HEALTH RISK ASSESSMENT OF INHALATION AND DERMAL EXPOSURE TO PARTICLE-BOUND POLYCYCLIC AROMATIC HYDROCARBONS OF E-WASTE DISMANTLING WORKERS IN BURIAM PROVINCE, THAILAND

Miss Sarasanant Bungadaeng

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การประเมินความเสี่ยงต่อสุขภาพจากการรับสัมผัสสารพอลิไซคลิกอะโรมาติกไฮโดรคาร์บอนที่ดูดซับบนอนุภาคฝุ่นผ่านทางการหายใจและทางผิวหนังของผู้รื้อแยกขยะอิเล็กทรอนิกส์ ในจังหวัดบุรีรัมย์

นางสาวสรัสนันท์ บุหงาแดง

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต

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Thesis Title	HEALTH RISK ASSESSMENT OF INHALATION AND DERMAL EXPOSURE TO PARTICLE-BOUND POLYCYCLIC AROMATIC HYDROCARBONS OF E-WASTE DISMANTLING WORKERS IN BURIRAM PROVINCE, THAILAND
By	Miss Sarasanant Bungadaeng
Field of Study	Hazardous Substance and Environmental Management
Thesis Advisor	Assistant Professor Tassanee Prueksasit, Ph.D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Graduate School
(Associate Professor Thumnoon Nhujak, Ph.D.)

THESIS COMMITTEE

....Chairman
(Assistant Professor Chantra Tongcumpou, Ph.D.)

....Thesis Advisor
(Assistant Professor Tassanee Prueksasit, Ph.D.)

....Examiner
(Nutta Taneepanichskul, Ph.D.)

....External Examiner
(Daisy Morknoy, Ph.D.)

สรัสนันท์ บุหงาแดง : การประเมินความเสี่ยงต่อสุขภาพจากการรับสัมผัสสารพอลิไซคลิกอะโรมาติกไฮโดรคาร์บอนที่ดูดซับบนอนุภาคฝุ่นผ่านทางการหายใจและทางผิวหนังของผู้รื้อแยกขยะอิเล็กทรอนิกส์ ในจังหวัดบุรีรัมย์ (HEALTH RISK ASSESSMENT OF INHALATION AND DERMAL EXPOSURE TO PARTICLE-BOUND POLYCYCLIC AROMATIC HYDROCARBONS OF E-WASTE DISMANTLING WORKERS IN BURIRAM PROVINCE, THAILAND) อ.ที่ปรึกษาวิทยานิพนธ์หลัก : ผศ. ดร. ทรรศนีย์ พฤกษาสิทธิ์, 146 หน้า.

งานวิจัยนี้มุ่งเน้นการศึกษาวิเคราะห์ปริมาณการรับสัมผัสสารพอลิไซคลิกอะโรมาติกไฮโดรคาร์บอน (PAHs) ที่ดูดซับอยู่บนอนุภาคฝุ่นซึ่งเกิดขึ้นจากกระบวนการเผาไหม้ของขยะอิเล็กทรอนิกส์ และทำการประเมินความเสี่ยงต่อสุขภาพที่ผู้ประกอบอาชีพรื้อแยกขยะอิเล็กทรอนิกส์ได้รับจากการสัมผัสสารดังกล่าวผ่านทางการหายใจและทางผิวหนัง ผลการศึกษาพบว่าสาร PAHs ที่ถูกดูดซับบนอนุภาคฝุ่น PM$_{2.5-10}$ มีค่าความเข้มข้นรวมอยู่ในช่วง 0.0703 ถึง 20.9800 μg/m^3 ส่วนฝุ่น PM$_{2.5}$ พบค่าความเข้มข้นรวมอยู่ในช่วง 0.2669 ถึง 89.9645 μg/m^3 ในส่วนของฝุ่นที่เก็บตัวอย่างจากมือของผู้ทำการเผาขยะอิเล็กทรอนิกส์ ผลการศึกษาพบว่าฝุ่นที่เก็บตัวอย่างก่อนการทำงานมีค่าความเข้มข้นรวมของสาร PAHs อยู่ในช่วง 8.1072 ถึง 253.6118 mg/kg โดยมีค่าเฉลี่ยอยู่ที่ 95.3894 mg/kg ในฝุ่นที่เก็บตัวอย่างหลังกิจกรรมการทำงานมีค่าความเข้มข้นรวมของสาร PAHs อยู่ที่ 117.5432 to 4,315.9496 mg/kg ค่าเฉลี่ยเท่ากับ 1,187.9897 mg/kg และสำหรับความเข้มข้นของ PAHs ในตัวอย่างฝุ่นที่เก็บตัวอย่างหลังการล้างมือมีค่าเฉลี่ยอยู่ที่ 309.9614 mg/kg ซึ่งค่าที่พบในตัวอย่างทั้งหมดอยู่ในช่วง 109.1063 ถึง 876.9778 mg/kg เมื่อนำผลการศึกษามาทำการประเมินความเสี่ยงของการก่อเกิดมะเร็ง พบว่าสำหรับการรับสัมผัสทางการหายใจ ค่าความเสี่ยงของการก่อมะเร็งจาก PAHs บนอนุภาค PM$_{2.5-10}$ ที่ระดับความเชื่อมั่น 95% มีค่าอยู่ในช่วง 3.44 x 10^{-7}– 1.98 x 10^{-5} และใน PM$_{2.5}$ ความเสี่ยงมีค่าอยู่ในช่วง 2.02 x 10^{-5} - 6.71 x 10^{-4} ค่าความเสี่ยงรวมจากการรับสัมผัสทางการหายใจ ซึ่งเป็นผลรวมของค่าความเสี่ยงที่เกิดขึ้นจากฝุ่นทั้งสองชนิด มีค่าที่ระดับความเชื่อมั่น 95% อยู่ในช่วง 2.75 x 10^{-5}-8.00 x 10^{-5} โดยมีค่าความเสี่ยงเกินเกณฑ์ที่ยอมรับได้คิดเป็น 90.91% จากตัวอย่างทั้งหมด ในส่วนของการรับสัมผัสทางผิวหนัง ค่าความเสี่ยงของการก่อมะเร็งที่ระดับความเชื่อมั่น 95% ของการรับสัมผัสสาร PAHs ที่ดูดซับบนฝุ่นจากผิวหนังก่อนการทำงาน หลังการทำงาน และหลังการล้างมือ มีค่าอยู่ในช่วง 1.32 x 10^{-6}–2.62 x 10^{-6}, 1.25 x 10^{-4}-2.85 x 10^{-4}, และ 2.07 x 10^{-5}-4.22 x 10^{-5} ตามลำดับ และสำหรับความเสี่ยงรวมในการก่อเกิดมะเร็งจากทั้งสองช่องทางการรับสัมผัส มีค่าที่ระดับความเชื่อมั่น 95% อยู่ในช่วง 1.74 x 10^{-4} ถึง 3.74 x 10^{-4} ซึ่งความเสี่ยงรวมนี้พบค่าเกินกว่าระดับความเสี่ยงที่ยอมรับได้ในทุกตัวอย่าง

สาขาวิชา การจัดการสารอันตรายและสิ่งแวดล้อม
ลายมือชื่อนิสิต ....
ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
ปีการศึกษา 2561

5887535020 : MAJOR HAZARDOUS SUB STANCE AND ENVIRONMENTAL MANAGEMENT

KEYWORDS: PARTICLE-BOUND PAHS / E-WASTE BURNING / INHALATION / DERMAL / RISK ASSESSMENT

SARASANANT BUNGADAENG: HEALTH RISK ASSESSMENT OF INHALATION AND DERMAL EXPOSURE TO PARTICLE-BOUND POLYCYCLIC AROMATIC HYDROCARBONS OF E-WASTE DISMANTLING WORKERS IN BURIRAM PROVINCE, THAILAND. ADVISOR: ASST. PROF. TASSANEE PRUEKSASIT, Ph.D., 146 pp.

This research mainly studied on the inhalation and dermal exposure concentrations of particle-bound polycyclic aromatic hydrocarbon (PAHs) that e-waste burning workers probably received during their work and further estimated the health risk assessment in both route of exposure. According to the obtained results, the total concentrations of PAHs on $PM_{2.5-10}$ ranged from 0.0703 to 20.9800 $\mu g/m^3$. For $PM_{2.5}$, the total concentrations of PAHs varied from 0.2669 to 89.9645 $\mu g/m^3$. In the dermal dust samples, the total concentrations of PAHs on the particles before burning work ranged from 8.1072 to 253.6118 mg/kg with the average concentration at 95.3894 mg/kg. For the samples of dust after finish burning work, the total concentrations of PAHs varied from 117.5432 to 4,315.9496 mg/kg and the mean concentration was 1,187.9897 mg/kg. Also, the average concentration of PAHs on the dust after hand washing was 309.9614 mg/kg and the range of values varied from 109.1063 to 876.9778 mg/kg. Regarding to the risk assessment results, the life time cancer risk (LCR) of $PM_{2.5-10}$ bounded PAHs at 95% CI ranged from 3.44×10^{-7}– 1.98×10^{-5}, and 95% CI cancer risk for PAHs in $PM_{2.5}$ ranged from 2.02×10^{-5} - 6.71×10^{-4}. The total inhalation LCR, which was the summation of both two inhalation LCR, at 95% CI ranged from 2.75×10^{-5} to 8.00×10^{-5} with 90.91% unacceptable risk. Furthermore, the LCR at 95% CI of the workers exposed to PAHs in dermal dust before burning work, after finish burning work, and after hand washing ranged from 1.32×10^{-6}–2.62×10^{-6}, 1.25×10^{-4}- 2.85×10^{-4}, and 2.07×10^{-5}- 4.22×10^{-5}, respectively. Lastly, the multi route cancer risk, which was the combination of total inhalation LCR and dermal LCR after finish burning work, at 95% CI ranged from 1.74×10^{-4} to 3.74×10^{-4} with 100% unacceptable risk, which necessarily should be concerned.

Field of Study:	Hazardous Substance and Environmental Management	Student's signature ....
		Advisor's signature ....
Academic Year:	2018	

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CHAPTER I

INTRODUCTION

1.1 Background and significance problem addressed

Nowadays, with the continuous worldwide development of information and communication technology (ICT), the global market of electrical and electronic equipment is expanded rapidly in accordance with the large economic demand (UNU, 2015). According to the high consumption rate and the shorter lifespan of the products, the waste of electrical and electronic equipment (WEEE or e-waste) becomes a type of waste that has fastest generation rate in the world (Huisman, 2012), and the problem of increasing number of e-waste has received considerable critical attention in these recent years.

Compare with other types of waste such as municipal or industrial waste, e-waste is chemically and physically prominent because it composed of both useful valuable materials and also toxic substances. Therefore, special disposal and recycling methods to avoid the impact on environment and side effects on human health is required (Magalini, 2016). Recycling is the best way to create an opportunity for bringing back reusable components. However, developed countries tend not to recycle e-waste in order to abstain from high cost and some limited environmental regulations. In contrast, they manage e-waste by sending to landfill or export to other developing countries, where primitive recycling techniques (e.g. dismantling, crushing, separating, and open burning) are commonly used and contributes more severe environmental contamination and even detrimental health burdens on workers from lacking of technology and appropriate protection (Cobbing, 2008).

Open burning of electric wire is one of the primitive methods used to separate the copper from the inside of the wires. Previous studies revealed that many types of toxic air pollutants can be released from the combustion of e-waste, including Dioxins, Furans, Hydrogen Chloride, Polyhalogenated Aromatic Hydrocarbons (PHAHs), and Polycyclic Aromatic Hydrocarbons (PAHs) (Robinson, 2009).

Many recent studies provided that PAHs are emitted into environmental media in various ways that associated with the e-waste recycling process. Deng et al. (2006) determined PAHs concentrations in ambient air collected from an e-waste recycling site at Guiyu, southeast China. The concentration of PAHs in the Guiyu air from the research was higher than in Guangzhou, which is one of the most pollution contaminated cities in China. This high level of PAHs possibly indicates the significant emission of PAHs from e-waste recycling activities, especially due to open burning of plastics and metal scrap. Wong et al. (2007) also supported the detection of concentrations of Persistent Organic Pollutants (POPs), including Polychlorinated Dibenzo-p-Dioxins/Furans (PCDD/Fs), Polybrominated Diphenyl Ethers (PBDEs), Polycyclic Aromatic Hydrocarbons (PAHs), and Polychlorinated Biphenyls (PCBs), and heavy metals in the Guiyu ambient air, which were higher when compared with those from other cities due to incomplete combustion of e-wastes products such as plastic chips, wire insulations, PVC materials and metal scraps. By atmospheric movement and deposition, the emission of POPs and heavy metal in the air enlarged more severe pollution to other media of environment including soil and river body, which may affect the surrounding environment by accumulation in rice fields and rivers and eventually came to animal and human bodies via food chain consumption. Moreover, Feldt et al. (2014) found obvious higher urinary PAH levels in the people who exposed to e-waste recycling processes compared to unexposed control population. The study also showed that PAHs exposed participants obtained more clinical symptoms such as cough, chest pain and vertigo, suggested that the involvement in the e-waste recycling activities increased the chance of PAHs exposure.

As information mentioned above, there are evidences support that open burning of e-waste is one of the significant source of PAHs emission, which PAHs is a toxic substance that may pose some serious health risks to the worker and resident people. After expose to several types of PAHs via breathing, eating, and long-term skin contact, the studies have shown the potential of PAHs to cause tumors in laboratory animals. Research have also shown the harmful effects of PAHs in animals after both short and long-term exposure, the compound can affect skin, body fluids, and the body immune system. Studies in human, moreover, suggested that inhalation and chronic dermal exposure to the mixtures that contain PAHs and other compounds can also develop cancer, which is the most threaten critical endpoint on human health. The potential of PAHs as carcinogenic to humans is classified by many world organization, including Department of Health and Human Services (DHHS), International Agency for Research on Cancer (IARC), and Environmental Protection Agency (EPA) (ATSDR, 1995).

Currently, Thailand is now facing the problem of e-waste management due to the large quantity of e-waste generated continuously year by year. According to Thailand State of Pollution Report 2015, the estimated amount of household hazardous waste generated in 2015 was increase from 2014 by 2.57%, and the largest proportion was belonged to e-waste, which accounted for 65% from all (PCD, 2015).

Several district in Kalasin and Buriram province are the main area where e-waste are received for separation and recycle valuable components by primitive methods (PCD, 2014). Open burning is one of the main process in the dismantling activities to separate the precious metal from the residues, which can be found normally in the dismantling workplace in Buriram (Ban Pao Sub district Administrative Organization, 2015). In addition, Puangprasert (2015), who studied about inhalation exposure to heavy metals and health risk assessment of separating electronic waste workers in Buriram Province, found that the concentration of PM_{10} obtained from the day that workers had open burning activities was 0.4608 mg/m^3, higher than average PM_{10} from other separation activities (0.0646 mg/m^3) about seven folds. This result revealed that workers who proceed burning activities may have higher opportunity to be exposed with particulate matter and also other toxic substance adsorbed on the surface of particle, including PAHs. Moreover, the result from questionnaire survey found that the workers had developed some unusual symptom from lacking of personal protective equipment, especially dermal allergy and skin irritation. However, there has not been studied about the concentration of PAHs emitted into environment from the open burning of e-waste directly, and the health risk of the workers who expose PAHs from each route still has not been evaluated. Therefore, this research aims to study about the emission of PAHs from the open burning of e-waste in Buriram province, Thailand, which the measured results will also be used in the further step to assess the health risk from inhalation and dermal contact of the dismantling workers in this site. The research outcomes can be served as the warning guideline for workers and for further surveillance and management planning to protect both people and environmental health.

1.2 Objectives

This research consisted of two major objectives, which could be divided into the sub objectives as follows.

1) To analyze the concentrations of polycyclic aromatic hydrocarbons (PAHs) emitted from the open burning activities of e-waste in the dismantling site that exposed to the workers via inhalation and dermal route

1.1) The inhalation exposure concentrations of particle-bound PAHs that were quantified from two particle sizes, including $PM_{2.5}$ and $PM_{2.5-10}$, and analyzed statistically to examine the relationship with the factors that probably had an impact on their concentrations, which are the quantity of burnt e-waste and the pattern of burning activity.

1.2) The dermal exposure concentrations of PAHs obtained from the dust that adsorbed on the workers' hands were also analyzed by statistical process to find the relationship with the possible concentration increasing factors, including the pattern of burning activity and the use of personal protective equipment.

2) To estimate the lifetime cancer risk of polycyclic aromatic hydrocarbons (PAHs) that probably occurs to the workers in the e-waste dismantling site from both of inhalation and dermal exposure.

1.3 Hypotheses

1) Open burning of e-waste provides the higher exposure level of PAHs via inhalation route than dermal contact.

2) The probability of lifetime cancer risk from inhalation and dermal contact of PAHs in workers who proceed e-waste open burning activities tends to be greater than acceptable level that should be in concerned.

1.4 Scope of the study

1.4.1 Interested toxic substance

1) The interested toxic substances in this study were the group of US EPA priority PAHs, which this study mainly focused only on 13 types of the semi-volatile and particle-bound phase of PAHs, including Fluorene, Phenanthrene, Anthracene, Fluoranthene, Pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Dibenzo(a,h)anthracene, Benzo(g,h,i)perylene, and Indeno(1,2,3-c,d)pyrene.

2) The PAHs inhalation exposure samples were extracted from 2 types of particulate matter, including fine ($PM_{2.5}$) and coarse particles ($PM_{2.5-10}$), which were collected from the breathing zone of the workers.

3) The PAHs dermal exposure samples were extracted from the dust that was adhered on the surface of workers' hands.

1.4.2 Study areas

1) The sampling and questionnaire collected area was conducted at the e-waste dismantling site in Daeng Yai sub-district (located in Ban Mai Chaiyaphot district) and Ban Pao sub-district (located in Putthaisong district), Buriram province, Thailand.

2) The laboratory experiment was proceeded at the laboratory of Department of Environmental Science, International Program of Hazardous Substance

and Environmental Management, Chulalongkorn University, and Faculty of Physical Education, Srinakharinwirot University.

1.4.3 Participants in this research

The participants in this study can be divided into two groups. Group 1 is the group of e-waste dismantling workers in Daeng Yai sub-district within Ban Mai Chaiyaphot district that were suggested by local authorities and allowed to be installed the sampling equipment and wiped their hands to study exposure to PAHs during their burning activities. Group 2 is the group of all e-waste dismantling workers in Daeng Yai sub-district (located in Ban Mai Chaiyaphot district) and Ban Pao sub-district (located in Putthaisong district), which are the two main areas in Buriram province that have dominant e-waste dismantling workplaces. Participants in this group were asked for permission to collect data from questionnaires about their profile and working activities in order to be used for health risk evaluation and for result discussion.

The involvement of participants in this study was under an approval by a Committee for Research Involving Human Research Subjects, Health Science Group, responsible for ethics on human and/or animal experimentation with the certificate of approval number (COA. No.) 230/2016

1.4.4 Sampling duration

Collecting the samples from the starting until ending of e-waste open burning processes, which sampling duration began from February to August, 2017.

1.4.5 Sampling and analytical method

1) For inhalation exposure, samples were collected by Personal Air Samplers connected with Personal Modular Impactors. For dermal exposure, samples were compiled by Hand wiping method.

2) All types of samples were extracted by Ultrasonic Extraction and analyzed by High Performance Liquid Chromatography (HPLC) technique.

1.5 Expected outcome of research

1) The qualitative and quantitative data of PAHs concentrations from the open burning of e-waste would be obtained.

2) The risk assessment results would be used as warning information and guideline for the workers who had high chance to expose PAHs in the recycling site.

Moreover, awareness in using appropriate personal protective equipment would be enhanced from risk communication activities.

3) The results from this research could be used as the secondary data for the further development of plan or policy to control and reduce consequences from recycling activities for more safety of people and environmental health.

CHAPTER II

LITERATURE REVIEW

2.1 Types of particulate matter, source, and health effects

2.1.1 Classification of particulate matter

Particulate matter (PM), also known as particle pollution, is the general term defined by United States Environmental Protection Agency (US EPA, 2014) as the fusion of solid particles and liquid droplets found in the atmospheric environment. Particulate matter consists of compounds with the variety of sizes, numbers, chemical compositions, and the emission sources. The particulate matter is significantly categorized by the ranges of particle sizes, which can be classified into 5 main types, including Thoracic particles (PM_{10}), with an aerodynamic diameter less than 10 micrometers, Coarse particles ($PM_{2.5-10}$), with an aerodynamic diameter between 2.5 micrometers to 10 micrometers, Fine particles ($PM_{2.5}$), with the diameter smaller than 2.5 micrometers, Ultrafine particles (UFP; $PM_{0.1}$), with the diameter less than 0.1 micrometers, and Nanoparticles ($PM_{0.05}$), with the diameter smaller or equal to 0.05 micrometers (U.S.EPA, 2004 and Guevara, 2016). The name, abbreviation, and particle sizes of each type of particulate matter were summarized in Table 2.1.

