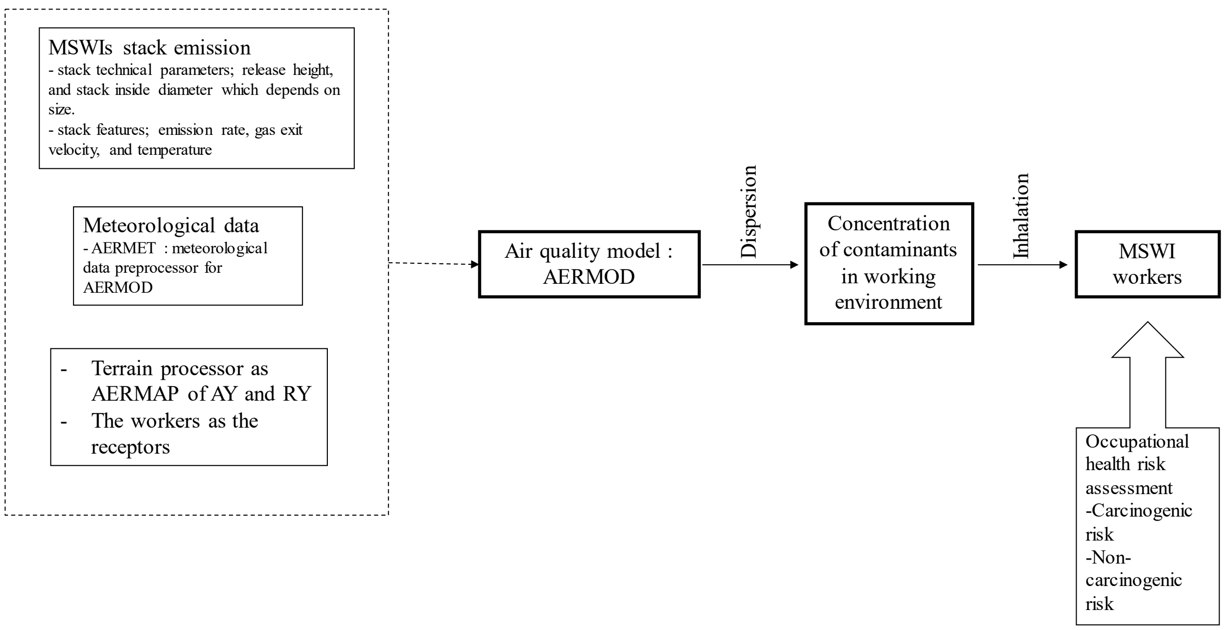

Figure 2. Conceptual paradigm of an occupational health risk assessment of municipal solid waste incinerators (MSWIs) workers
Note: AERMET = meteorology pathway, AERMOD = air quality model, AERMAP = terrain processor, AY = Phra Nakhon Si Ayutthaya, RY = Rayong

Table 3. Contaminants concentration in workplace environment

Contaminants	Maximum 8-h average concentration (μg/m³)		OELs (mg/m³)	Type of exposure limits
	Phra Nakhon Si Ayutthaya	Rayong		
Arsenic	1.96E-03	1.10E-03	0.01*	TWA
Cadmium	4.99E-03	2.80E-03	0.005*	TWA
Chromium	4.11E-03	2.30E-03	0.1**	TWA
Mercury	2.56E-03	1.44E-04	0.1*	ceiling
Nickel	3.60E-03	2.02E-03	1**	TWA
Lead	9.78E-02	5.50E-02	0.05*	TWA
CDD and CDF	7.62E-07	4.29E-07	n/a	-

Note: CDD = mono- to tri-chlorinated dibenzodioxin, CDF = mono- to tri-chlorinated dibenzofuran, OELs = occupational exposure limits, TWA*:* time-weighted average as an 8 h working time, ceiling = at no time should this exposure limit be exceeded

*Legislated by Notification of the Department of Labour Protection and Welfare (2017)