Table 2.1 Types of particulate matter classified by particle size

Types of particulate matter	Abbreviation	Aerodynamic diameter
Thoracic particles	PM_{10}	< 10 µm
Coarse particles	$PM_{2.5-10}$	> 2.5 µm but < 10 µm
Fine particles	$PM_{2.5}$	< 2.5 µm
Ultrafine particles	UFP or $PM_{0.1}$	< 0.1 µm
Nanoparticles	$PM_{0.05}$	< 0.05 µm

2.1.2 Emission sources of particulate matter

The emission sources of particulate matter can be divided into two main sources according to the generation and formation of particulate matter, which are primary source and secondary source.

Primary particles are particulate matter that released or emitted directly from the generation sources to the air. The generation sources can be both anthropogenic (man-made) or natural sources. Primary PM originates predominantly from combustion (e.g. vehicle engines) and high-temperature processes (e.g. smelting and welding industrial operations) as well as from mechanical disruption processes and man- or wind-induced events causing suspension of particles (e.g. traffic re-suspension of street dust). In general, coarse PM is composed largely of primary particles than fine particles.

Primary coarse particles are usually formed by mechanical disruption processes (e.g. crushing, grinding, and abrasion of surfaces) and also include windblown dust, sea salt, road dust, and combustion-generated particles such as fly ash and soot.

Primary fine particles are emitted from sources either directly as particles or as vapors that rapidly condense to form ultrafine or nuclei-mode particles. This includes soot from diesel engines, a great variety of organic compounds condensed from incomplete combustion or cooking, and compounds of As, Se, Zn, and others that condense from vapor formed during combustion or smelting. The concentration of primary particles depends on their emission rate, transport and dispersion, and removal rate from the atmosphere (EPA, 2004).

However, the direct emissions of $PM_{2.5}$ constitute only a portion of the $PM_{2.5}$ found in ambient air. Secondary fine particulates can also comprise as much as half the $PM_{2.5}$ measured in the United States (Karmel, 2002).

Secondary particles, on the other hand, are the particles formed in the atmosphere from chemical reactions involving primary gaseous emissions, gas-to-particle conversion, and/or condensation of gaseous compounds on pre-existing aerosol particles, mainly involving NOx, SOx, NH_3 and VOCs, which may react with O_3, OH and other reactive molecules forming secondary inorganic aerosols (SIA) and secondary organic aerosols (SOA). Thus, these particles can form at locations distant from the sources that release the precursor gases. Examples include sulfates formed from sulfur dioxide emissions from power plants and industrial facilities and nitrates formed from nitrogen oxides released from power plants, mobile sources, and other combustion sources. Secondary formation processes can result in either the formation of new particles or the addition of PM to preexisting particles. Unlike coarse PM, a much greater portion of $PM_{2.5}$ contains secondary particles (Guevara, 2016).

2.1.3 Health effects from size-different particulate matter

As previously stated, particulate matter consisted of the various range of sizes according to its aerodynamic diameter, the size of PM is directly linked to its potential for causing health problems since smaller particles penetrate further down the respiratory tract and even transfer to extra pulmonary organs, including the central nervous system (Heal et al., 2012). The ability of PM to induce adverse health effects in humans may be a function of combination of many related factors, some of which are likely to determine its deposition in the respiratory tract and ability to induce both local pulmonary and also systemic vascular effects. These factors include size, shape, composition and density of ambient particles. Particle size appears to be an important determinant of PM toxicity. For instance, while PM_{10} has been associated with ischemic cardiovascular events, there is increasing evidence that smaller particles may be responsible for most of cardiovascular adverse health effects. Consequently, $PM_{2.5}$ and UFP are thought to be more toxic than larger particles, which may be partly based on their ability to access deeper portions into the lungs. These particles can pass the proximal airway of the respiratory system (throat and larynx) and get deposited into the tracheobronchial airway of the lungs or in the gas exchange region, which is alveolar ducts or alveoli of the lungs (Oberdorster et al. 2005).

2.1.4 PM from e-waste dismantling and burning processes

Currently, there are many research unveiled that the processes of e-waste recycling activities released the significant higher amount of both fine and coarse particulate matter than the concentrations obtained from the normal background ambient atmosphere. Fang et al. (2013) studied about PM_{10} and $PM_{2.5}$ in a Typical Factory for Cathode Ray Tube Television Recycling and discovered that the mass concentrations of $PM_{2.5}$ in mechanical and dismantling workshops (average of 276.8 μg/ m^3 in the mechanical workshop, 141.1 μg/ m^3 in the dismantling workshop, and 98.5 μg/ m^3 around the workshops) collected in all sampling points were much higher than the Air Quality Standard of China. Meanwhile, the contents of PM_{10} were all below the risk threshold, except that (360.4 μg/ m^3) monitored in the mechanical workshop. The fine particles would diffuse into the ambience of the workshops through the bag filter and other open ways to impact workers and residents. Zheng et al. (2016) measured the concentrations of $PM_{2.5}$ from the air in an informal electronic waste recycling site of China and found that the geometric mean of $PM_{2.5}$ concentrations (49.9 μg/ m^3) was significantly higher than that in the reference area with no e-waste recycling work (37.6 μg/ m^3). The mean $PM_{2.5}$ concentrations obtained for both Guiyu and the reference site exceeded the current World Health Organization (WHO, 2014) 24h $PM_{2.5}$ ambient air quality guidelines (25 μg/ m^3) and Chinese 2012 National Ambient Air Quality Standards Level I (NAAQS I, 35 μg/ m^3). Moreover, Zeping et al. (2010) investigated the $PM_{2.5}$ concentration collected from ambient in the big e-waste industrial park in

Fengjiang, China and found that the pollution level at Fengjiang was obviously higher than the reference urban site in both summer and winter (49.61 µg/ m^3 in summer and 153.88 µg/ m3 in winter). The mass concentration of $PM_{2.5}$ at Fengjiang in winter was much higher than that found in urban Shanghai, and comparable with that of Beijing during the space-heating season. As a coastal site without other industrial activities and space-heating, the high level of $PM_{2.5}$ at Fengjiang in winter indicated the severe air pollution caused by the e-waste recycling industry.

In case of coarse particles, Ogundele et al. (2016) identified the potential sources responsible for the particulate matter emission from secondary iron and steel smelting factory environment, $PM_{2.5}$ and $PM_{2.5-10}$ particles were collected using the low volume air samplers twice a week for a year. The average mass concentrations were 216.26, 151.68, and 138. 62 µg/ m^3 for $PM_{2.5}$ and 331.36, 190.01, and 184.60 µg/ m^3 for $PM_{2.5-10}$ for the production, outside (upwind) and outside (downwind) sampling sites, respectively. The same size resolved data set were used as input for the positive matrix factorization (PMF), principal component factor analysis (PCFA), and Unmix (UNMIX) receptor modeling in order to identify the possible sources of particulate matter and their contribution. The study concluded that metal processing and e-waste are the major sources contributing to the fine fraction while coking and soil contributed to the coarse fraction within the factory environment.

In addition, Puangprasert (2015), who studied about inhalation exposure to heavy metals and health risk assessment of separating electronic waste workers in Buriram Province, found that the concentration of PM_{10} obtained from the day that workers had open burning activities was 0.4608 mg/m^3, higher than average PM_{10} from other separation activities (0.0646 mg/m^3) about seven folds. This result revealed that workers who proceed burning activities may have higher opportunity to be exposed with particulate matter and also other toxic substance adsorbed on the surface of particles.

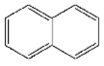
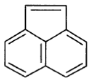
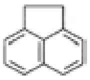
2.2 Polycyclic aromatic hydrocarbon, characteristic, and sources

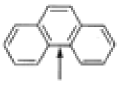
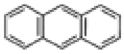
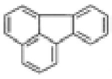
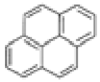
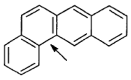
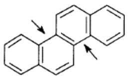
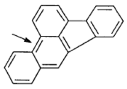
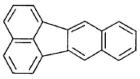
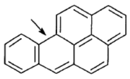
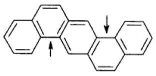
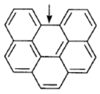
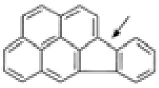
Polycyclic aromatic hydrocarbons have two or more single or fused aromatic rings with a pair of carbon atoms shared between rings in their molecules. PAHs containing up to six fused aromatic rings are often known as “small” PAHs, and those containing more than six aromatic rings are called “large” PAHs. The majority of research on PAHs has been conducted on small PAHs due to the availability of samples of various small PAHs. The simplest PAHs, as defined by the International Agency for Research on Cancer, are Phenanthrene and Anthracene, which both contain three fused aromatic rings. On the other hand, smaller molecules, such as benzene, are not PAHs. Naphthalene, which consists of two coplanar six-membered rings sharing an edge, is another aromatic hydrocarbon. Therefore, it is not a true PAH, though is referred to as a bicyclic aromatic hydrocarbon (Hussein et al., 2016).

2.2.1 Characteristics

Physical and chemical characteristics of PAHs vary with molecular weight, which shown in Table 2.2. In addition, PAH resistance to oxidation, reduction, and vaporization increases with increasing molecular weight, whereas the aqueous solubility of these compounds decreases. As a result, PAHs differ in their behavior, distribution in the environment, and their effects on biological systems.

Table 2.2 Physical-chemical characteristics of 16 US EPA priority PAHs

Compound	Chemical structure	Molecular weight (g)	Solubility at 25°C (µg/L)	Vapor pressure at 25 °C (mm Hg)	Log K_{ow} (Log K_{oc})
Naphthalene		128.2	12500 - 34000	1.8 x 10^{-2}	3.37 (-)
Acenaphthylene		152.2	3420	10^{-3}- 10^{-4}	4.07 (3.40)
Acenaphthene		154.2	-	-	3.98 (3.66)

Compound	Chemical structure	Molecular weight (g)	Solubility at 25°C (µg/L)	Vapor pressure at 25 °C (mm Hg)	Log K_{ow} (Log K_{oc})
Fluorene		166.2	800	-	4.18 (3.86)
Phenanthrene		178.2	435	6.8×10^{-4}	4.46 (4.15)
Anthracene		178.2	59	2.4×10^{-4}	4.5 (4.15)
Fluoranthene		202.3	260	-	4.90 (4.58)
Pyrene		202.1	133	6.9×10^{-7}	4.88 (4.58)
Benzo[a]anthracene		228.3	11.0	1.1×10^{-7}	5.63 (5.30)
Chrysene		228.3	1.9	-	5.63 (5.30)
Benzo[b]fluoranthene		252.3	2.4	-	6.04 (5.74)
Benzo[k]fluoranthene		252.3	-	9.59×10^{-11}	-
Benzo[a]pyrene		252.3	3.8	5.5×10^{-9}	6.06 (5.74)
Dibenzo[a,h]anthracene		278.3	0.4	-	6.86 (6.52)
Benzo[g,h,i]perylene		276.4	0.3	1.0×10^{-10}	6.78 (6.20)
Indeno[1,2,3-cd] pyrene		276.3	-	-	6.58 (6.20)

Source: modified from ATSDR, 1995

2.2.2 PAHs emission sources

The major source of PAHs is the incomplete combustion of organic material such as coal, oil and wood. PAHs are not synthesized chemically for industrial purposes. Nevertheless, there are a few commercial uses for many PAHs. They are mostly used as intermediaries in pharmaceuticals, agricultural products, photographic products, thermosetting plastics, lubricating materials, and other chemical industries. However, the general uses of some PAHs are:

1. Acenaphthene: manufacture of pigments, dyes, plastics, pesticides and pharmaceuticals.
2. Anthracene: diluent for wood preservatives and manufacture of dyes and pigments.
3. Fluoranthene: manufacture of agrochemicals, dyes and pharmaceuticals.
4. Fluorene: manufacture of pharmaceuticals, pigments, dyes, pesticides and thermoset plastic.
5. Phenanthrene: manufacture of resins and pesticides.
6. Pyrene: manufacture of pigments.

Other PAHs may be contained in asphalt used for the construction of roads, in addition to roofing tar. Furthermore, specific refined products, of precise PAHs, are used also in the field of electronics, functional plastics, and liquid crystals. If source inventories are lacking or incomplete, the first task is to clarify whether the known or unknown sources of PAHs are petrogenic, pyrogenic or natural. This is usually accomplished by observing PAH fingerprints that show the relative PAH abundances (Douglas et al., 2007)

2.2.2.1 Petrogenic source

Petrogenic substances (petrogenics) are defined as the substances that originate from petroleum, including crude oil, fuels, lubricants, and their derivatives (Saber et al. 2006). Petrogenic PAHs are introduced into the aquatic environment through accidental oil spills, discharge from routine tanker operations, municipal and urban runoff, etc. (Zakaria et al. 2002). There have been no observations of widespread, and continuous (i.e., nationwide and non-accidental) input of petrogenic PAHs (Zakaria et al. 2002).

The main PAH components of a petroleum source include the EPA 16 parent

PAHs and the petroleum-specific alkylated (PAH1-PAH4) homologues of selected PAHs: viz., alkylated Naphthalene, Phenanthrene, Dibenzothiophene, fluorene, and Chrysene series, which are also called “the alkylated five” or “five target” (Bertilsson and Widenfalk 2002; Wang et al. 1999a; Zeng and Vista 1997). These PAHs are source-specific (concentrations vary among different oils) and their abundance in sediment is taken to indicate petrogenic sources (Boll et al. 2008; De Luca et al. 2004; Stout and Wang 2007; Wang et al. 2001). For example, Dibenzothiophenes, together with Phenanthrenes, are widely used for PAH source apportionment because of their numerous isomers and their mild and similar degradabilities (absolute concentrations of the Methyldibenzothiophenes increase during weathering) (Page et al. 1996; Stout and Wang 2007; Wang and Fingas 1995, 2003; Wang et al. 1999a, 2001).

2.2.2.1 Pyrogenic source

Pyrogenic substances are defined as organic substances produced from oxygen depleted, high-temperature combustion of fossil fuels and biomass (e.g., incomplete combustion, pyrolysis, cracking, and destructive distillation) (Saber et al. 2006). Pyrogenic PAHs are released in the form of exhaust and solid residues, and are largely prevalent in aquatic environments (De Luca et al. 2004; Zakaria et al. 2002).

In pyrogenic PAH patterns, unsubstituted compounds predominate over their alkylated homologues. As the alkylation level increases, the PAH homologues become less abundant (i.e., a skewed pattern), whereas the HMW four- to six-ringed PAHs are more abundant than LMW two- to three-ringed PAHs (e.g., Boll et al. 2008; Ou et al. 2004; Page et al. 2006; Stout 2007; Stout et al. 2004; Wang et al. 1999a). Furthermore, the abundance of alkyl PAHs relative to parent PAHs, and also the abundance of LMW PAHs relative to HMW ones in combustion products, decrease with increasing combustion temperature (Laflamme and Hites 1978; Sporstol et al. 1983; Takada et al. 1990; Tobiszewski and Namiesnik 2012; Zeng and Vista 1997). Some researchers (Budzinski et al. 1997; Sicre et al. 1987) have noted that catacondensed PAHs (wherein no more than two rings have a carbon atom in common) are abundant in pyrolytic PAHs.

The most abundant pyrogenic PAHs are Fluoranthene, Pyrene, and, to a lesser extent, Phenanthrene (Page et al. 1999). Predominance of P0, FL0 and PY0 indicates the pyrolytic origin of the contamination (Morillo et al. 2008a). Like Phenanthrene, Anthracene is also common to pyrogenic sources (De Luca et al. 2004; Gogou et al. 2000). In sediments, absence of IP has been interpreted as the absence of pyrogenic PAHs (De Luca et al. 2004). Moreover, it has been shown that the use of HMW PAHs (e.g., MW=252, Benzo[k]fluoranthene, Benzo[b]fluoranthene, Benzo[a]pyrene, Benzo[e]pyrene, Benzo[j]fluoranthene, and Perylene) is adequate to discriminate between different high-temperature processes, e.g., carbonization and coking in manufacturing gas plants, and combustion in motor vehicle engines (Boll et al. 2008; Costa and Sauer 2005; Costa et al. 2004; Ollivon et al. 1999; Stout and Graan 2010).

2.2.2.3 Incomplete combustion source

Anthropogenic PAHs in the environment are formed either by thermal alteration of organic matter, or its open burning or incomplete combustion of the carbon contained compound. Conesa et al. (2013) studied about decomposition of two types of electrical wires considering the effect of the metal in the production of pollutants. Two different electric wires (PVC and halogen-free wire) were burnt in a horizontal laboratory furnace that carried on the combustion runs at 700° C. The results revealed that almost of 16 US EPA priority PAHs were found, and the main PAHs emitted in all cases of simulations (both with and without metal addition) are Naphthalene and Acenaphthylene. It was prabable in both cases that the presence of metal reduces the production of this kind of pollutants, probably due to the catalysis of cracking reactions that produces low molecular weight compounds. In addition, Alawi et al. (2018) researched about the determination of polycyclic aromatic hydrocarbons (PAHs) in carbon black-containing plastic consumer products from the Jordanian market. Carbon black, which is the composition in plastic materials in the study, is produced during the incomplete combustion of carbon containing materials such as coal and wood, and it is produced under controlled conditions with specific properties. The concentrations of 13 Polycyclic Aromatic Hydrocarbons (PAHs) were determined using a developed and validated Gas Chromatography/Mass Spectrometry (GC/MS) method in 12 carbon black-containing rubber and plastic samples. The obtained results illustrated that the 13 studied PAHs compounds were found in almost all samples. The total concentrations of the studied PAHs were ranged from 1.5 to 547 mg/kg with the dominant species of PAHs varied in each type of samples, depended on the compositions of each plastic products. For electrical wire samples, which is the major types of burnt e-waste in this study, the dominant compounds of PAHs found in Alawi et al. research were Benzo(b)fluoranthene, followed by Phenanthrene, and Pyrene, respectively.

2.2.2.4 Biogenic/Diagenetic source

Diagenetic PAHs are produced during the slow transformation of organic materials in lake sediments, whereas biogenic PAHs are produced by plants, algae/phytoplankton and microorganisms (Venkatesan 1988). Perylene (PER) is produced under several conditions: by diagenesis and biosynthesis from terrestrial precursors (e.g., Perylenequinone pigment) or other organic matter; under anoxic conditions; and in soil and subtidal, marine and freshwater sediments (e.g., Boll et al. 2008; Guo et al. 2007; Venkatesan 1988; Zakaria et al. 2002). In the tropics, termite nests may act as a Perylene source in soil (Barra et al. 2007; Mandalakis et al. 2004; Wilcke et al. 2002).

If Perylene does not correlate with the total organic carbon, then the Perylene is likely to have a natural origin (Luo et al. 2008). In such a case, Perylene may not yield its source of organic matter, although it can be a useful tracer for water and for depositional conditions (Budzinski et al. 1997). For instance, assuming a biogenic Perylene origin, Page et al. (1996) used Perylene depth gradients to show lack of vertical mixing.

Other PAHs such as Benzo[b]fluoranthene (BbF), Phenanthrene (P0) and naphthalene (N0) can originate from vascular land plants or termite activity (Bakhtiari et al. 2009; Irwin et al. 1997; Tobiszewski and Namiesnik 2012). Benzo[a]pyrene can be biosynthesized by certain bacteria and plants (Peters et al. 2005). Retene (RET) can be produced from the anaerobic microbial degradation of dehydroabietic acid (present in tire particles in urban areas) in soils and sediments (Mandalakis et al. 2004).

Perylene or biogenic-diagenetic PAHs also potentially have anthropogenic sources. PER has been detected in trace amounts after pyrolytic processes (Luo et al. 2008), such as coal pyrolysis in municipal incinerator waste products and automotive emissions (Abrajano et al. 2003; Boll et al. 2008; Gogou et al. 2000). Retene has other anthropogenic sources, such as fresh oil, diesel, exhaust emissions from heavy-duty diesel fuels, pulp/paper mill effluents, and emissions from coals (Mandalakis et al. 2004; Yan et al. 2005).

2.2.3 PAHs found in e-waste dismantling sites

Many recent studies provided that PAHs are emitted into the environmental media in various ways that associated with the e-waste recycling process. Deng et al. (2006) determined the PAHs concentrations of ambient air collected from an e-waste site was carried out at Guiyu, southeast China. The current level of PAHs in the Guiyu air was higher than in Guangzhou, one of the most polluted cities in China. This possibly reflects the higher emission of PAHs from e-waste recycling, especially due to open burning of plastics and metal scrap. Wong et al. (2007) also found the concentrations of POPs (PCDD/Fs, PBDEs, PAHs, and PCBs) and heavy metals/metalloid detected in the Guiyu air, which were high when compared with those from other cities due to incomplete combustion of e-wastes (e.g., plastic chips, wire insulations, PVC materials and metal scraps). This led to the severe pollution of soils by POPs and heavy metals, which may also affect the surrounding environment such as rice fields and rivers by atmospheric movement and deposition. Dumping of waste materials at riverbanks further led to the rather high concentrations of all these toxic chemicals in river sediments which received the dumped materials. The concentrations of some of the POPs and heavy metals in different environmental media are alarming, when compared with data available in other regions/countries. It is envisaged that under such high concentrations of toxic chemicals, the workers and local residents will be adversely affected through inhalation, dermal exposure and oral ingestion of contaminated drinking water and food. Moreover, Feldt et al. (2014) found distinctly higher urinary PAH levels in individuals exposed to e-waste recycling processes compared to unexposed controls. Furthermore, individuals, who were exposed to the emissions of the e-waste recycling process complained more frequently about clinical symptoms as cough, chest pain and vertigo. The findings suggest that involvement in the e-waste recycling process is associated with additional PAH exposure.

2.3 PAHs size distribution

Once released to the atmosphere, PAHs are found in three separate phases, a vapor phase, semi-volatile phase, and a solid phase in which the PAHs are sorbet onto particulate matter. The gas phase PAHs contains volatile 2-rings species and a fraction of semi-volatile, which consisted of 3 and 4 rings PAHs. Lastly, the particle phase contains the remain of particle associated semi-volatile PAHs, along with the 5 and 6 ring heavy PAHs adsorbed on the surface of particles (Finlayson-Pitts et al., 2000).

As previously mentioned, PM comes in a wide range of sizes according to its aerodynamic diameter. The size of PM is directly linked to the potential of particle-bound PAHs to attached and distribute on the surface of molecule. The smaller size of particles reflect in the larger active surface area and, consequently, created the higher chance for chemicals to adsorb on the particles. Moreover, the size of particles and the source of PAHs emission also correlated with each other. The major source of PAHs is mainly from an incomplete combustion process, which is also the primary source of generating small size particulate matter, such as fine and ultrafine particles. Therefore, the particle-bound PAHs released from combustion activity are significantly adsorb on the small particulate matter. Shue et al. (1996) studied about particle-bound PAH content in ambient air, investigated that in general, smaller particles have a higher PAH content. This is due to the fact that the soot from the combustion sources is primarily a fine particulate, which carries a high PAH content. In addition, smaller particles have a higher specific surface area and a higher attachment rate for organic pollutants. It may therefore contain a greater amount of organic carbon, which allows more PAH adsorption.

Slezakova et al. (2013), which studied about the impact of vehicular traffic emissions on particulate-bound PAHs also found that PAHs associated with coarse particles accounted for only 6% and 17% in the samples, while $PM_{2.5}$ bound PAHs accounted, respectively, for 94% and 83% of total PAHs concentrations. His further work on air pollution from traffic emissions in Oporto, Portugal also in agreement with other studies, supported that particulate-bound PAHs were predominantly present in $PM_{2.5}$ fraction. The results showed that 92% of particulate PAHs was associated with $PM_{2.5}$ and only 8% of PAH content was present in other particles with the size bigger than 2.5 µm (i.e. $PM_{2.5-10}$), Therefore, the research results demonstrated that particulate bound PAHs were significantly tend to associated with particles of smaller sizes.

2.4 Toxicokinetic of PAHs

2.4.1 Adsorption and absorption

Occupational studies provide evidence that PAHs from inhalation exposure are absorbed by humans. Animal studies also show that pulmonary absorption of benzo[a]pyrene occurs and may be influenced by carrier particles and solubility of the vehicle; however, the extent of absorption is not known. Absorption of benzo[a]pyrene following ingestion is low in humans, while oral absorption in animals varies among the PAH compounds depending on the lipophilicity. Oral absorption increases with more lipophilic compounds or in the presence of oils in the gastrointestinal tract. Percutaneous absorption of PAHs appears to be rapid for both humans and animals, but the extent of absorption is variable among these compounds and may be affected by the vehicle used for administration. Therefore, absorption of PAHs following inhalation, oral, or dermal exposure may be affected by vehicle of administration.

There was no information available on the distribution of PAHs in humans. PAHs appear to be widely distributed in tissues of animals following oral and inhalation exposure; peak tissue concentrations occurred earlier with higher exposure levels. Placental transfer of PAHs appears to be limited, and therefore, fetal levels are not as high as maternal levels

Absorption of inhaled PAHs appears to occur through the mucous lining of bronchi, while ingested PAHs are taken up by the gastrointestinal tract in fat-soluble compounds. Percutaneous absorption is through passive diffusion. The mechanism of action of most PAHs involves covalent binding to DNA by PAH metabolites. The bay region diol epoxide intermediates of PAHs are currently considered to be the ultimate carcinogen for alternant PAHs. Once the reactive bay region epoxide is formed, it may covalently bind to DNA and other cellular macromolecules and presumably initiate mutagenesis and carcinogenesis. (ATSDR, 1995).

2.4.2 Metabolism

Metabolism of PAHs occurs in all tissues and involves several possible pathways. Metabolism of PAHs has been studied extensively in vitro and in vivo. The metabolism products include epoxide intermediates, dihydrodiols, phenols, quinones, and their various combinations. The phenols, quinones, and dihydrodiols can all be conjugated to glucuronides and sulfate esters; the quinones also form glutathione conjugates (ATSDR, 1995).

2.4.3 Excretion

Quantitative data on the excretion of PAHs in humans are lacking. In general, feces is the major elimination route of PAHs in animals following inhalation exposure. Excretion of benzo[a]pyrene appears to be high following low-level exposure in rats but low in dogs and monkeys. PAHs are eliminated to a large extent within 2 days following low- and high-level oral exposure in rats. Following dermal exposure, elimination of PAHs occurs rapidly in the urine and feces of guinea pigs and rats (ATSDR, 1995).

2.4.4 PAHs toxicity summary

PAHs can be divided into two groups based on their physical, chemical, and biological characteristics. The lower molecular weight PAHs (e.g., 2 to 3 ring group of PAHs such as naphthalenes, fluorenes, phenanthrenes, and anthracenes) have significant acute toxicity to aquatic organisms, whereas the high molecular weight PAHs, 4 to 7 ring (from chrysenes to coronenes) do not. However, several members of the high molecular weight PAHs have been known to be carcinogens. PAHs can be harmful to human health under some circumstances, after intake of several types of PAHs including benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, and indeno [1,2,3-c,d]pyrene via breathing, eating, and long-term skin contact, the studies have shown the potential of PAHs to cause tumors in laboratory animals. Studies of people show that individuals exposed by breathing or skin contact for long periods to mixtures that contain PAHs and other compounds can also develop cancer.

Benzo(a)pyrene, which is one of PAHs compound, has an impact on pregnant mice that were fed by high dose of this chemical by increasing difficulty of reproducing and offspring and also showed birth defects and decreasing body weight of infants. Studies have also shown the harmful effects of PAHs in animals after both short and long-term exposure, the compound can affect skin, body fluids, and the body immune system. These effects still have no report in human study, but similar effects could occur in people. Studies in human, moreover, suggested that inhalation and chronic dermal exposure to the mixtures that contain PAHs and other compounds can also develop cancer, which is the most threaten critical endpoint on human health. The Department of Health and Human Services (DHHS) has determined that several PAHs compounds are known animal carcinogens, and some of them are classified as chemical that probably and possibly carcinogenic to humans by The International Agency for Research on Cancer (IARC) and Environmental Protection Agency (EPA) (ATSDR, 1995).

2.5 Health risk assessment of PAHs inhalation and dermal exposure

In order to process the estimation of the probability of adverse health effects in workers who may be exposed to PAHs in contaminated working environment, there are following four steps of human health risk assessment framework suggested from United State Environmental Protection Agency (US EPA), which the overall framework was shown in Figure 2.1.

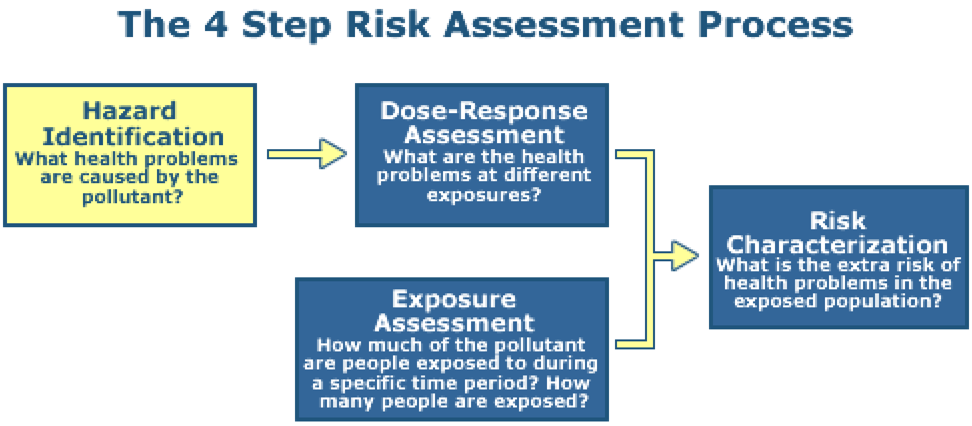


Figure 2.1 Risk assessment overall framework (US EPA, 2016)

2.5.1 Hazard identification

Hazard identification is the first step of a human health risk assessment, which mainly aimed to identify the types of adverse health effects that can be caused by exposure to some agent in question, and to characterize the quality and weight of evidence supporting this identification. Hazard Identification is the process of determining whether exposure to a stressor can cause an increase in the incidence of specific adverse health effects (e.g., cancer, birth defects). It is also whether the adverse health effect is likely to occur in humans.

The most harmful critical of PAHs is carcinogenicity. Many types of compound in PAHs group are defined as carcinogen substance from various world organizations. The carcinogenicity of each PAHs compound is summarized in the Table 2.3.

Table 2.3 The carcinogenicity of each PAHs compound

Not classifiable	Potential carcinogen
Acenaphthene	Benzo[a]anthracene
Anthracene	Benzo[a]pyrene
Benzo[g,h,i]perylene	Benzo[b]fluoranthene
Fluoranthene	Benzo[j]fluoranthene
Fluorene	Benzo[k]fluoranthene
Napthalene	Chrysene
Phenanthrene	Dibenzo[a,h]anthracene
Pyrene	Indeno[1,2,3-c,d]pyrene

Source: Agency for Toxic Substances and Disease Registry, 1995

2.5.2 Dose-response assessment

Dose-response assessment, the second step of a human health risk assessment, has the objective to document the relationship between dose and toxic effect. A dose-response relationship describes how the likelihood and severity of adverse health effects (the responses) are related to the amount and condition of exposure to an agent (the dose provided). Although this webpage refers to the "dose-response" relationship, the same principles generally apply for studies where the exposure is to a concentration of the agent (e.g., airborne concentrations applied in inhalation exposure studies), and the resulting information is referred to as the "concentration-response" relationship. In this step, the reference values from research studies were gathered for further risk calculation in the next step.

Regarding to the limitation of present available data about reference potency values from all types of compounds in PAHs group, non-carcinogenic risk could not be estimated caused by the insufficiency reference dose data. Some of inhalation and dermal cancer slope factor are also still unavailable, only Benzo(a)pyrene (BaP) that the date were readily provided. In this case, BaP equivalence approach were implemented and the BaP Potency Equivalency Factors (PEFs) from research studies were announced for converting the concentrations of other species of PAHs into the concentrations in term of BaP for further risk estimation in the next steps. The inhalation and dermal cancer slope factor, and Potency Equivalency Factors (PEFs) are shown in Table 2.4.

Table 2.4 The inhalation and dermal cancer slope factor, and BaP Potency Equivalency Factors of PAHs

Compound	Inhalation cancer slope factor $(mg/kg/day)^{-1}$ [1]	Dermal cancer slope factor $(mg/kg/day)^{-1}$ [2]	BaP Potency Equivalency Factors[3]
Naphthalene	-	-	0.001
Acenaphthylene	-	-	0.001
Acenaphthene	-	-	0.001
Fluorene	-	-	0.001
Phenanthrene	-	-	0.001
Anthracene	-	-	0.01
Fluoranthene	-	-	0.001
Pyrene	-	-	0.001
Benzo[a]anthracene	3.9 E-1	-	0.1
Chrysene	3.9 E-2	-	0.01
Benzo[b]fluoranthene	3.9 E-1	-	0.1
Benzo[k]fluoranthene	-	-	0.1
Benzo[a]pyrene	3.9 E+1	2.5 E+1	1
Dibenzo[a,h]anthracene	4.1 E-0	-	1
Benzo[ghi]perylene	-	-	0.01
Indeno[1,2,3-cd]pyrene	3.9 E-1	-	0.1

Source: [1] OEHHA, 2009

[2] Knafla et al., 2006

[3] Nisbet and Lagoy, 1992

2.5.3 Exposure assessment

Exposure assessment is the process of measuring or estimating the magnitude, frequency, and duration of human exposure to an agent in the environment, or estimating future exposures for an agent that has not yet been released. An exposure assessment includes some discussion of the size, nature, and types of human populations exposed to the agent, as well as discussion of the uncertainties in the above information.

Exposure can be measured directly, but more commonly is estimated indirectly through consideration of measured concentrations in the environment, consideration of models of chemical transport and fate in the environment, and estimates of human intake over time.

In this study, two routes of exposure were assessed, including inhalation and dermal exposure, but since the limitation of available data about reference potency values from all types of compounds in PAHs group, only inhalation and dermal cancer slope factors of BaP were both accessible. In this case BaP equivalence approach were implemented by convert the concentrations of each PAHs to BaP equivalence concentrations using Potency Equivalency Factors (PEFs) focusing on BaP as the index compound. Thus, the concentrations used for further Chronic Daily Intake (CDI) calculation are in the form of total BaP equivalent concentration. The equation used to calculate BaP equivalent concentration shows in Eq. 2.1 and the Potency Equivalency Factors (PEFs) were already shown in Table 2.4.

Chronic Daily Intake (CDI) calculation is basically used for exposure assessment of carcinogenic substances, which can be calculated by the equation 2.2 and 2.3 for inhalation and dermal exposure, respectively. All of parameters that used for CDI calculation are explained in Table 2.5.

$$\text{Total Bap}_{eq} = \sum (C_{PAHs,i} \times PEFs) \qquad \text{(Eq. 2.1)}$$

Where;
Bap_{eq} = BaP equivalent concentration
$C_{PAHs,I}$ = Concentration of each type of PAHs
PEFs = BaP Potency Equivalency Factors

$$CDI_{inhalation} = \frac{C \times IR \times ET \times EF \times ED \times EV}{BW \times AT} \qquad \text{(Eq. 2.2)}$$

$$CDI_{dermal} = \frac{C \times CF \times SA \times EV \times EF \times ED \times AF \times ABS}{BW \times AT} \qquad \text{(Eq. 2.3)}$$

Table 2.5 Parameters used for Chronic Daily Intake (CDI) calculation

Parameter	Definition	Unit
ABS	Dermal absorption fraction	Unit less
AF	Adherence Factor	mg/cm^2-event
AT	Average time	days
BW	Body weight	kg
C	Total BaP equivalent concentration	mg/m^3 and mg/kg
CDI_{dermal}	Chronic daily intake for dermal exposure	mg/kg/day
$CDI_{inhalation}$	Chronic daily intake for inhalation exposure	mg/kg/day
CF	Conversion factor	kg/mg

Parameter	Definition	Unit
ET	Exposure time	min/day
EV	Event frequency	(events/day)
ED	Exposure duration	years
EF	Exposure frequency	days/year
IR	Inhalation rate	m^3/min
SA	Surface area available for contact (Hands)	cm^2

2.5.4 Risk characterization

Risk characterization is the last step of health risk assessment to summarize and integrate information from the proceeding steps of the risk assessment to synthesize an overall conclusion about risk and to estimate the probability of risk that could occur to individuals who expose to the toxic chemical. Lifetime Cancer Risk values would obtained from this step by calculation using chronic daily intake (CDI) from BaP equivalent concentration multiplied by cancer slope factor of BaP from each route of exposure, as shown in equation Eq. 2.3, and the multi route lifetime cancer risk in this study could be calculated by the summation of total inhalation lifetime cancer risk and dermal lifetime cancer risk after burning work, as shown in equation Eq. 2.4.

$$\text{Lifetime Cancer Risk (LCR)} = \text{CDI} \times \text{Cancer Slope Factor} \qquad \text{(Eq. 2.3)}$$

$$\text{Multi route LCR} = \text{Total inhalation LCR} + \text{Dermal LCR after working} \qquad \text{(Eq. 2.4)}$$

The probability of health risk can be interpreted by lifetime cancer risk value. When the cancer risk is equal or lower than 10^{-6}, the risk level is still under acceptable level; however, if the value is greater than 10^{-6}, the carcinogenic risk is in concerned because it may have an opportunity to occur.

CHAPTER III

RESEARCH METHODOLOGY

3.1 Study areas

3.1.1 PAHs occupational exposure sampling area

In this study, the samples of occupational exposure to PAHs could be divided into two routes, including inhalation exposure that the samples were collected from $PM_{2.5}$ and $PM_{2.5\text{-}10}$ that bound PAHs, and dermal exposure that the samples were obtained directly from workers' hand wiping method. These two types of samples were taken from the workers in volunteer households in the e-waste dismantling community at Daeng Yai subdistrict in Ban Mai Chaiyapot district, Burirum province, Thailand, which is shown in Figure 3.1.

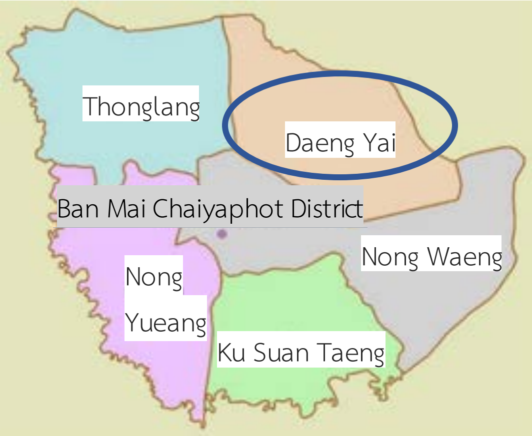


Figure 3.1 PAHs occupational exposure sampling area at Daeng Yai subdistrict in Ban Mai Chaiyapot district, Burirum province, Thailand.

According to the procedure of e-waste burning work, the waste that needed to be burnt, such as electrical wire, small motors and ballasts, would be collected from dismantling processes of the electronic equipment. When the quantity of waste was plenty enough to get burn, the collected e-waste would be loaded in the containers and transported from the dismantling sites in the village to proceed the burning work at the central landfill by trucks. Figure 3.2 demonstrates the location of central landfill and the direction from the dismantling sites to the landfill for e-waste transportation.

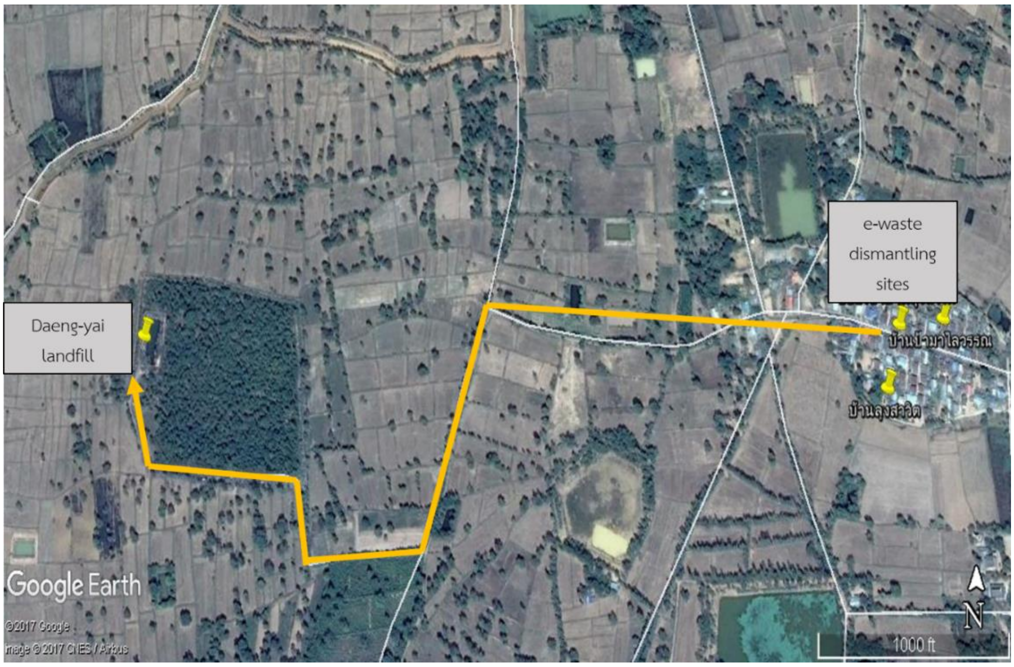


Figure 3.2 Location of central landfill, which was the area for e-waste burning, and the direction of e-waste transportation from the dismantling sites.