**Permissible exposure limit standard by the Occupational Safety and Health Administration (2020; 2021)

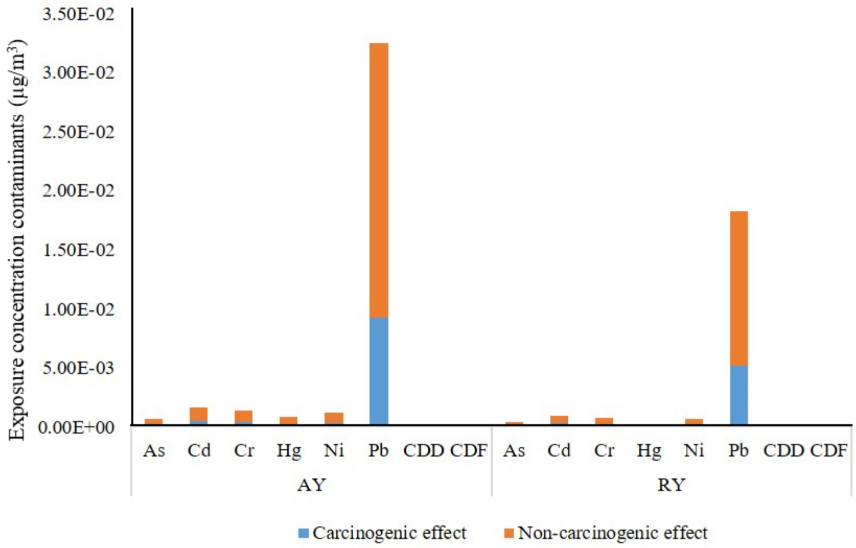

Figure 3. Calculated levels of direct inhalation of both carcinogenic and non-carcinogenic contaminants

Note: As = Arsenic, Ni = nickel, Pb = lead, Cd = cadmium, Cr = chromium, Hg = mercury, CDD = mono- to tri-chlorinated dibenzodioxin, CDF = mono- to tri-chlorinated dibenzofuran AY = Phra Nakhon Si Ayutthay, and RY = Rayong

3.2 Health risk assessment

3.2.1 CR assessment

For each particular pollutant, the CR from direct inhalation exposure was determined. To the cumulative lifetime subsistence risk, workers contributed a portion of the total risk. Because all contaminants can cause lung cancer, according to the International Agency for Research on Cancer (2021). The total CR in this study was summed by the CR of all contaminants, as shown in Table 4. The total in both areas exceeded the reference level (10^{-6}), 6.55E-06 and 3.68E-06, as defined by the U.S. Environmental Protection Agency (1991).

Among all of the contaminants, with the exception of Cr, the majority of the contaminants found did not exceed the reference level. Contaminant CRs ranged from 1.34E-08 to 8.50E-07. For Cr, the highest CR was discovered in both sites, with values of 4.66E-06 and 2.61E-06, respectively, which exceeded the reference level. It could be predicted that the workers might suffer an adverse cancer health effect if they continued to be exposed consistently at a similar concentration of contaminants. Even though, the concentration in the workplace did not exceed the OELs, the CR did, which was similar to the findings of Wang et al. (2021), who found that workers were being exposed to chemicals at an exceeding health risk. The findings from this study were consistent with the results of CR found for those residing near the MSWIs (Srivieng et al., 2021b). According to comparisons performed in China, there were significantly elevated blood concentrations of Cr in the local citizens also, as revealed in Li et al. (2017).

The CR was found to be higher in Phra Nakhon Si Ayutthaya than in Rayong, presumably because Rayong is located near the Gulf of Thailand and the weather in that area is generally rainy and windy, allowing pollutants in the ambient air to be diluted. Phra Nakhon Si Ayutthaya, on the other hand, is in the central region, where it is surrounded by fields that can induce winds and where there is both a lack of rain and periodic droughts during the summer season. As a result of these findings, both geographical and meteorological variables can have an impact on the current risks (Borge et al., 2019)

Table 4. Exposure to contaminants of workers through inhalation, contributing to risks

Contaminants	Inhalation cancer risk		Inhalation hazard quotient	
	Phra Nakhon Si Ayutthaya	Rayong	Phra Nakhon Si Ayutthaya	Rayong
Arsenic	7.95E-07	4.47E-07	3.10E-02	1.74E-02
Cadmium	8.50E-07	4.78E-07	1.19E-01	6.66E-02
Chromium	4.66E-06*	2.61E-06*	1.95E-04	1.09E-04
Mercury	n/a	n/a	2.02E-03	1.14E-04
Nickel	8.18E-08	4.60E-08	9.51E-03	5.34E-03
Lead	1.11E-07	6.25E-08	n/a	n/a
Mono- to tri-chlorinated dibenzodioxin	2.38E-08	1.34E-08	9.05E-02	5.09E-02
Dibenzofuran	2.74E-08	1.54E-08	5.17E-08	2.91E-08
Total	6.55E-06*	3.68E-06*	2.52E-01	1.40E-01

Note: *Exceeds the cancer risk reference level (10^{-6})