3.1.2 Questionnaire collected area

The questionnaires about personal profile, occupational data, and working activities were used to interview people who have e-waste dismantling work as their main occupation, especially the leader of each family. The studied area was located in e-waste dismantling community at Ban Pao subdistrict in Phutthaisong district, and Daeng Yai subdistrict in Ban Mai Chaiyapot district, Burirum province, Thailand, shown in Figure 3.3, which have 65 e-waste dismantling households per each site, according to survey data from the questionnaires in this study.

Figure 3.3 Questionnaire collected area at Ban Pao subdistrict in Phutthaisong district, and Daeng Yai subdistrict in Ban Mai Chaiyapot district, Burirum province, Thailand

3.2 Participants in this research

The participants in this research could be divided into two main groups as follows. The involvement of participants in this study was under an approval by a Committee for Research Involving Human Research Subjects, Health Science Group, responsible for ethics on human and/or animal experimentation with the certificate of approval number (COA. No.) 230/2016

3.2.1 Group 1 was the group of e-waste dismantling workers in Daeng Yai subdistrict within Ban Mai Chaiyaphot district that were suggested by local authorities and allowed to be installed the sampling equipment and wiped their hands to study exposure to PAHs during their burning activities. The population in this group were chosen from the houses that have continuous working activities to be the representative of e-waste burning workers in Buriram province.

3.2.2 Group 2 was the group of all e-waste dismantling workers in Daeng Yai subdistrict (located in Ban Mai Chaiyaphot district) and Ban Pao subdistrict (located in Putthaisong district), which are the two main areas in Buriram province that have dominant e-waste dismantling workplaces. The population in this group consisted of each 65 surveyed households either from Daeng Yai subdistrict or Ban Pao subdistrict that recycle e-waste as the main occupation of the family. According to survey data in 2017 from the questionnaires in this study, the population in Group 1 mentioned above was also included in Group 2. The participants in this group were asked for permission to collect data from questionnaires in order to be used for health risk evaluation and result discussion.

3.3 Sampling Preparation

3.3.1 Preparation methods for inhalation exposure sampling

3.3.1.1 Sampling filter preparation

1) $PM_{2.5}$ and $PM_{2.5-10}$ samples were collected by using Polytetrafluoroethylene (PTFE) filters with 37 mm diameter and 2 µm pore size, and PTFE filters with 25 mm diameter and 0.2 µm pore size, respectively. Both size of filters were cleaned by soaking with 25 mL acetone in a beaker that is closed by aluminum foil to prevent the evaporation of solvent for 15 minutes. Then, the filters were dried up on a watch glass in fume hood for 10 minutes.

2) The cleaned filters were stored in opaque plastic cases and kept in a desiccator for at least 24 hours before weighing.

3) Each filter was weighed by a 7 decimal places analytical balance (Mettler-Toledo UMX2 Ultra Microbalance) and was stored in opaque plastic case until the sampling period.

3.3.1.2 Personal air sampler preparation

1) The personal air samplers (SKC Airchek Sampler Model 224-PCXR8) were charged and calibrated by the primary gas flow calibrator (Defender 530, Drycal TECHNOLOGY) with sampling flow rate about 3 L/min.

2) The Personal Modular Impactor (PMI) that contained both two size of filters was connected to the personal air sampler. The joints between all equipment were wrapped by parafilm to prevent the leakage of the air flow system. This whole set of equipment was ready for sampling in the next step.

3.3.2 Preparation methods for dermal exposure sampling

3.3.2.1 Sample container preparation

A light brown glass vial was used to collect hand washed sample on wiping material. The vials were cleaned by rinsing with acetone and followed by detergent washing with hot water and rinsing with copious amounts of tap water and several portions of reagent water. The glassware should then be drained dry and heated in an oven for four hours (US EPA, 1999).

3.3.2.2 Hand wipe material preparation

Gauze pads with standard size 3”× 3” were used as the wiping material in this study. Before sampling, all of gauze pads were sterilized by heating in oven at 60° C for 24 hours and stored in the desiccator to evaporate moisture for at least 24 hours. Then, the gauze were kept in light brown glass vials and weighted the mass by five decimal balance. Finally, they were ready for dermal exposure sampling.

3.4 Sampling methods

This study was defined as a cross-sectional study, which was mainly focused and analyzed data from the population at a specific point in time. The samples collected from the workers in this study could be divided into 4 main parts, including the personal inhalation exposure, the personal dermal exposure, questionnaire collection, and additional information recorded during sampling. The methodology for sampling each type of samples was described as follows.

3.4.1 $PM_{2.5-10}$ and $PM_{2.5}$ sampling method for PAHs inhalation exposure

1) The whole set of personal air sampler with personal modular impactor that contained two types of filters was installed at each worker who was going to burn e-waste as same as in the Figure 3.4. Personal modular impactors were pinched at workers’ collars in order to be the representative of breathing zone, the hemisphere in front of the shoulders within a radius of approximately six to nine inches (OSHA, 2014). The personal air samplers were turned on when the workers started burning activities, and they were stopped when the workers finished e-waste burning work. The real total sampling time, amount of e-waste for burning, composition of e-waste, and the activities of each worker were recorded in each time of sampling.

2) After finish sampling, the flow rates of personal air samplers were measured to calculate the volume of air flow through pumps. The sampled filters were kept in opaque plastic cases that were covered all joints with parafilm and stored in a desiccator for at least 48 hours before weighing when they were arrived the laboratory.

3) The sampled filters were weighed by the 7 decimal places analytical balance again to obtain the weight after sampling, used for PM mass calculation. Then, the sampled filters were stored in refrigerator at lower than 0° C until further extraction and analysis in the next step. The total samples for inhalation exposure were 33

samples. Field blank were kept each time of sampling, and the samples from control area were kept at the studied site on the day that has no burning activity.

Figure 3.4 Installation of the personal air sampler equipment at worker's breathing zone

3.4.2 Sampling method for PAHs dermal exposure

1) The exposure of PAHs on workers' hands were sampled by hand wiping at the beginning before working, at the end of burning activity before and after hand washing. The workers' hands were wiped on the surface both in front and back, not included the parts of skin bridging the fingers, in "s-like" or "z-like" pattern, as shown in Figure 3.5, and flip into a top-to-bottom direction in the second pass (ASTM, 2016) by using prepared gauze pad that is soaked up by 5 ml isopropanol. (Applied from Taneepanichskul, 2009)

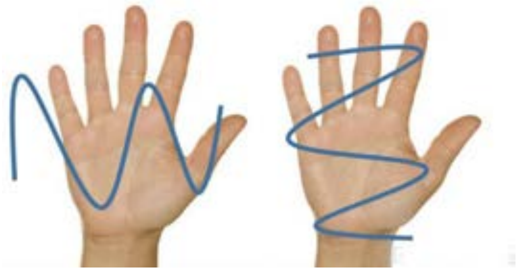


Figure 3.5 Hand wiping method in "s-like" or "z-like" pattern

2) The wiped samples were stored in a light brown glass vials, which were weighted by five decimal balance to find the mass of particulate matter on the wiped samples and stored at lower than 0° C before further analysis step. The total sets of samples for dermal exposure were 33 sets and the field blank were kept every time of samplings.

3.4.3 Questionnaire collection

The questionnaires in this study were collected to gather the personal information of the burning workers about their body weight, exposure time, event frequency, exposure duration, and exposure frequency, in order to use the information for risk calculation in the further step. The questionnaires, which the format was shown in Appendix D, were handed to the participants group 2 to complete during the meeting arranged by the local hospital and authorities, and were finished collection after the end of the meeting.

3.4.4 Additional data collection during inhalation and dermal sampling

During every sampling times, data about the factors that may be related and have an impact on the results, including meteorological data, types of burnt e-waste, quantity of burnt e-waste, total sampling time, individual pattern of burning activity, and the use of PPE were all recorded. Meteorological data were measured by hygrometer and obtained from satellite data, and the quantity of burnt e-waste were approximately weighted by the workers before transportation of waste to burn at the landfill. Another additional data were recorded by the real time observation during burning activity.

In order to summary about the sample collection in this study, the description of the samples was summarized in Table 3.1. The provided data in the table were included the characteristic of collected samples and the number of each type of samples.

Table 3.1 Description of the samples in this study

Types of samples	Characteristic of collected samples	Number of samples
Personal inhalation exposure	$PM_{2.5-10}$ and $PM_{2.5}$	N = 33 for each types of PM
Personal dermal exposure	Dust adhered on the surface of workers' hands, which was collected 3 times for each sample, including 1. Before burning work 2. After burning work	N = 33 sets

Types of samples	Characteristic of collected samples	Number of samples
	3. After hand washing	
Questionnaire	Personal information from questionnaires, including 1. Body weight 2. Exposure time 3. Event frequency 4. Exposure duration 5. Exposure frequency	Total amount of questionnaires was 130 sets, but the obtained data were co-used for other studies. Due to the individual risk assessment in this study, the exact number of questionnaire data was 33.
Additional data	Recorded data during every sampling times, including 1. Meteorological data 2. Types of burnt e-waste 3. Quantity of burnt e-waste 4. Total sampling time 5. Pattern of burning activity 6. The use of PPE	For meteorological data, types and quantity of burnt e-waste, and total sampling time, the amounts were in accordance with the sampling times. For pattern of burning activity and the use of PPE, the number of data were 33.

3.5 Quality assurance/ quality control

3.5.1 The optimum conditions of high performance liquid chromatography (HPLC)

The concentrations of 16 types of PAHs were analyzed by high performance liquid chromatography (HPLC), Shimadzu, SPD-M20A composed of two detectors, fluorescence and UV with SUPELCOSIL™ LC-PAH HPLC Column (I.D. 25 cm × 4.6 mm, 5.0 µm particle size). The mobile phases that used for analysis were acetonitrile (HPLC grade) mixed with 18 MΩ deionized water and filtrated through PTFE plain white membrane filters, 47 mm diameter with 0.45 µm pore size (Filtres Fioroni, France). The analytical standard solution used in this research was PAH Calibration Mix

10 µg/mL each component in acetonitrile manufactured by Supelco Company. The optimum conditions of HPLC used for PAHs analysis was presented in Table 3.2.

Table 3.2 The optimum conditions of HPLC

Main Column	SUPELCOSIL™ LC-PAH 25 cm x 4.6 mm ID, 5.0 µm particle size			
Mobile Phase	A: Acetonitrile : Water (60 : 40) B: Acetonitrile : Water (88 : 12)			
Oven Temperature	40 °C			
Flow rate	1.6 ml/min			
Detector	A : UV detector B: Fluorescence detector			
Wavelength	UV = 254 nm			
Injection volume	20 µl			
Gradient Program	Time (min)	Mobile Phase (A:B)	Excitation (nm)	Emission (nm)
	5.00	100:0	270	330
	8.40		250	370
	10.05		330	430
	13.00	20:80		
	14.00		270	390
	16.50		290	430
	22.00		370	460
	25.00	20:80		
	26.00	100:0		
	40.00	(stop)		

3.5.2 Standard curve preparation

The standard calibration curve were created from the series of five concentrations of PAHs mixed standard diluted by acetonitrile, including 0.625, 1.25, 2.50, 5.00, and 10.00 ppm. After preparation of PAHs mixed standard series, the solutions were analyzed by HPLC and the obtained peak areas were plotted in Y-axis of standard calibration curve, while X-axis represents the known concentrations of PAHs mixed standard.

3.5.3 Limit of detection (LOD) and Limit of quantification (LOQ)

To characterize HPLC performance, limit of detection (LOD) and limit of quantification (LOQ) were the factors that used in this study. Both two values were calculated from Eq. 3.1-3.2, where the standard deviation (SD) came from the concentrations of PAHs mixed standard at 0.05 ppm that were analyzed ten replicates by HPLC. Percentage of relative standard deviation (%RSD) could also calculated by Eq. 3.3 using SD from standard concentration results.

$$\mathrm{LOD} = 3\times\mathrm{SD} \qquad \text{(Eq. 3.1)}$$

$$\mathrm{LOQ} = 10\times\mathrm{SD} \qquad \text{(Eq. 3.2)}$$

$$\%\mathrm{RSD} = \frac{(\mathrm{SD}\times 100)}{\mathrm{Mean}} \qquad \text{(Eq. 3.3)}$$

3.5.4 Recovery test

Recovery test were implemented to determine the efficiency of extraction method. Two types of filters and wiping material that were injected known concentration of PAHs standard were extracted by the same extraction method with the samples for seven replicates. Then, they were analyzed by HPLC to find the exact concentrations in order to calculate the percentage of recovery.

3.5.4.1 Recovery test for particle-bound PAHs extraction

Each type of blank cleaned filters was put in the 40 ml light brown vials and injected 50 µl of 1.00 ppm PAHs standard solution. Ten milliliters of dichloromethane was added into the vials after waiting for an adsorption of standard into the filters for 15 minutes, and the vials then were inserted to ultrasonic homogenizer for 30 minutes. The obtained solutions were filtrated through 0.2 µm PTFE syringe filter into new 40 ml light brown vials. The previous vials that contained the standard injected filter were rinsed by 5 ml of dichloromethane and inserted to ultrasonic homogenizer again for 15 minutes and then transferred through the same filtration sets to combine the obtained solutions with the former filtrated ones. The solutions in the new vial were added 20 µl dimethyl sulfoxide (DMSO) to prevent the volatilization of the analysts before the solvents in the solutions were evaporated and transferred into the inserts held by 2 ml light brown glass vials until they remained around 20 µl with pure nitrogen gas by heating box that was control temperature at 35° C. These final solutions were stored in the dark at the temperature lower than 0° C until the analysis process, which had to adjust volume to 50 µl by adding 30 µl of (60 : 40) Acetonitrile : Water before an injection to HPLC. (Nonthakanok, 2013). The flowchart of extraction procedure for recovery test of inhalation exposure samples is shown in Figure 3.6.

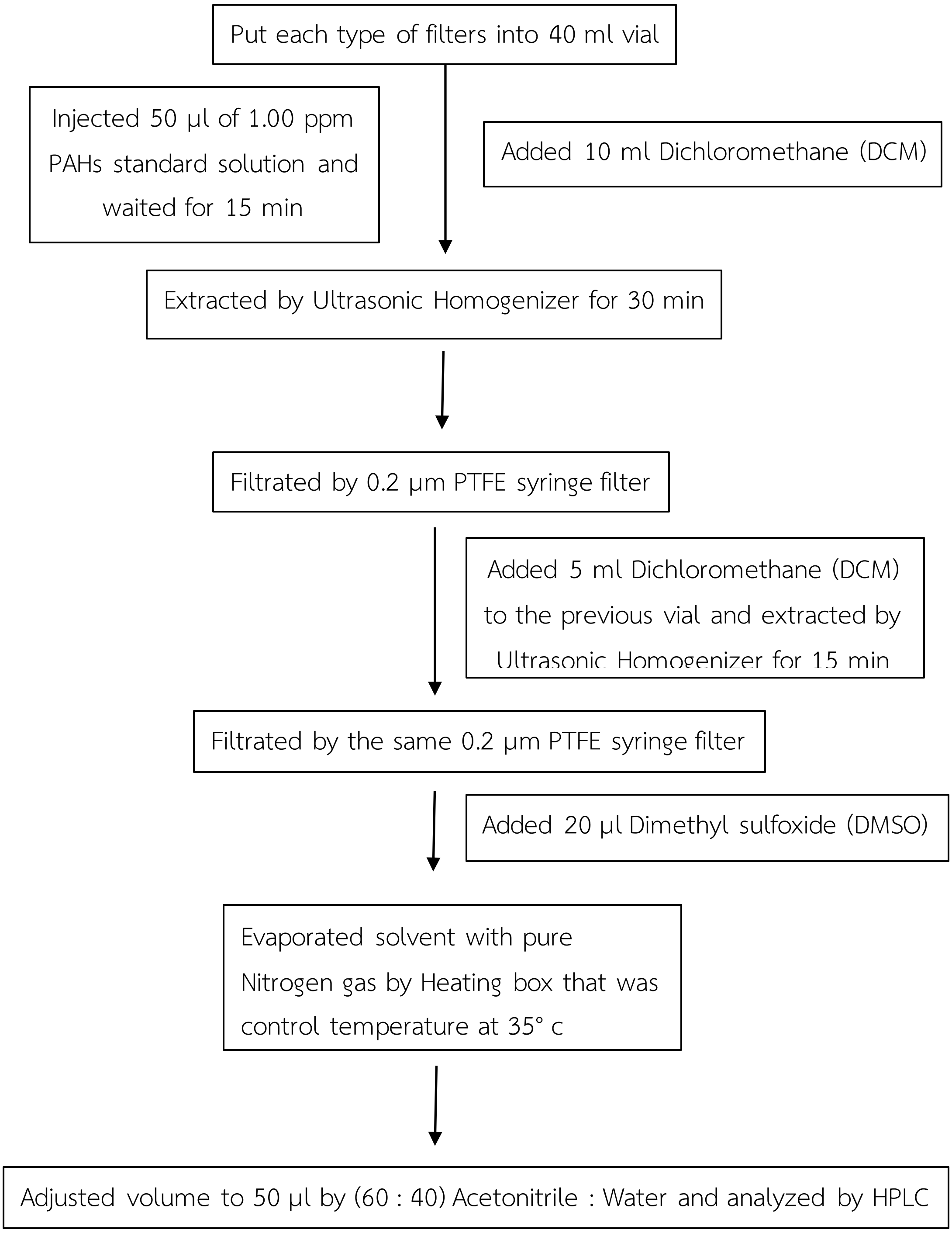


Figure 3.6 PAHs extraction method for recovery test of inhalation exposure samples

3.5.4.2 Recovery test for hand wiped sample extraction

The blank cleaned gauze pads were cut into small pieces around 3 x 3 mm^2 sized and sampling for about 0.3 g; then, they were put into the 40 ml light brown vial and injected 100 μl of 1.00 ppm PAHs standard solution. The first part of extraction method was totally the same with the extraction method for inhalation samples, but after the secondary rinsing of the previous vials by 5 ml of dichloromethane and again inserted to ultrasonic homogenizer for 15 minutes and filtrated through the same filtration sets, the previous vials that contained the standard injected gauze pads had to be rinsed for two more times with 3 ml and 2 ml dichloromethane, respectively, and poured the rinsed liquor into the same filtration sets again without sonication. The solutions in the new vials were added 50 μl dimethyl sulfoxide (DMSO) to prevent the volatilization of the analysts before the solvents in the solutions were purged with pure nitrogen gas by heating box that was control temperature at 35° C and transferred into the inserts held by 2 ml light brown glass vials until it remained around 50 μl. These final solutions were stored in the dark at the temperature lower than 0° C until the analysis process, which had to adjust volume to 100 μl by adding 50 μl of (60 : 40) Acetonitrile : Water before an injection to HPLC. (Applied from Vaananen, 2004 and Nonthakanok, 2013). The flowchart of extraction procedure for recovery test of dermal exposure samples shows in Figure 3.7.