3.2.2 HQ

For both sites, the HI (total HQ) for non-carcinogenic risk from the presence of contaminants was determined to be lower than the reference level (<1) (U.S. Environmental Protection Agency, 1991). The values for Phra Nakhon Si Ayutthaya and Rayong, respectively, were 2.52E-01 and 1.40E-01, indicating that contaminants were not the cause of adverse non-cancer health impacts to the employees (Table 4) (National Air Toxics Assessment, 2017). Nonetheless, it was worth mentioning that the risk assessment was based on the highest concentration predicted by the air quality model, which was then followed by a calculation representing the highest inhalation exposure for the workers (Office of Solid Waste and Emergency Response, 2005). Along with the result of health-risk assessment in Thailand for people surround-ding the MSWIs, it was revealed that none of the chemicals was higher than the reference level (Srivieng et al, 2021a). The study of Vilavert et al. (2012) monitored the dioxin and furan by using active and passive sampling devices and found that the HQ was lower than the maximum recom-mended guidelines. Also, from a study of the 17 PCDD/Fs and 11 heavy metals (Sb, Mn, As, Ni, Co, Cr, Cu, Hg, Cd, Zn and Pb) in soil samples collected near MSWI plants in Sichuan province, it was found that most of them did not exceed the upper acceptable levels, but Ni had carcinogenic risk values in the dermal pathway (Bo et al., 2022).

4. CONCLUSION

In terms of occupational air monitoring, the 8-h predicted air concentration did not exceed the OELs of Thailand and Occupational Safety and Health Administration, which specifies the contaminants to which nearly all workers were believed to have been repeatedly exposed every working day for the duration of their working lifetimes, but without adverse health effects. Among all contaminants, Pb was determined to be the closest to the standard in the two research locations, hence Pb surveillance monitoring should be implemented as a result. There is no applicable workplace standard for CDD and CDF.

From the HRA that was conducted, the total CR results have been shown not to be acceptable for workers. The reason for this negative result could be that Cr caused an increased risk of cancer, and the waste input at both research sites was in the form of a large cluster Provided that control measures, personal protective equipment such as respirator, should be properly applied.

REFERENCES

Agency for Toxic Substances and Disease Registry. (2005). *Public health assessment guidance manual*. [Online URL: https://www.atsdr.cdc.gov/pha-guidance/about.html] accessed on December 11, 2020.

Bena, A., Orengia, M., Gandini, M., Bocca, B., Ruggieri, F., Pino, A., Alimonti, A., Ghione, F., and Farina, E. (2020). Human biomonitoring of metals in workers at the waste-to-energy incinerator of Turin: An Italian longitudinal study. *International Journal of Hygiene and Environmental Health*, 225, 113454.

Bo, X., Guo, J., Wan, R., Jia, Y., Yang, Z., Lu, Y., and Wei, M. (2022). Characteristics, correlations and health risks of PCDD/Fs and heavy metals in surface soil near municipal solid waste incineration plants in southwest China. *Environmental Pollution*, 298, 118816.

Borge, R., Requia, W. J., Yagüe, C., Jhun, I., and Koutrakis, P. (2019). Impact of weather changes on air quality and related mortality in Spain over a 25-year period [1993-2017]. *Environment International*, 133(Part B), 105272.

Buranasingh. N. (2015). *Devalue Waste: Unexpected Value in Energy Terms*, Bangkok: The Secretariat of the House of Representatives, pp. 1-17. [in Thai]

Cai, Y., Li, F., Zhang, J., and Wu, Z. (2018). Occupational health risk assessment in the electronics industry in China based on the occupational classification method and EPA model. *International Journal of Environmental Research and Public Health*, 15(10), 2061.

Notification of the Department of Labour Protection and Welfare. (2017, August 3). *Royal Thai Government Gazette (No. 134, p. 34).* [Online URL: http://cste.sut.ac.th/csteshe/wp-content/lews/Law28.pdf] accessed on December 11, 2020.

Michigan Department of Environmental Quality. (2015). *Chemical update worksheet*. [Online URL: https://www.michigan.gov/-/media/Project/Websites/egle/Documents/Programs/RRD/Remediation/Rules---Criteria/Chemical-Update-Worksheets/A---C/Antimony-Datasheet.pdf?rev=bdd623b21e174dd8998922ee3d396afc] accessed on December 11, 2020.

International Agency for Research on Cancer. (2021) *List of classifications by cancer sites with sufficient or limited evidence in humans*. [Online URL: https://monographs.iarc.who.int/wp-content/uploads/2019/07/Classifications_by_cancer_site.pdf] accessed on December 15, 2021.

Li, T., Wan, Y., Ben, Y., Fan, S., and Hu, J. (2017). Relative importance of different exposure routes of heavy metals for humans living near a municipal solid waste incinerator. *Environmental Pollution*, 226, 385-393.

Ma, W., Tai, L., Qiao, Z., Zhong, L., Wang, Z., Fu, K., and Chen, G. (2018). Contamination source apportionment and health risk assessment of heavy metals in soil around municipal solid waste incinerator: A case study in north China. *Science of The Total Environment*, 631-632, 348-357.

National Air Toxics Assessment. (2017). *Glossary of term*. [Online URL: https://19january2017snapshot.epa.gov/national-air-toxics-assessment/nata-glossary-terms_.html] accessed on January 2, 2022.