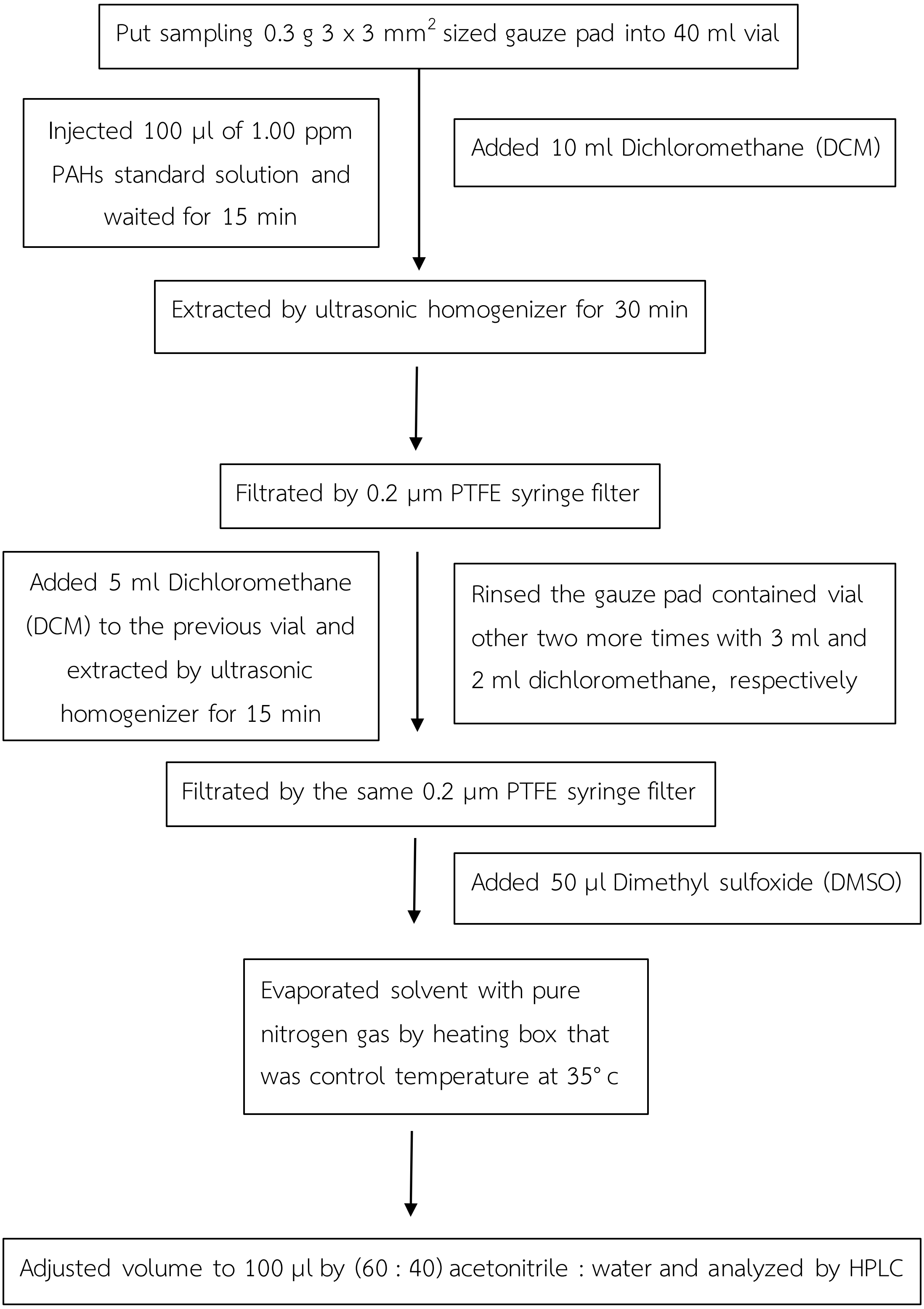


Figure 3.7 PAHs extraction method for recovery test of dermal exposure samples

3.5.4.3 Blank test

Blank samples in this study were field blank, which was defined as a clean sample of a matrix that was taken from the laboratory to the sampling site and transported back to the laboratory without having been exposed to sampling procedures (EPA, 2009). Both two sizes of blank filters and the blank gauze pad were transported to the e-waste burning site every sampling times and kept back to laboratory. The blank medias were weighted by analytical balance to quantify the masses of increased particulate matter and dust; then, they were extracted by the same method as proceeded in recovery test, but without the spike of PAHs standard.

3.6 Extraction and analysis methods

3.6.1 Particle-bound PAHs extraction and analysis method

The filter samples were extracted by the same method with the recovery test but without the spike of known standard solution. The final solutions were stored in the dark at the temperature lower than 0° c until the analysis process, which had to adjust volume to 50 µl by adding 30 µl of (60:40) acetonitrile : water before an injection to HPLC (Nonthakanok, 2013).

3.6.2 Hand wiped sample extraction method

Without the spike of PAHs standard solution, the wiped samples were all extracted by the same method with the recovery test, the final solutions were also stored in the dark at the temperature lower than 0° c until the analysis process, which had to adjust volume to 100 µl by adding 50 µl of (60:40) acetonitrile : water before an injection to HPLC. (Applied from Vaananen, 2004 and Nonthakanok, 2013).

3.7 Calculation of PM and PAHs concentration

1) The concentrations of particulate matter (PM) were calculated by Eq. 3.4 -3.11 as the following;

$$C_{PM} = \frac{M_{PM}}{V_{air}} \qquad \text{(Eq. 3.4)}$$

$$M_{PM} = W_{filter,\ post} - W_{filter,\ pre} \qquad \text{(Eq. 3.5)}$$

$$W_{filter,\ pre} = (W_{filter,\ pre,1} + W_{filter,\ pre,2} + W_{filter,\ pre,3})/3 \qquad \text{(Eq. 3.6)}$$

$$W_{filter,\ post} = (W_{filter,\ post,1} + W_{filter,\ post,2} + W_{filter,\ post,3})/3 \qquad \text{(Eq. 3.7)}$$

$$C_{PM10} = C_{PM2.5} + C_{PM2.5\text{-}10} \qquad \text{(Eq. 3.8)}$$

where:

C_{PM} = PM concentration (mg/m^3)
$C_{PM2.5}$ = $PM_{2.5}$ concentration (mg/m^3)
$C_{PM2.5\text{-}10}$ = $PM_{2.5\text{-}10}$ concentration (mg/m^3)
C_{PM10} = PM_{10} concentration (mg/m^3)
M_{PM} = Mass of PM (mg)
V_{air} = Air volume (m^3)
= Flow rate of air (m^3/min) x sampling time (min)
$W_{filter,\ post}$ = Weight of filter after sampling (mg)
$W_{filter,\ pre}$ = Weight of the filter before sampling (mg)

2) The concentration of PAHs were calculated by these following Eq.;

$$PA_{PAHs} = PA_{sample} - PA_{blank} \qquad \text{(Eq. 3.9)}$$

$$C_{sample} = PA_{PAHs}/\text{slope of standard curve} \qquad \text{(Eq. 3.10)}$$

For inhalation;

$$C_{PAHs} = \frac{(C_{sample} - C_{blank}) \times V_{sample}}{V_{air}} \qquad \text{(Eq. 3.11)}$$

For dermal;

$$C_{PAHs} = \frac{(C_{sample} - C_{blank}) \times V_{sample} \times W_{gauze}}{W_{gauze,sampling} \times M_{dust} \times 1000} \qquad \text{(Eq. 3.12)}$$

where:

C_{blank} = Concentration of PAHs in blanks (mg/l; ng/µl)
C_{PAHs} = Concentration of PAHs in samples (ng/m^3 or mg/kg)
C_{sample} = Concentration of PAHs in samples (mg/L; ng/µl)
M_{dust} = Mass of dermal dust (g)
Pa_{blank} = Peak area of blank
PA_{PAHs} = Peak area of PAHs
PA_{sample} = Peak area of samples

V_{sample} = Volume of sample solution (µl)

$\underline{W_{gauze}}$ = Weight of gauze pad (g)

$W_{gauze,sampling}$ = Weight of sampling gauze pad (g)

3.8 Health risk assessment

In order to process the estimation of the probability of adverse health effects in workers who may be exposed to PAHs in contaminated working environment, there are following four steps of human health risk assessment framework suggested from United State Environmental Protection Agency (US EPA).

3.8.1 Hazard identification

Hazard Identification is the process of determining whether exposure to a stressor can cause an increase in the incidence of specific adverse health effects. The most harmful critical of PAHs is carcinogenicity. Many types of compound in PAHs group are defined as carcinogen substance from various world organizations. The carcinogenicity of each PAHs compound is summarized in the Table 3.3.

Table 3.3 The carcinogenicity of each PAHs compound

Not classifiable	Potential carcinogen
Acenaphthene	Benzo[a]anthracene
Anthracene	Benzo[a]pyrene
Benzo[g,h,i]perylene	Benzo[b]fluoranthene
Fluoranthene	Benzo[j]fluoranthene
Fluorene	Benzo[k]fluoranthene
Napthalene	Chrysene
Phenanthrene	Dibenzo[a,h]anthracene
Pyrene	Indeno[1,2,3-c,d]pyrene

Source: Agency for Toxic Substances and Disease Registry, 1995

3.8.2 Dose-response assessment

Dose-response assessment describes the relationship between the likelihood and severity of adverse health effects (the responses) and the amount and condition of exposure to an agent (the dose provided). In this step, the reference values from research studies were gathered for further risk calculation in the next step. Regarding to the limitation of present available data about reference potency values from all types of compounds in PAHs group, non-carcinogenic risk could not be estimated caused by the insufficiency reference dose data. Some of inhalation and dermal cancer slope factor are also still unavailable, only Benzo(a)pyrene (BaP) that the date were readily provided. In this case, BaP equivalence approach were implemented and the BaP Potency Equivalency Factors (PEFs) from research studies were announced for converting the concentrations of other species of PAHs into the concentrations in term of BaP for further risk estimation in the next steps. The inhalation and dermal cancer slope factor, and Potency Equivalency Factors (PEFs) are shown in Table 3.4.

Table 3.4 The inhalation and dermal cancer slope factor, and BaP Potency Equivalency Factors of PAHs

Compound	Inhalation cancer slope factor $(mg/kg/day)^{-1}$ [1]	Dermal cancer slope factor $(mg/kg/day)^{-1}$ [2]	BaP Potency Equivalency Factors[3]
Naphthalene	-	-	0.001
Acenaphthylene	-	-	0.001
Acenaphthene	-	-	0.001
Fluorene	-	-	0.001
Phenanthrene	-	-	0.001
Anthracene	-	-	0.01
Fluoranthene	-	-	0.001
Pyrene	-	-	0.001
Benzo[a]anthracene	3.9 E-1	-	0.1
Chrysene	3.9 E-2	-	0.01
Benzo[b]fluoranthene	3.9 E-1	-	0.1
Benzo[k]fluoranthene	-	-	0.1
Benzo[a]pyrene	3.9 E+1	2.5 E+1	1
Dibenzo[a,h]anthracene	4.1 E-0	-	1
Benzo[ghi]perylene	-	-	0.01
Indeno[1,2,3-cd]pyrene	3.9 E-1	-	0.1

Source: [1] OEHHA, 2009
[2] Knafla et al., 2006
[3] Nisbet and Lagoy, 1992

3.8.3 Exposure assessment

Exposure assessment is the process of measuring or estimating the concentration of contaminant that human intake over time of exposure, which considers both the exposure pathway as well as the exposure route. In this study, two routes of exposure were assessed, including inhalation and dermal exposure, but since the limitation of available data about reference potency values from all types of compounds in PAHs group, only inhalation and dermal cancer slope factors of BaP were both accessible. In this case BaP equivalence approach were implemented by convert the concentrations of each PAHs to BaP equivalence concentrations using Potency Equivalency Factors (PEFs) focusing on BaP as the index compound. Thus, the concentrations used for further Chronic Daily Intake (CDI) calculation are in the form of total BaP equivalent concentration. The equation used to calculate BaP equivalent concentration shows in Eq. 3.13 and the Potency Equivalency Factors (PEFs) were already shown in Table 2.4.

Chronic Daily Intake (CDI) calculation is basically used for exposure assessment of carcinogenic substances, which can be calculated by the equation 3.14 and 3.15 for inhalation and dermal exposure, respectively. All of parameters that used for CDI calculation are explained in Table 2.5.

$$\text{Total Bap}_{eq} = \sum (C_{PAHs,i} \times \text{PEFs}) \qquad \text{(Eq. 3.13)}$$

Where; Bap_{eq} = BaP equivalent concentration

$C_{PAHs,I}$ = Concentration of each type of PAHs

PEFs = BaP Potency Equivalency Factors

$$CDI_{inhalation} = \frac{C \times IR \times ET \times EF \times ED \times EV}{BW \times AT} \qquad \text{(Eq. 3.14)}$$

$$CDI_{dermal} = \frac{C \times CF \times SA \times EV \times EF \times ED \times AF \times ABS}{BW \times AT} \qquad \text{(Eq. 3.15)}$$

Table 3.5 Parameters used for Chronic Daily Intake (CDI) calculation

Parameter	Definition	Unit	Value	Reference
ABS	Dermal absorption fraction	Unit less	0.13	EPA, 2004
AF	Adherence Factor	mg/cm^2-event	0.2	EPA, 2014
AT	Average time	days	Men = 26,353 (72.2 yrs x 365 days/yr)	Institute for Population

Parameter	Definition	Unit	Value	Reference
			Women = 28,798.5 (78.9 yrs x 365 days/yr)	and Social Research, 2018
BW	Body weight	kg	-	From questionnaire
C	Total BaP equivalent concentration	mg/m^3 and mg/kg	-	-
CDI_{dermal}	Chronic daily intake for dermal exposure	mg/kg/day	-	-
$CDI_{inhalation}$	Chronic daily intake for inhalation exposure	mg/kg/day	-	-
CF	Conversion factor	kg/mg	10^{-6}	-
ET	Exposure time	min/day	-	From questionnaire
EV	Event frequency	(events/day)	-	From questionnaire
ED	Exposure duration	years	-	From questionnaire
EF	Exposure frequency	days/year	-	From questionnaire
IR	Inhalation rate	m^3/min	31 to <41 years = 0.0111 41 to <51 years = 0.0111 51 to <61 years = 0.0109	EPA, 2011
SA	Surface area available for contact (Hands)	cm^2	Men = 1070 Women = 890	EPA, 2011

3.8.4 Risk characterization

Risk characterization is the last step of health risk assessment to estimate the probability of risk that could occur to individuals who expose to the toxic chemical. Lifetime Cancer Risk values would obtained from this step by calculation using chronic daily intake (CDI) from BaP equivalent concentration multiplied by cancer slope factor of BaP from each route of exposure, as shown in equation Eq. 3.16, and the multi route lifetime cancer risk in this study could be calculated by the summation of total inhalation lifetime cancer risk and dermal lifetime cancer risk after burning work, as shown in equation Eq. 3.17.

$$\text{Lifetime Cancer Risk (LCR)} = \text{CDI} \times \text{Cancer Slope Factor} \quad \text{(Eq. 3.16)}$$

$$\text{Multi route LCR} = \text{Total inhalation LCR} + \text{Dermal LCR after working} \quad \text{(Eq. 3.17)}$$

The probability of health risk can be interpreted by lifetime cancer risk value. When the cancer risk is equal or lower than 10^{-6}, the risk level is still under acceptable level; however, if the value is greater than 10^{-6}, the carcinogenic risk is in concerned because it may have an opportunity to occur.

3.9 Statistical analysis

In this research, SPSS statistical program was used for statistical analysis, which were included these following topics.

1) The difference between average PM concentrations in each size of particles were compared by T-test.

2) The relationship between $PM_{2.5-10}$, $PM_{2.5}$, and PM_{10} concentrations were analyzed by Pearson's correlation.

3) The relationship between $PM_{2.5-10}$, $PM_{2.5}$, and the significant activities were analyzed by Pearson's correlation.

4) The relationship between $PM_{2.5-10}$, $PM_{2.5}$, and PAHs concentration were analyzed by Pearson's correlation.

5) The relationship between dermal dust masses after finished working and the significant activities analyzed by Pearson's correlation.

6) The relationship between dermal dust masses after finished working and the use of hand personal protective equipment were analyzed by Pearson's correlation.

7) The relationship between dermal dust after finished working and PAHs concentration were analyzed by Pearson's correlation.

8) The range of life time cancer risk in general scenario would be estimated by 95% confidence interval.

3.10 Overall conceptual framework

In order to conclude and wrap up the overall studied topics in this research, the conceptual framework was demonstrated in Figure 3.8. All of 33 e-waste burning workers were collected 4 types of samples, including personal inhalation exposure, personal dermal exposure, questionnaire data, and other related additional data. Every types of samples were extracted and analyzed; then, they were eventually used for data analysis by statistic for result discussion and conclusion of the study.

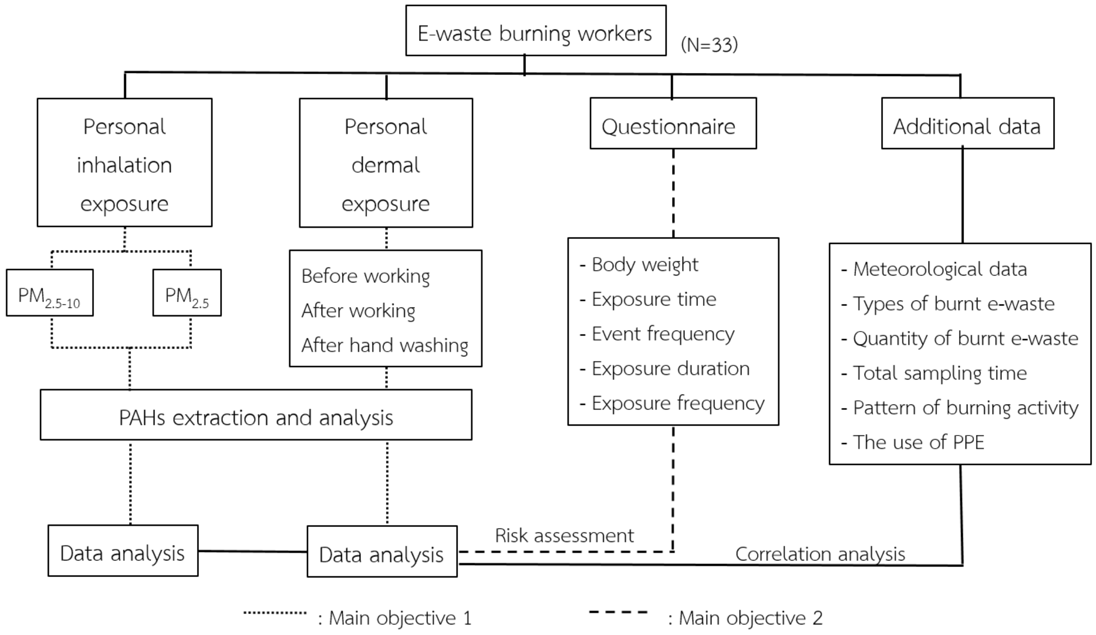


Figure 3.8 Overall conceptual framework in this study

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Quality assurance of the experiment

4.1.1 Standard calibration curves

The standard calibration curves were created from the series of five concentrations of PAHs mixed standard diluted by acetonitrile, including 0.625, 1.25, 2.50, 5.00, and 10.00 ppm. The obtained peak areas of each PAHs compound after analyzed by HPLC were plotted in Y-axis of standard calibration curve, while X-axis represents the known concentrations of PAHs mixed standard. The R^2 of calibration curve for each type of PAHs presents in the Table 4.1, which the values are in the range of 0.9994 – 0.9998. Figure 4.1 shows the chromatogram from florescence detector of 15 species of standard PAHs at 10.00 ppm which another one compound, Acenaphthylene, had to be interpreted from different detector, UV, so it was excluded from the shown chromatogram. The graph plotted of standard calibration curves were provided in Appendix A.

Table 4.1 The R^2 of each type of PAHs standard from calibration curve

Types of PAHs standard	R^2
Naphthalene	0.9998
Acenaphthylene	0.9985
Acenaphthene	0.9997
Fluorene	0.9991
Phenanthrene	0.9998
Anthracene	0.9994
Fluoranthene	0.9998
Pyrene	0.9999
Benzo[a]anthracene	0.9998
Chrysene	0.9998
Benzo[b]fluoranthene	0.9998
Benzo[k]fluoranthene	0.9998
Benzo[a]pyrene	0.9998
Dibenzo[a,h]anthracene	0.9998
Benzo[ghi]perylene	0.9998
Indeno[1,2,3-cd]pyrene	0.9998

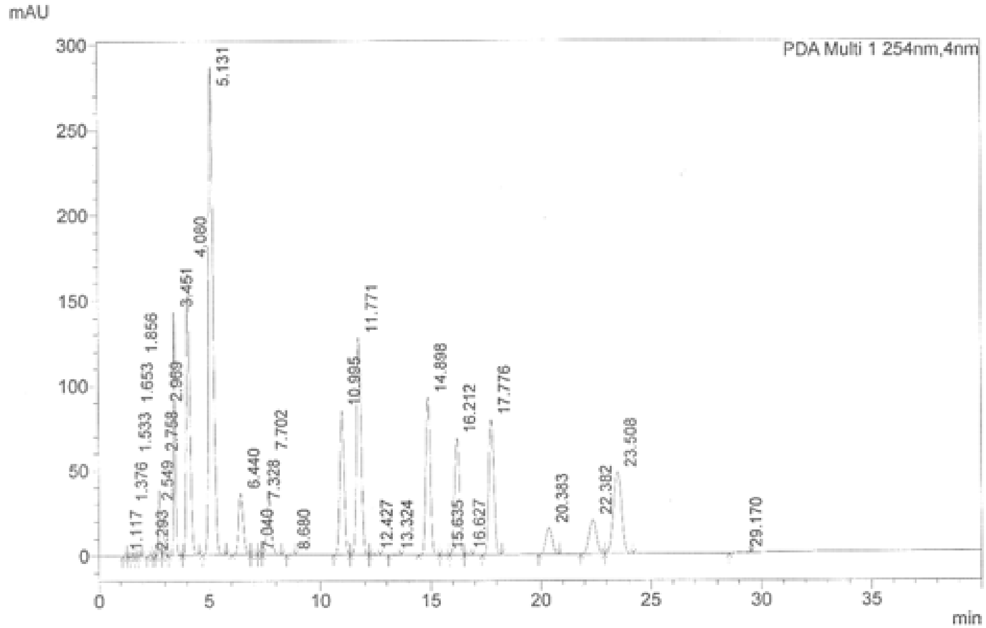


Figure 4.1 The chromatogram from florescence detector of 10.00 ppm standard PAHs

4.1.2 Limit of detection (LOD) and Limit of quantification (LOQ)

To characterize the performance of HPLC, limit of detection (LOD) and limit of quantification (LOQ) are the factors using in this study. Both two values were calculated from the concentrations of PAHs mixed standard that were analyzed ten replicates by HPLC. Percentage of relative standard deviation (%RSD) were also calculated using SD from standard concentration result. The obtained LOD, LOQ, and %RSD in this study indicates in Table 4.2 below.

Table 4.2 The LOD, LOQ, and %RSD for each type of PAHs

Types of PAHs standard	LOD (ppm)	LOQ (ppm)	%RSD
Naphthalene	0.0010	0.0033	0.67
Acenaphthylene	0.0060	0.0200	4.00
Acenaphthene	0.0017	0.0057	1.13
Fluorene	0.0013	0.0043	0.87
Phenanthrene	0.0011	0.0037	0.73
Anthracene	0.0007	0.0023	0.47
Fluoranthene	0.0016	0.0060	1.33
Pyrene	0.0016	0.0053	1.07

Types of PAHs standard	LOD (ppm)	LOQ (ppm)	%RSD
Benzo[a]anthracene	0.0018	0.0060	1.20
Chrysene	0.0030	0.0100	2.00
Benzo[b]fluoranthene	0.0011	0.0037	0.73
Benzo[k]fluoranthene	0.0015	0.0050	1.00
Benzo[a]pyrene	0.0020	0.0067	1.33
Dibenzo[a,h]anthracene	0.0017	0.0057	1.15
Benzo[ghi]perylene	0.0018	0.0060	1.21
Indeno[1,2,3-cd]pyrene	0.0015	0.0050	1.02

4.1.3 Recovery test

Recovery test was implemented to determine the efficiency of extraction method. Two types of filters and wiping materials that were spiked known concentration of PAHs standard were extracted by the same extraction method as the samples for seven replicates. Then, they were analyzed by HPLC to find the exact concentrations in order to calculate the percentage of recovery, which the values of each type of medias are summarized in Table 4.3.

Table 4.3 %Recovery for Particle-bound PAHs extraction method

Types of PAHs standard	%Recovery (mean±SD)		
	$PM_{2.5-10}$ (25 mm PTFE)	$PM_{2.5}$ (37 mm PTFE)	Hand wiping material (gauze pad)
Naphthalene	81 ± 5.07	83 ± 3.76	80 ± 4.32
Acenaphthylene	86 ± 4.56	88 ± 1.57	82 ± 3.21
Acenaphthene	87 ± 1.37	89 ± 2.67	79 ± 5.68
Fluorene	90 ± 2.98	92 ± 4.15	83 ± 4.11
Phenanthrene	94 ± 4.05	97 ± 3.89	84 ± 2.37
Anthracene	98 ± 2.32	99 ± 1.32	90 ± 2.54
Fluoranthene	95 ± 4.19	94 ± 2.31	86 ± 3.19
Pyrene	93 ± 2.60	92 ± 6.74	87 ± 2.77
Benzo[a]anthracene	97 ± 2.73	96 ± 4.09	87 ± 3.67
Chrysene	97 ± 1.89	98 ± 3.46	86 ± 2.94
Benzo[b]fluoranthene	96 ± 2.23	96 ± 3.14	88 ± 1,47
Benzo[k]fluoranthene	94 ± 4.92	93 ± 5.33	89 ± 1.24

Types of PAHs standard	%Recovery (mean±SD)		
	$PM_{2.5\text{-}10}$ (25 mm PTFE)	$PM_{2.5}$ (37 mm PTFE)	Hand wiping material (gauze pad)
Benzo[a]pyrene	93 ± 3.87	94 ± 2.17	89 ± 2.07
Dibenzo[a,h]anthracene	91 ± 6.41	91 ± 5.13	86 ± 2,38
Benzo[ghi]perylene	92 ± 4.16	90 ± 4.34	87 ± 1.72
Indeno[1,2,3-cd]pyrene	94 ± 3.56	93 ± 2.22	88 ± 2.36

4.2 Observed data during site sampling

4.2.1 Meteorological data

All of the samples in this study were collected during February to August, 2017, which were the duration from summer to rainy season in Thailand. The temperature ranged from 25 to 34° C with the mean value at 28.7° C, while the humidity ranged from 56 to 87 % with the average percent of humidity at 72.00 %. The pressure ranged from 754.38 to 762.00 mmHg with the average value at 757.94 mmHg, and the speed of wind ranged from 1 to 11 mph, with the average velocity at 6.3 mph. The meteorological data during every sampling periods were concluded in the Table C1, which was contained in Appendix C.

4.2.2 Types and quantity of burnt e-waste

The streams of e-waste that would be burnt each time were variety in terms of types and quantity, which depended on the waste that the workers received from the middlemen. Types of burnt e-waste mostly were electrical wires, small motors, and some other residue parts that contained valuable metals and could not be separated by any mechanical processes such as small pieces of ballasts and circuits. Some of discarded residues, for example polyurethane foam in refrigerators, tires, and papers from the bases of electric fans, were burnt together with e-waste to be served as the fuel. Not only the same types of burnt e-waste, but the same team of workers that went to do burning work together would also share the equal amount of e-waste for burning. The quantity of burnt e-waste in this study was approximately weighted by the workers at their dismantling sites before the transportation of e-waste to burn at landfill, which the amount ranged from 100 to 300 kg, and the average amount of waste was 201.52 kg. The information about the types and quantity of burnt e-waste for each group of workers was summarized in Table 4.4 below.

Table 4.4 Types and quantity of burnt e-waste for each group of workers

No. of sampling time	Worker no.	Quantity of burnt e-waste (kg)	Types of burnt e-waste
1	1-2	100	- Electrical wires - Motor from motorcycles and drills
2	3-5	150	- Electrical wires - Telephone wires
3	6-7	100	- Electrical wires - Motor from televisions and hair dryers - Accessories from CD players
4	8-9	100	- Electrical wires
5	10-13	200	- Electrical wires - Motor - Electric fan guard
6	14-17	200	- Electrical wires - Motors from drills - printer accessories
7	18-21	250	- Electrical wires - Refrigerator doors
8	22-25	150	- Electrical wires - Motors from televisions
9	26-29	300	- Electrical wires - Motors from hair dryers, blenders, and aquarium power filters - Electrical circuits from televisions and computers
10	30-33	300	- Electrical wires - Motors - Refrigerator doors

4.2.3 Pattern of burning activity

Regarding to the observation record, the procedures for e-waste burning could be separated into five important activities after the waste was delivered and arrived the landfill, including piling of waste, fire mixing to the pile of waste, sweeping the small residue metals after finish burning processes, compiling the metal after finishing, and pounding the finished burnt waste to remove the non-valuable leftover. The personal air samplers were turned on at the beginning of the fire mixing process when the workers lit the fire in the piles of waste, and the samplings were ended up when the workers finished their compiling or pounding of the waste (in case of the workers proceeded pounding process at burning site, most of them took the finished burnt waste to pound at their dismantling sites). Therefore, this research mainly focused on only four burning activities during sampling time, which was fire mixing, sweeping, pounding, and compiling.

The pattern of burning activities among the workers in this study could be approximately divided into 13 certain patterns classified by the percentages of each burning process, as shown in Table 4.5. The proportion of each activity was estimated from the time that each activity was taken, accounted in each total sampling time and divided into the form of percentage. The data were also supported by the face to face interview from each workers about their working plan and work sharing in their groups on the sampling day to consider the duty of each worker and roughly assume the main activity of them to take responsible.

Table 4.5 The number of workers who proceeded each pattern and the categorized percentages of burning processes in each pattern

No. of pattern	No. of worker who proceeded the pattern	Percentages of each burning activities (%)			
		Fire mixing	Sweeping	Pounding	Compiling
1	10	5	95	-	-
2	3	10	90	-	-
3	8	55	45	-	-
4	7, 18, and 23	60	40		
5	4, 6, 25, 31, and 32	70	30	-	-

No. of pattern	No. of worker who proceeded the pattern	Percentages of each burning activities (%)			
		Fire mixing	Sweeping	Pounding	Compiling
6	11, 14, 15, 20, 22, 26, 27, 28, 29, 30, and 33	80	20	-	-
7	9 and 12	90	10	-	-
8	1 and 2	60	-	40	-
9	19	35	50	-	15
10	21	50	30	-	20
11	24	70	10	-	20
12	16 and 17	70	20	-	10
13	5 and 13	80	10	-	10

The proportions of burning processes accounted in each activity pattern was also summarized in Figure 4.2 to illustrate the differences percentage of each activity within the 13 certain activity patterns.

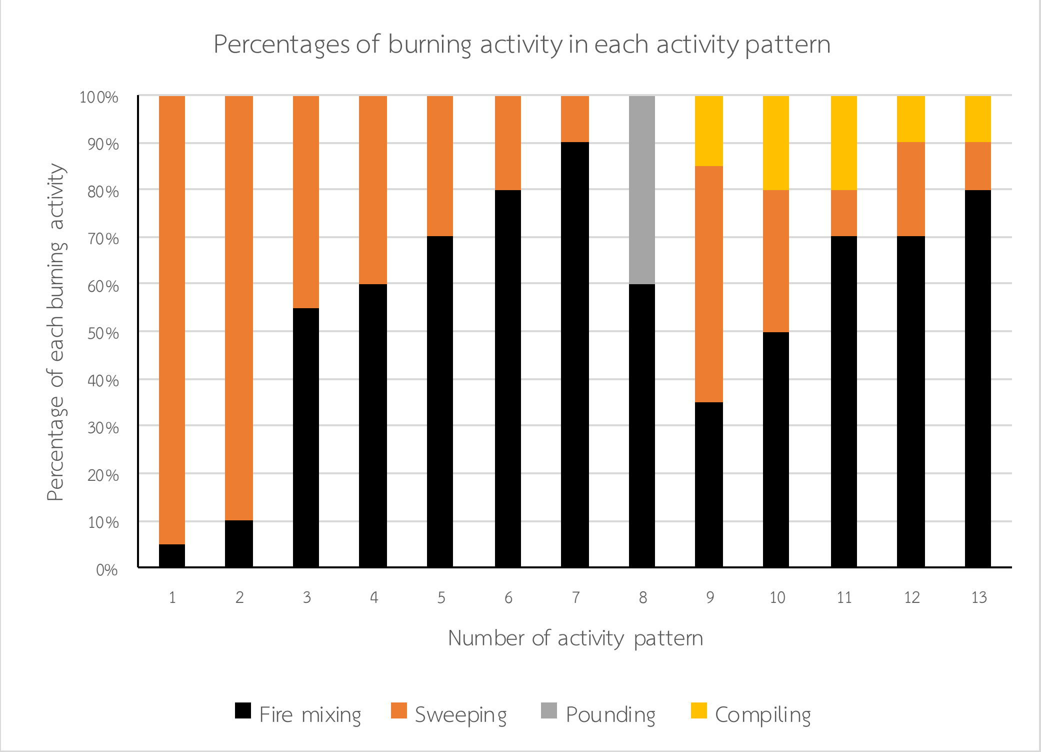


Figure 4.2 The proportions of burning processes accounted in each activity pattern

4.3 Exposure concentration of particulate matter of the workers via inhalation

4.3.1 Particulate matter concentrations

The particulate matter personal inhalation exposure samples were calculated the concentrations by the gravimetric masses of particulate matter divided by the volume of air, which all of the raw values of all related factors were already concluded in Table C2, Appendix C.

Regarding to the obtained results that were summed up in Table 4.6 and Figure 4.3, the concentrations of $PM_{2.5-10}$ ranged from 0.0679 to 2.2851 mg/m^3 with the average concentration of 0.4417 mg/m^3 (N = 33). For $PM_{2.5}$, the concentrations ranged from 0.1442 to 17.4300 mg/m^3 and the mean concentration was 2.7736 mg/m^3 (N = 33). The concentrations of PM_{10}, which were the summation of $PM_{2.5}$ and $PM_{2.5-10}$ concentrations, ranged from 0.2321 to 18.3606 mg/m^3 with the average concentration 3.2154 mg/m^3 (N=33).

Comparing with other study, the average concentration of $PM_{2.5}$ was obviously higher than an average ambient $PM_{2.5}$ concentration that was measured from the air in an informal electronic waste recycling site of China (49.9 $\mu g/m^3$) for 55.58 times (Xiangbin et al., 2016). The concentration also higher than an average $PM_{2.5}$ concentration collected from ambient in the big e-waste industrial park in Fengjiang, China (49.61 $\mu g/ m^3$ in summer and 153.88 $\mu g/ m^3$ in winter) for 18.02 to 55.91 folds, respectively (Zeping et al., 2010). The average concentration of $PM_{2.5}$ in this study was also significantly larger than the average concentration of $PM_{2.5}$ sampled from the e-waste mechanical workshop in China (271.7 $\mu g/ m^3$) for 10 times (Wenxiong et al., 2013). The result revealed that the open burning process of electronic waste emitted the significant amount of particulate matter, which was distinctively higher than the concentrations detected in ambient atmosphere of e-waste recycling site and the concentration from other process of e-waste dismantling activities. Thus, the workers who carried the burning work might have the larger opportunity to expose the coarse and fine particulate matter that also contained the other kinds of pollutants which are absorbed on the surface of the particles, and may lead to the more severe health consequences later on.

For $PM_{2.5-10}$ average concentration in this study, compared with Ogundele et al. (2016) that identified the potential sources responsible for the particulate matter emission from secondary iron and steel smelting factory environment, $PM_{2.5-10}$ particles were collected using the low volume air samplers twice a week for a year, the average mass concentration of $PM_{2.5-10}$ in this study was apparently higher than those that were detected in the production, outside (upwind) and outside (downwind) sites in an iron and steel scrap smelting factory (the average mass concentration of $PM_{2.5-10}$ were 331.36, 190.01, and 184.60 $\mu g/m^3$) for 1.33, 2.32, and 2.39 folds, respectively. This comparison supported that the open burning processes of e-waste can significantly generate the high concentrations of particulate matter not only $PM_{2.5}$ but also $PM_{2.5-10}$.

Table 4.6 Personal exposure concentrations of $PM_{2.5}$, $PM_{2.5-10}$, and PM_{10} during open burning activity

Worker No.	$PM_{2.5}$ concentrations (mg/m^3)	$PM_{2.5-10}$ concentrations (mg/m^3)	PM_{10} concentrations (mg/m^3)
1	0.7966	0.2635	1.0602
2	0.6497	0.1731	0.8228
3	0.2184	0.7327	0.9511
4	1.4972	0.6845	2.1817
5	1.3294	0.1815	1.5110
6	0.2263	0.1010	0.3274
7	0.2464	0.1376	0.3840
8	0.4150	0.3778	0.7927
9	0.9327	0.1715	1.1042
10	0.1442	0.0879	0.2321
11	1.0314	0.2356	1.2670
12	0.6669	0.0679	0.7348
13	0.4351	0.0839	0.5190
14	0.9409	0.1250	1.0659
15	0.6963	0.1345	0.8308
16	0.4479	0.1061	0.5540
17	0.3827	0.1020	0.4846

Worker No.	$PM_{2.5}$ concentrations (mg/m^3)	$PM_{2.5-10}$ concentrations (mg/m^3)	PM_{10} concentrations (mg/m^3)
18	0.8606	0.5414	1.4020
19	1.2688	2.2851	3.5539
20	1.6076	0.5013	2.1088
21	1.1571	1.9370	3.0940
22	0.7530	0.3996	1.1526
23	0.5218	0.3281	0.8499
24	0.2657	0.0756	0.3413
25	0.7288	0.1465	0.8753
26	0.7524	0.2756	1.0280
27	1.4044	0.2907	1.6951
28	17.4300	0.9306	18.3606
29	16.7949	0.5886	17.3835
30	12.5154	0.3960	12.9114
31	9.6274	0.6923	10.3197
32	7.6983	0.7514	8.4497
33	7.0864	0.6714	7.7579

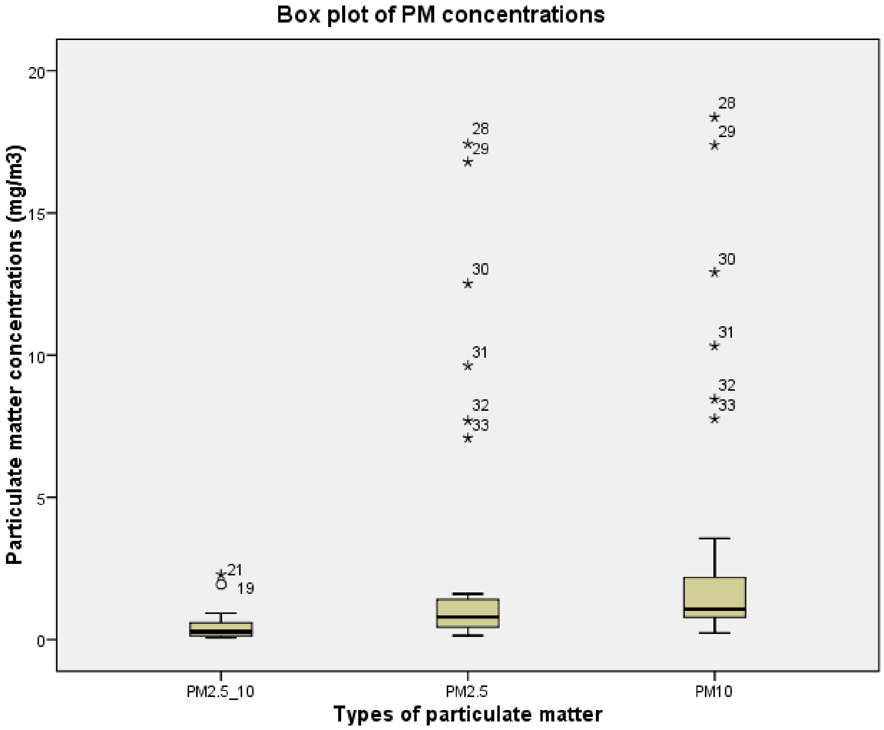


Figure 4.3 Box plot of personal exposure concentrations of $PM_{2.5}$, $PM_{2.5-10}$, and PM_{10} during open burning activity

According to the Pearson's correlation statistical analysis, the mass concentrations of $PM_{2.5}$ and $PM_{2.5-10}$ had no significant relationship with each other at 95% confidence interval ($p > 0.05$), and which the concentration for each type of PM might be involved with the other specific factors that would be discussed in the next part. As same as the relationship between $PM_{2.5-10}$, and PM_{10} concentrations, the Pearson's correlation statistical analysis showed non-significant correlation from both two types of particulate matter at 95% confidence interval ($p > 0.05$). However, there was the strong positive relationship between $PM_{2.5}$ and PM_{10} mass concentrations at 99% confidence interval ($r=0.995$, $p<0.01$), which indicated that the higher concentrations of $PM_{2.5}$, the more total concentrations of PM_{10}. Table 4.7 and Figure 4.4 summarized the percentage of $PM_{2.5}$ proportion in PM_{10} mass concentrations. The average $PM_{2.5}$ mass concentrations accounted for 74.93 ± 17.94% from PM_{10} mass concentrations, which the proportion was greater than a half of total PM_{10} mass concentrations, suggested that $PM_{2.5}$ was the main composition of PM_{10} in this study.