National Research Council. (2000). *Waste Incineration & Public Health*, Washington, DC: The National Academies Press, pp. 6-9. [Online URL: https://www.ncbi.nlm.nih.gov/books/NBK233619] accessed on March 20, 2021.

The National Institute for Occupational Safety and Health. (1988). *1988 OSHA PEL project documentation*. [Online URL: https://www.cdc.gov/niosh/pel88/pelstart.html] accessed on December 11, 2021.

Occupational Safety and Health Administration. (n.d.). *Long work hours, extended or irregular shifts, and worker fatigue.* [Online URL: https://www.osha.gov/worker-fatigue#:~:text=Long%20work%20hours%20may%20increase,of%20physical%20activity%20and%20illness] accessed on December 15, 2021.

Occupational Safety and Health Administration. (2020). *Chromium (VI) compounds (Hexavalent chromium).* [Online URL: https://www.osha.gov/chemicaldata/537] accessed on February 17, 2022.

Occupational Safety and Health Administration. (2021). *Nickel, Metal & Insoluble compounds (as Ni)*. [Online URL: https://www.osha.gov/chemicaldata/509] accessed on February 17, 2022.

Office of Solid Waste and Emergency Response. (2005), Chapter 6 : Quantifying exposure. In *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities*, pp. 1-3; 19-21. Cincinnati, Ohio: United State Environmental Protection Agency.

Ravindra, K., Sokhi, R., and Grieken, V. R. (2008). Atmospheric polycyclic aromatic hydrocarbons: Source attribution, emission factors and regulation. *Atmospheric Environment*, 42(13), 2895-2921.

Ranzi, A, Fano, V., Erspamer, L., Lauriola, P., Perucci, C. A., and Forastiere, F. (2011). Mortality and morbidity among people living close to incinerators: A cohort study based on dispersion modeling for exposure assessment. *Environmental Health*, 10, 22.

Srivieng, P., Suadee, W., and Watchalayann, P. (2021a). Health risk assessment of air pollutants emitted from municipal solid-waste incinerators in Thailand. *EnvironmentAsia*, 14(2), 51-63.

Srivieng, P., Watchalayann, P., and Suadee W. (2021b). Cancer risk assessment around municipal solid waste incinerators. *EnvironmentAsia*, 14(3), 102-116.

Tait, P. W., Brew, J., Che, A., Costanzo, A., Danyluk, A., Davis, M., Khalaf, A., McMahon, K., Watson, A., Rowcliff, K., and Bowles, D. (2020). The health impacts of waste incineration: A systematic review. *Australian and New Zealand Journal of Public Health*, 44(1), 40-48.

The World Bank. (2019). *Life expectancy at birth, total (years) – Thailand*. [Online URL: https://data.worldbank.org/indicator/SP.DYN.LE00.IN?locations=TH] accessed on November 12, 2020.

U.S. Environmental Protection Agency. (1995). Solid waste disposal. In *AP-42: Compilation of Air Pollutant Emission Factors*, *Volume 1: Stationary Point and Area Sources,* 5th ed., pp. 20-24. North Carolina: Office of Air Quality Planning and Standards.

U.S. Environmental Protection Agency. (1989). *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual (Part A),* Washington, D.C.: Office of Emergency and Remedial Response, pp. 6-16.

U.S. Environmental Protection Agency. (1991). *Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals),* Washington D.C.: Office of Emergency and Remedial Response, pp. 1-6.

U.S. Environmental Protection Agency. (2011). *Exposure Factors Handbook: 2011 Edition (Final Report)*, Washington, D.C.: Office of Research and Development, pp. 8-10.

U.S. Environmental Protection Agency. (2021). *Conducting a human health risk assessment.* [Online URL: https://www.epa.gov/risk/conducting-human-health-risk-assessment] accessed on December 1, 2021.

Vilavert, L., Nadal, M., Schuhmacher, M., and Domingo, J. L. (2012). Long-term monitoring of dioxins and furans near a municipal solid waste incinerator: Human health risks. *Waste Management & Research*, 30(9), 908-916.

Wang, T. S., Song, B., Sun, Q. H., Lin, Y. X., Sun, Y., Sun, P., Jia, X. D., Au, W. W., Mei, C. H., and Xia, Z. L. (2021). Occupational health risk assessment of benzene, toluene, and xylene in Shanghai. *Biomedical and Environmental Sciences*, 34(4), 290-298.

Xu, P., Wu, L., Chen, Y., Xu, D., Wang, X., Shen, H., Han, J., Fu, Q., Chen, Z., and Lou, X. (2019). High intake of persistent organic pollutants generated by a municipal waste incinerator by breastfed infants. *Environmental Pollution*, 250, 662-668.