This finding supported that $PM_{2.5}$ was the primary type of particulate matter that was emitted directly from the open burning activities, which were the incomplete combustion process (US EPA, 2012).

Table 4.7 $PM_{2.5}/PM_{10}$ fraction and $PM_{2.5}/PM_{10}$ percentage collected from the burning activity of the workers

Worker No.	$PM_{2.5}/PM_{10}$ fraction	$PM_{2.5}/PM_{10}$ percentage (%)	Worker No.	$PM_{2.5}/PM_{10}$ fraction	$PM_{2.5}/PM_{10}$ percentage (%)
1	0.7514	75.1421	18	0.6138	61.3848
2	0.7897	78.9668	19	0.3570	35.7020
3	0.2297	22.9654	20	0.7623	76.2305
4	0.6863	68.6259	21	0.3740	37.3964
5	0.8799	87.9857	22	0.6533	65.3288
6	0.6914	69.1400	23	0.6140	61.3972
7	0.6416	64.1615	24	0.7786	77.8568
8	0.5235	52.3453	25	0.8326	83.2602
9	0.8447	84.4701	26	0.7319	73.1902
10	0.6212	62.1197	27	0.8285	82.8498
11	0.8140	81.4017	28	0.9493	94.9317
12	0.9076	90.7568	29	0.9661	96.6140
13	0.8383	83.8348	30	0.9693	96.9326
14	0.8827	88.2687	31	0.9329	93.2915
15	0.8381	83.8072	32	0.9111	91.1075
16	0.8085	80.8497	33	0.9135	91.3452
17	0.7896	78.9625			

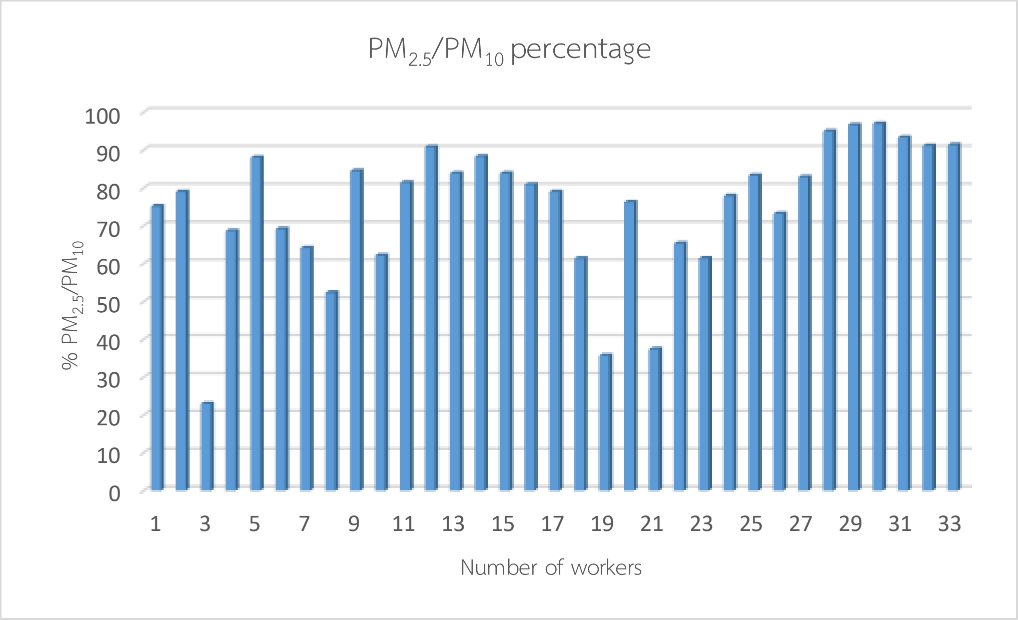


Figure 4.4 Percent contribution of $PM_{2.5}$ in PM_{10} from each samples

4.3.2 Influencing factors for particulate matter concentrations from e-waste burning activity

The personal exposure concentrations of $PM_{2.5}$ and $PM_{2.5\text{-}10}$ in this study had no statistically significant relationship with the meteorological conditions during sampling time, which was included temperature, humidity, pressure, and wind speed. The probable supported reasons might come from the very specific activity of open burning process that released the very high amount of particles within the short period of time; moreover, the weather for outdoor open burning needed to be dry and had no rain, so the humidity was considered and limited. Consequently, the meteorological factors were not clearly shown the impact and involvement in the obtained concentrations of both two types of particulate matter. However, there were other related factors that had relationships with the concentrations of particulate matter from open burning of e-waste, which were discussed as follows.

4.3.2.1 The quantity of burnt e-waste

The correlation between quantity of burnt e-waste and the concentrations of $PM_{2.5\text{-}10}$ analyzed by Pearson correlation suggested the positive correlation ($r=0.393$, $p<0.05$) between 2 factors above. The same correlation also showed in the $PM_{2.5}$

concentrations, the Pearson correlation between quantity of burnt e-waste and the concentrations of $PM_{2.5}$ had the positive relationship ($r=0.627$, $p<0.01$). Consequently, these results examined that the increasing of amount of burnt e-waste influenced the higher concentration of coarse and fine particles emitted through the ambient air.

4.3.2.2 Pattern of burning activities

In order to interpret the recorded data of burning activity patterns into the numerical quantity for statistical analysis, the information was decoded into the form of scores calculated by Eq. 4.1 – 4.2, which the weight of scores were valued from the probability to be the emission source of each types of particles, and arrange the order by the significance of each activities in term of an impact to the mass concentration of each types of particulate matter. The highest score for each type of PM went to the activity that was suspected to be the major source of the particles emission according to the theory.

$$\text{Activity score } PM_i = WS_{PMi} \times (\text{\% Burning activity } /100) \qquad \text{(Eq. 4.1)}$$

$$\text{Total activity score } PM_i = \Sigma \text{ activity score } PM_i \qquad \text{(Eq. 4.2)}$$

For fine particle samples, the main source of $PM_{2.5}$ comes from an incomplete combustion process; therefore, the highest impact activity that had the most effect on $PM_{2.5}$ mass concentrations suspected to be the fire mixing process, which the workers had to take most of their time closest to the fume of smoke directly, the second highest impact activity anticipated to be the sweeping process, followed by pounding, and compiling of the waste, respectively. The weight of scores of each process for $PM_{2.5}$ samples was shown in Table 4.8 and the total scores of each samples was shown in Table 4.9.

Table 4.8 The weight of scores of related burning process considerable as source of $PM_{2.5}$ and $PM_{2.5\text{-}10}$

Activities	Weight of scores for $PM_{2.5}$ source strength ($WS_{PM2.5}$)	Weight of scores for $PM_{2.5\text{-}10}$ source strength ($WS_{PM2.5\text{-}10}$)
Fire mixing (F)	100	1
Sweeping (S)	50	2
Pounding (P)	2	5
Compiling (C)	1	100

Table 4.9 Burning activity scores for $PM_{2.5}$ samples

No.	$PM_{2.5}$ concentrations (mg/m^3)	Activity percentages (%)				Scores				
		F	S	P	C	Score F	Score S	Score P	Score C	Total score
1	0.7966	60	0	40	0	60	0	0.8	0	60.8
2	0.6497	60	0	40	0	60	0	0.8	0	60.8
3	0.2184	10	90	0	0	10	45	0	0	55
4	1.4972	70	30	0	0	70	15	0	0	85
5	1.3294	80	10	0	10	80	5	0	0.1	95
6	0.2263	70	30	0	0	70	15	0	0	85
7	0.2464	60	40	0	0	60	20	0	0	80
8	0.4150	55	45	0	0	55	22.5	0	0	77.5
9	0.9327	90	10	0	0	90	5	0	0	95
10	0.1442	5	95	0	0	5	47.5	0	0	52.5
11	1.0314	80	20	0	0	80	10	0	0	90
12	0.6669	90	10	0	0	90	5	0	0	95
13	0.4351	80	10	0	10	80	5	0	0.1	95
14	0.9409	80	20	0	0	80	10	0	0	90
15	0.6963	80	20	0	0	80	10	0	0	90
16	0.4479	70	20	0	10	70	10	0	0.1	90
17	0.3827	70	20	0	10	70	10	0	0.1	90
18	0.8606	60	40	0	0	60	20	0	0	80
19	1.2688	35	50	0	15	35	25	0	0.15	75
20	1.6076	80	20	0	0	80	10	0	0	90
21	1.1571	50	30	0	20	50	15	0	0.2	85
22	0.7530	80	20	0	0	80	10	0	0	90
23	0.5218	60	40	0	0	60	20	0	0	80
24	0.2657	70	10	0	20	70	5	0	0.2	95

No.	$PM_{2.5}$ concentrations (mg/m^3)	Activity percentages (%)				Scores				
		F	S	P	C	Score F	Score S	Score P	Score C	Total score
25	0.7288	70	30	0	0	70	15	0	0	85
26	0.7524	80	20	0	0	80	10	0	0	90
27	1.4044	80	20	0	0	80	10	0	0	90
28	17.4300	80	20	0	0	80	10	0	0	90
29	16.7949	80	20	0	0	80	10	0	0	90
30	12.5154	80	20	0	0	80	10	0	0	90
31	9.6274	70	30	0	0	70	15	0	0	85
32	7.6983	70	30	0	0	70	15	0	0	85
33	7.0864	80	20	0	0	80	10	0	0	90

To examine the types of activities that had relationship with coarse particle samples, the same method was implemented. The primary source of $PM_{2.5-10}$ comes from the more mechanical process than the source of $PM_{2.5}$, the compiling process, in contrast with the case of fine particle samples, was suspected to be the highest impact activity affected on $PM_{2.5-10}$ mass concentrations, followed by pounding, sweeping, and fire mixing to the pile of waste, respectively. The weight of scores of each process for $PM_{2.5-10}$ source strength was also already shown in Table 4.8 and the total scores of each samples was shown in Table 4.10.

Table 4.10 Burning activity scores for $PM_{2.5-10}$ samples

No.	$PM_{2.5-10}$ concentrations (mg/m^3)	Activity percentages (%)				Scores				
		F	S	P	C	Score F	Score S	Score P	Score C	Total score
1	0.2635	60	0	40	0	0.6	0	2	0	2.6
2	0.1731	60	0	40	0	0.6	0	2	0	2.6
3	0.7327	10	90	0	0	0.1	1.8	0	0	1.9
4	0.6845	70	30	0	0	0.7	0.6	0	0	1.3

No.	$PM_{2.5-10}$ concen-trations (mg/m^3)	Activity percentages (%)				Scores				
		F	S	P	C	Score F	Score S	Score P	Score C	Total score
5	0.1815	80	10	0	10	0.8	0.2	0	10	11
6	0.1010	70	30	0	0	0.7	0.6	0	0	1.3
7	0.1376	60	40	0	0	0.6	0.8	0	0	1.4
8	0.3778	55	45	0	0	0.55	0.9	0	0	1.45
9	0.1715	90	10	0	0	0.9	0.2	0	0	1.1
10	0.0879	5	95	0	0	0.05	1.9	0	0	1.95
11	0.2356	80	20	0	0	0.8	0.4	0	0	1.2
12	0.0679	90	10	0	0	0.9	0.2	0	0	1.1
13	0.0839	80	10	0	10	0.8	0.2	0	10	11
14	0.1250	80	20	0	0	0.8	0.4	0	0	1.2
15	0.1345	80	20	0	0	0.8	0.4	0	0	1.2
16	0.1061	70	20	0	10	0.7	0.4	0	10	11.1
17	0.1020	70	20	0	10	0.7	0.4	0	10	11.1
18	0.5414	60	40	0	0	0.6	0.8	0	0	1.4
19	2.2851	35	50	0	15	0.35	1	0	15	16.35
20	0.5013	80	20	0	0	0.8	0.4	0	0	1.2
21	1.9370	50	30	0	20	0.5	0.6	0	20	21.1
22	0.3996	80	20	0	0	0.8	0.4	0	0	1.2
23	0.3281	60	40	0	0	0.6	0.8	0	0	1.4
24	0.0756	70	10	0	20	0.7	0.2	0	20	20.9
25	0.1465	70	30	0	0	0.7	0.6	0	0	1.3
26	0.2756	80	20	0	0	0.8	0.4	0	0	1.2
27	0.2907	80	20	0	0	0.8	0.4	0	0	1.2
28	0.9306	80	20	0	0	0.8	0.4	0	0	1.2
29	0.5886	80	20	0	0	0.8	0.4	0	0	1.2
30	0.3960	80	20	0	0	0.8	0.4	0	0	1.2
31	0.6923	70	30	0	0	0.7	0.6	0	0	1.3

No.	$PM_{2.5-10}$ concentrations (mg/m^3)	Activity percentages (%)				Scores				
		F	S	P	C	Score F	Score S	Score P	Score C	Total score
32	0.7514	70	30	0	0	0.7	0.6	0	0	1.3
33	0.6714	80	20	0	0	0.8	0.4	0	0	1.2

The Pearson's correlation between the mass concentrations of $PM_{2.5}$, $PM_{2.5-10}$ and the total scores of burning activity patterns for each types of particulate matter samples was examined to investigate the relationship between the factors. The obtained results, which were concluded in an Appendix B, showed the positive relationship at 90% confidence interval between $PM_{2.5}$ concentrations and their own total scores of activity patterns that were weight the highest score to fire mixing process followed by sweeping process, pounding, and compiling of the waste, respectively ($r=0.305$, $p<0.10$). $PM_{2.5-10}$ mass concentrations also had the positive correlation with their own total scores of activity patterns that were weight the highest score to the order of compiling process followed by pounding, sweeping, and fire mixing to the pile of waste at 95% confidence interval ($r=0.397$, $p<0.05$).

These results indicated that the activities that had more effect to increase the concentration of $PM_{2.5}$ was fire mixing, which was the process that the workers had to be close or covered by the smoke fume of burning waste directly for a period of working time, so the chance to expose fine particles which were primarily generated from the incomplete combustion process would be higher than other activities. In contrast, the activities that influenced the mass concentration of $PM_{2.5-10}$ were the more mechanical activities, such as compiling and sweeping of waste, which were the processes that emitted and spread the larger size of particulate matter into the air around working environment.

Confirming by Figure 4.5, which presents the contribution of an average concentrations of each type of PM generated from each activity pattern. The lower and upper parts of the bars represent the concentrations of $PM_{2.5}$ and $PM_{2.5-10}$, respectively, while PM_{10}, which is the summation of both two types of particulate matter, was presented by each whole bar.

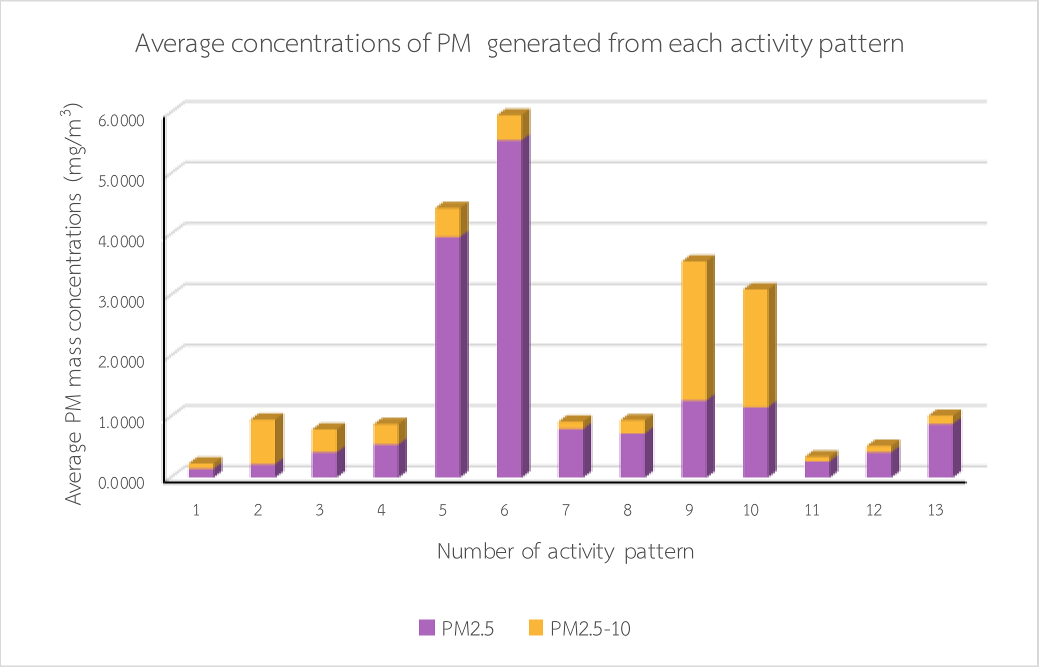


Figure 4.5 Average concentrations of $PM_{2.5}$, $PM_{2.5-10}$ and PM_{10} generated from each activity pattern

In addition, all of the values of ranges and average concentrations of both two types of PM generated from each burning activity pattern were summarized in Table 4.11. The concentrations of $PM_{2.5}$ and $PM_{2.5-10}$ also obviously corresponded with the results of the relationship between their concentrations and the activity score since the highest concentration of $PM_{2.5}$ contributed in activity pattern number 5th and 6th that consisted of the greatest percent of fire mixing process, while the biggest concentration of $PM_{2.5-10}$ revealed in the pattern number 9th and 10th that had the large percent of mechanical processes.

Table 4.11 The ranges and average concentrations of both two types of PM generated from each burning activity pattern

Pattern No.	N	$PM_{2.5-10}$			$PM_{2.5}$		
		Min	Max	Average	Min	Max	Average
1	1	0.0879	0.0879	0.0879	0.1442	0.1442	0.1442
2	1	0.7327	0.7327	0.7327	0.2184	0.2184	0.2184
3	1	0.3778	0.3778	0.3778	0.4150	0.4150	0.4150
4	3	0.1376	0.5414	0.3357	0.2464	0.8606	0.5429
5	5	0.1010	0.7514	0.4751	0.2263	9.6274	3.9556

Pattern No.	N	$PM_{2.5-10}$			$PM_{2.5}$		
		Min	Max	Average	Min	Max	Average
6	11	0.1250	0.9306	0.4135	0.6963	17.4300	5.5466
7	2	0.0679	0.1715	0.1197	0.6669	0.9327	0.7998
8	2	0.1731	0.2635	0.2183	0.6497	0.7966	0.7232
9	1	2.2851	2.2851	2.2851	1.2688	1.2688	1.2688
10	1	1.9370	1.9370	1.9370	1.1571	1.1571	1.1571
11	1	0.0756	0.0756	0.0756	0.2657	0.2657	0.2657
12	2	0.1020	0.1061	0.1040	0.3827	0.4479	0.4153
13	2	0.0839	0.1815	0.1327	0.4351	1.3294	0.8823

4.4 Amount of dust adsorbed on the workers' hands

4.4.1 Dust masses

The dust adsorbed on the surface of workers' hands were sampled by hand wiping technique three times for each person, including at the beginning before their burning work, at the end of burning activities, and after hand washing when the work finished, which all of the results were summed up in Table 4.12. The masses of particulate matter before burning work ranged from 0.00292 - 0.05206 g with the average weight at 0.02011 g (N = 33). For the masses of dust collected after finish burning work, the weight varied from 0.00974 – 0.18540 g, which 0.05923 g was the mean gravimetric mass (N = 33). The masses of dust after hand washing when the work finished varied from 0.00122 – 0.05170 g with the average mass at 0.01569 g (N = 33).

Table 4.12 The gravimetric masses of dust samples taken from the workers' hands

Worker no.	Dust masses before burning work (g)	Dust masses after finish burning work (g)	Dust masses after hand washing (g)
1	0.01589	0.02640	0.01449
2	0.01777	0.02664	0.01717
3	0.02168	0.02627	0.01257
4	0.02312	0.03213	0.01083
5	0.01937	0.03504	0.00749
6	0.01124	0.18168	0.01450
7	0.01440	0.17113	0.01928

Worker no.	Dust masses before burning work (g)	Dust masses after finish burning work (g)	Dust masses after hand washing (g)
8	0.02372	0.03376	0.01108
9	0.01865	0.05466	0.01067
10	0.02922	0.06936	0.01915
11	0.03430	0.12589	0.02747
12	0.03332	0.05639	0.03841
13	0.03607	0.18540	0.03020
14	0.02178	0.06365	0.02993
15	0.04712	0.03199	0.01538
16	0.05206	0.03293	0.02051
17	0.00890	0.02638	0.01364
18	0.01852	0.03733	0.00910
19	0.01023	0.06426	0.02082
20	0.01700	0.03364	0.00886
21	0.05059	0.06270	0.01018
22	0.01640	0.01731	0.01512
23	0.01102	0.01756	0.01415
24	0.03010	0.00974	0.00124
25	0.00695	0.10823	0.05170
26	0.02234	0.05461	0.01501
27	0.01006	0.01419	0.01360
28	0.01007	0.05790	0.01397
29	0.01194	0.04401	0.00163
30	0.00309	0.05403	0.01403
31	0.00684	0.08467	0.01219
32	0.00697	0.01926	0.00152
33	0.00292	0.09623	0.00122

According to the statistical analysis which were all summarized in an Appendix B, the mean gravimetric mass of dust after finish burning work was significantly higher than both of the mean gravimetric mass of dust before burning work and after hand washing at 99% confidence interval ($p<0.01$). The results indicated that the dust adsorbed on the hands of the workers had obviously larger amounts than the background dust that normally attached on the worker hands in their daily life activities that was represented from the quantity of particulate matter masses before working. The mean differences also revealed that burning work generated the significant amount of dermal dust and the washing of hands after finishing the work, which mostly handled by the water in reservoir containers and powdered detergent, soap or dishwashing liquid, could effectively reduce the major amount of the dust. Figure 4.6 that indicates the gravimetric masses of each type of dust categorized by the patterns of activity, also revealed the clearly higher masses of dust collected after burning work compared with other types of dust.

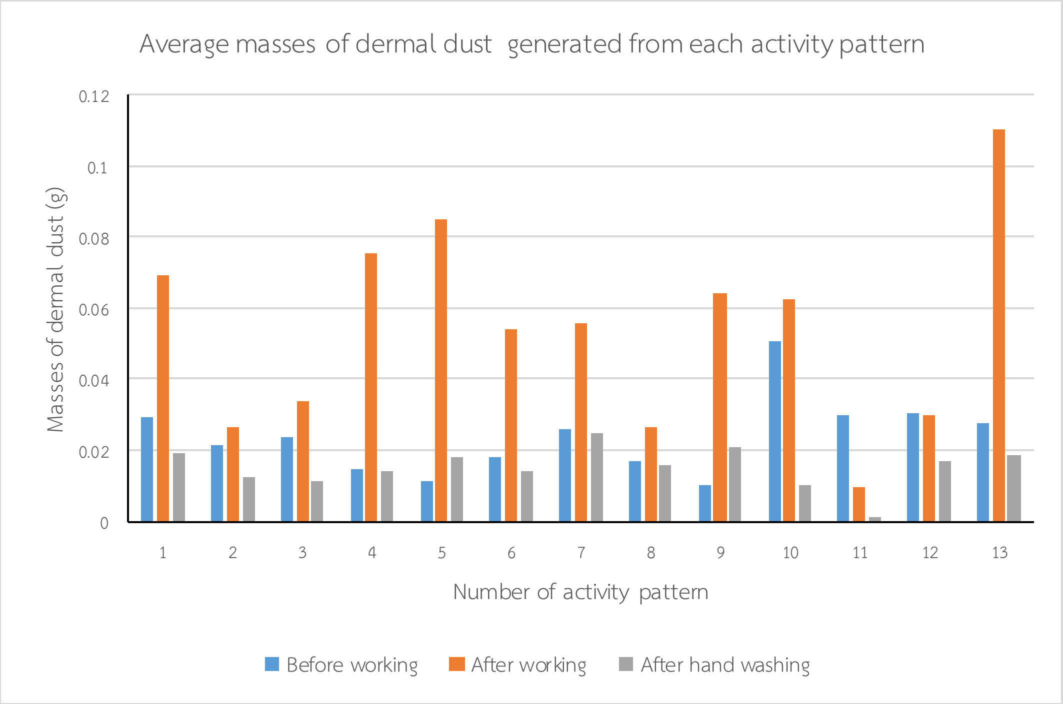


Figure 4.6 Average concentrations of each type of dermal dust classified by activity patterns

Table 4.13, in addition, elaborates the ranges and the average masses of every types of collected dust illustrated in Figure 4.6. The highest dermal dust masses collected after working distinctively belonged to activity pattern number 13th, which composed of the high percentages of almost activities. The variety of working activities could create the larger chance for workers to expose the dust via dermal contact during work. Moreover, according to the observed data in Table 4.5, the workers who took responsible for the activity number 13th were the workers number 5th and 13th, which used cotton knitted gloves and no personal protective equipment, respectively.

Not only the pattern of activity, but the use of PPE might be involved to the personal dermal exposure to dust during burning work. The relationships among these factors were discussed in the next part.

Table 4.13 The ranges and average concentrations of each type of dermal dust classified by activity patterns

Pattern No.	N	Before working (g)			After working (g)			After hand washing (g)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
1	1	0.02922	0.02922	0.02922	0.06936	0.06936	0.06936	0.01915	0.01915	0.01915
2	1	0.02168	0.02168	0.02168	0.02627	0.02627	0.02627	0.01257	0.01257	0.01257
3	1	0.02372	0.02372	0.02372	0.03376	0.03376	0.03376	0.01108	0.01108	0.01108
4	3	0.01102	0.01852	0.01465	0.01756	0.17113	0.07534	0.00910	0.01928	0.01418
5	5	0.00684	0.02312	0.01102	0.01926	0.18168	0.08519	0.00152	0.05170	0.01815
6	11	0.00292	0.04712	0.01791	0.01419	0.12589	0.05395	0.00122	0.02993	0.01420
7	2	0.01865	0.03332	0.02599	0.05466	0.05639	0.05553	0.01067	0.03841	0.02454
8	2	0.01589	0.01777	0.01683	0.02640	0.02664	0.02652	0.01449	0.01717	0.01583
9	1	0.01023	0.01023	0.01023	0.06426	0.06426	0.06426	0.02082	0.02082	0.02082
10	1	0.05059	0.05059	0.05059	0.06270	0.06270	0.06270	0.01018	0.01018	0.01018
11	1	0.03010	0.03010	0.03010	0.00974	0.00974	0.00974	0.00124	0.00124	0.00124
12	2	0.00890	0.05206	0.03048	0.02638	0.03293	0.02966	0.01364	0.02051	0.01708
13	2	0.01937	0.03607	0.02772	0.03504	0.18540	0.11022	0.00749	0.03020	0.01885

4.4.2 The impact of burning activity patterns and the use of personal protective equipment on the gravimetric masses of dermal dust

In order to evaluate the influencing factors that were related to the obtained gravimetric masses of dermal dust after finish burning work, the recorded data from observation during the sampling were decoded under the same concept parallel with what was done for inhalation particulate matter samples in topic 4.3.2.2. For dermal exposure cases, the factors that predicted to have the significant relationship with the amount of dust were the patterns of burning activities and the use of hand personal protective equipment (PPE). Therefore, both of these two factors were specified into the weight of score and calculated the total values to find the exact correlation with the gravimetric masses of the dust after working.

The dust that adsorbed on the surface of workers' hands was categorized as the coarse particles, which mainly produced by the mechanical break-up of the larger solid particles. By the same way with $PM_{2.5-10}$ samples, the highest impact activity that suspected to have the most effect on the masses of dust predicted to be the compiling process followed by pounding, sweeping, and fire mixing to the pile of waste, respectively. For dermal dust samples, total activity scores were calculated by Eq. 4.3 and 4.4. The weight of scores of related burning processes considerable as source of dermal dust used for calculation were summarized in Table 4.14 and the calculated results are shown in Table 4.15.

$$\text{Activity score Dust}_{\text{afer working}} = WS_{\text{Dust}} \times (\%\ \text{Burning activity}/100) \qquad \text{(Eq. 4.3)}$$

$$\text{Total activity score Dust}_{\text{afer working}} = \Sigma\ \text{activity score Dust}_{\text{afer working}} \qquad \text{(Eq. 4.4)}$$

Table 4.14 The weight of scores and calculation of related burning processes considerable as source of dermal dust

Activities	Weight of scores for dermal dust source strength (WS_{Dust})
Fire mixing (F)	1
Sweeping (S)	2
Pounding (P)	5
Compiling (C)	10

Table 4.15 Burning activity scores for dermal dust samples

No.	Dust masses after finish burning work (g)	Activity percentages (%)				Scores				
		F	S	P	C	score F	score S	score P	score C	total score
1	0.02640	60	0	40	0	0.6	0	2	0	2.6
2	0.02664	60	0	40	0	0.6	0	2	0	2.6
3	0.02627	10	90	0	0	0.1	1.8	0	0	1.9
4	0.03213	70	30	0	0	0.7	0.6	0	0	1.3

No.	Dust masses after finish burning work (g)	Activity percentages (%)				Scores				
		F	S	P	C	score F	score S	score P	score C	total score
5	0.03504	80	10	0	10	0.8	0.2	0	1	2
6	0.18168	70	30	0	0	0.7	0.6	0	0	1.3
7	0.17113	60	40	0	0	0.6	0.8	0	0	1.4
8	0.03376	55	45	0	0	0.55	0.9	0	0	1.45
9	0.05466	90	10	0	0	0.9	0.2	0	0	1.1
10	0.06936	5	95	0	0	0.05	1.9	0	0	1.95
11	0.12589	80	20	0	0	0.8	0.4	0	0	1.2
12	0.05639	90	10	0	0	0.9	0.2	0	0	1.1
13	0.1854	80	10	0	10	0.8	0.2	0	1	2
14	0.06365	80	20	0	0	0.8	0.4	0	0	1.2
15	0.03199	80	20	0	0	0.8	0.4	0	0	1.2
16	0.03293	70	20	0	10	0.7	0.4	0	1	2.1
17	0.02638	70	20	0	10	0.7	0.4	0	1	2.1
18	0.03733	60	40	0	0	0.6	0.8	0	0	1.4
19	0.06426	35	50	0	15	0.35	1	0	1.5	2.85
20	0.03364	80	20	0	0	0.8	0.4	0	0	1.2
21	0.0627	50	30	0	20	0.5	0.6	0	2	3.1
22	0.01731	80	20	0	0	0.8	0.4	0	0	1.2
23	0.01756	60	40	0	0	0.6	0.8	0	0	1.4
24	0.00974	70	10	0	20	0.7	0.2	0	2	2.9
25	0.10823	70	30	0	0	0.7	0.6	0	0	1.3
26	0.05461	80	20	0	0	0.8	0.4	0	0	1.2
27	0.0136	80	20	0	0	0.8	0.4	0	0	1.2

No.	Dust masses after finish burning work (g)	Activity percentages (%)				Scores				
		F	S	P	C	score F	score S	score P	score C	total score
28	0.0579	80	20	0	0	0.8	0.4	0	0	1.2
29	0.04401	80	20	0	0	0.8	0.4	0	0	1.2
30	0.05403	80	20	0	0	0.8	0.4	0	0	1.2
31	0.08467	70	30	0	0	0.7	0.6	0	0	1.3
32	0.01926	70	30	0	0	0.7	0.6	0	0	1.3
33	0.09623	80	20	0	0	0.8	0.4	0	0	1.2

The using of hand personal protective equipment in this study could be divided into 6 categories as listed in Table 4.16. in order to find out the relationship between the use of PPE along with the proceeded activity pattern with the masses of dust after finish working, the total activity scores were weighted more with the weighting scores set for each type of PPE, which could be calculated by Eq. 4.5. The weight of scores for each types of gloves was graded from the combination of criteria, including thickness, porosity, and the number of layer of the gloves, which the highest score belonged to the lacking of hand personal protective equipment that was presumed to have the largest chance for workers to directly expose the dust. The collected data about the types of personal protective equipment and the total sum score are shown in Table 4.17.

$$\text{Final total score Dust}_{\text{afer working}} = \text{WS}_{\text{PPE}} \times \text{Total activity score Dust}_{\text{afer working}} \quad \text{(Eq. 4.5)}$$

Table 4.16 The weight of scores of the using of hand personal protective equipment considerable as the related factor to dermal dust

Types of hand PPE	Weight of scores for dermal dust mass strength
Rubber cleaning gloves	0.1
Sanitary latex gloves (2 layers)	0.5
Sanitary latex gloves + PU palm coated gloves	2
Cotton knitted gloves	4
PU palm coated gloves	6
None	10

Table 4.17 Burning activity scores combined with hand personal protective equipment scores for dermal PM samples

No.	Dust masses after working (g)	Types of hand PPE	PPE score (P)	Activity total score (A)	Final total score (P x A)
1	0.0264	PU palm coated gloves	6	2.6	15.6
2	0.02664	PU palm coated gloves	6	2.6	15.6
3	0.02627	Sanitary latex gloves	2	1.9	3.8
4	0.03213	Rubber cleaning gloves	0.1	1.3	0.13
5	0.03504	Cotton knitted gloves	4	2	8
6	0.18168	None	10	1.3	13
7	0.17113	None	10	1.4	14
8	0.03376	Cotton knitted gloves	4	1.45	5.8
9	0.05466	Cotton knitted gloves	4	1.1	4.4
10	0.06936	PU palm coated gloves	6	1.95	11.7
11	0.12589	PU palm coated gloves	6	1.2	7.2
12	0.05639	Cotton knitted gloves	4	1.1	4.4
13	0.1854	None	10	2	20
14	0.06365	Cotton knitted gloves	4	1.2	4.8
15	0.03199	Cotton knitted gloves	4	1.2	4.8
16	0.03293	Cotton knitted gloves	4	2.1	8.4
17	0.02638	Cotton knitted gloves	4	2.1	8.4

No.	Dust masses after working (g)	Types of hand PPE	PPE score (P)	Activity total score (A)	Final total score (P x A)
18	0.03733	Sanitary latex gloves	2	1.4	2.8
19	0.06426	Cotton knitted gloves	4	2.85	11.4
20	0.03364	Sanitary latex gloves + PU palm coated gloves	0.5	1.2	0.6
21	0.0627	Cotton knitted gloves	4	3.1	12.4
22	0.01731	Sanitary latex gloves + PU palm coated gloves	0.5	1.2	0.6
23	0.01756	Sanitary latex gloves + PU palm coated gloves	0.5	1.4	0.7
24	0.00974	Sanitary latex gloves	2	2.9	5.8
25	0.10823	None	10	1.3	13
26	0.05461	Sanitary latex gloves + PU palm coated gloves	2	1.2	2.4
27	0.0136	Sanitary latex gloves + PU palm coated gloves	2	1.2	2.4
28	0.0579	Cotton knitted gloves	4	1.2	4.8
29	0.04401	PU palm coated gloves	6	1.2	7.2
30	0.05403	Sanitary latex gloves + PU palm coated gloves	0.5	1.2	0.6
31	0.08467	Sanitary latex gloves + PU palm coated gloves	0.5	1.3	0.65
32	0.01926	Cotton knitted gloves	4	1.3	5.2
33	0.09623	None	10	1.2	12

The impact of burning activity patterns and the use of personal protective equipment on the gravimetric masses of dermal particulate matter were verified by Pearson's correlation. The statistical analysis results presented the non-significant relationship between the masses of dermal dust and the scores of burning activity patterns. The obtained results, however, showed the strong positive relationship at 99% confidence interval between the quantity of dust and the total final scores, which were the combination of activity patterns and the use of personal protective equipment (r=0.562, p<0.01). According to the non-significant relationship between the masses of dust and the individual scores of activity pattern directly, to approximately estimate the effect of activities on the masses of dust adsorbed on hand surface, the samples with no use of PPE (worker number 6, 7, 13, 25, and 33) were compared. The highest mass of dust in this group belonged to the worker number 13, which was the only one person that had compiling activity (according to the information provided in Table 4.12). This data might inferred that the compiling of waste may possibly had the related positive impact on the masses of dust on the worker hands. However, the masses of dust not only depended on the activity pattern, but also associated with the types of PPE in used. The most effective type of gloves that had the best protection of dust during the burning work was rubber cleaning gloves and the double layers of sanitary latex gloves, which had the less porosity compared with other types of gloves, and the largest opportunity to expose the dust unsurprisingly went to the workers who did not wear the hand PPE while working. Figure 4.7 demonstrates the relationship between the mean masses of dust and the types of hand PPE that also had the same trend with the weight of scores of the using of hand personal protective equipment that considered as the related factor to dermal dust. All of the statistic results are summed up in an Appendix B.

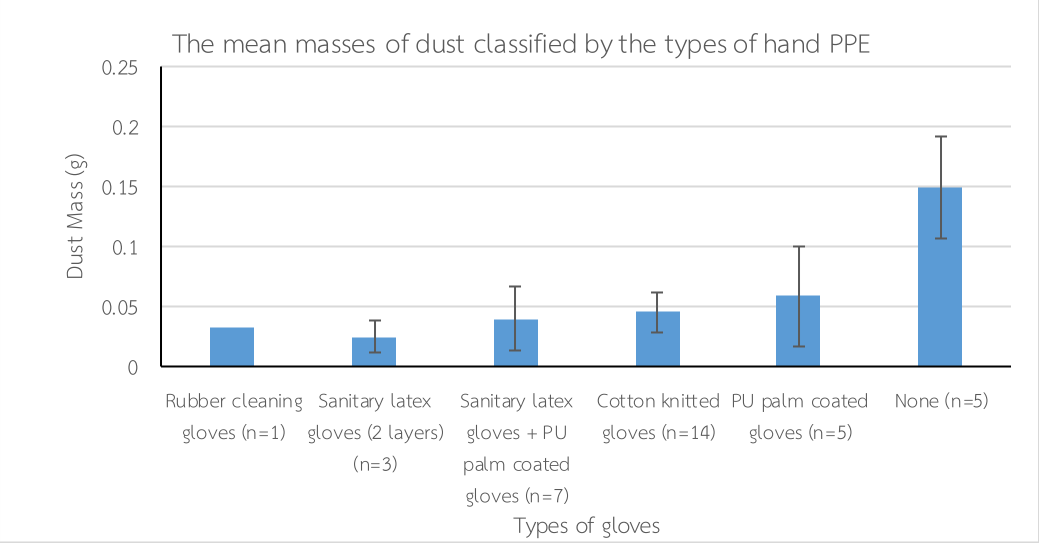


Figure 4.7 The mean masses of dust classified by the types of hand PPE

4.5 Exposure concentration of polycyclic aromatic hydrocarbons of the workers via inhalation route

The concentrations of each species of particle bound PAHs in this study quite varied in each samples, and the first three compounds with the small number of rings including Naphthalene, Acenaphthylene and Acenaphthene were not accounted in the results because two and three ring PAHs were dominant in the gas phase while four, five and six ring PAHs were abundant in the particle phase (Verma et al, 2017); thus, to focus on the particle bound PAHs, the total concentrations of only 13 types of PAHs in each individual workers were summed up. The total concentrations of PAHs on $PM_{2.5-10}$ particles ranged from 0.0703 to 20.9800 µg/m^3, while in $PM_{2.5}$ samples, the total concentrations of PAHs adsorbed on the particles varied from 0.2669 to 89.9645 µg/m^3. Indeno(1,2,3-c,d)pyrene of some samples were undetectable due to the close retention time with the background peaks, which resulted in the assemble of peak areas that were unable to be separated off from each other. The concentrations of each species of PAHs and the total concentrations on both two types of particles are enumerated in Table C3 and C4, contained in an Appendix C.

In comparison, the concentrations of total 13 PAHs on $PM_{2.5-10}$ were significantly lower than $PM_{2.5}$ ($p<0.05$), which might be the effect from the smaller size of $PM_{2.5}$ that reflected in the larger active surface area and created the higher chance for chemicals to attach on the particles. Slezakova et al. (2013), which studied about the impact of vehicular traffic emissions on particulate-bound PAHs also found that PAHs associated with coarse particles accounted for only 6% and 17% in the samples, while $PM_{2.5}$ bound PAHs accounted, respectively, for 94% and 83% of total PAHs concentrations, thus demonstrating that particulate bound PAHs were predominantly associated with particles of smaller sizes. Moreover, the concentrations of PAHs in this study obtained from e-waste burning process, which is the incomplete combustion that is known to be the main source of PAHs bound on fine particles; therefore, the process was reasonably generated the higher concentrations of PAHs bound on $PM_{2.5}$ than those in $PM_{2.5-10}$. The total PAHs concentrations in coarse and fine particulate matter had no significant relationship with each other in statistical test, which can be roughly compared in Figure 4.8 that shows the average total PAHs concentrations in both two types of particles classified by the same activity pattern. Table 4.18, furthermore, describes the minimum, maximum, and the average total concentrations of PAHs in $PM_{2.5-10}$ and $PM_{2.5}$ generated by each activity pattern.

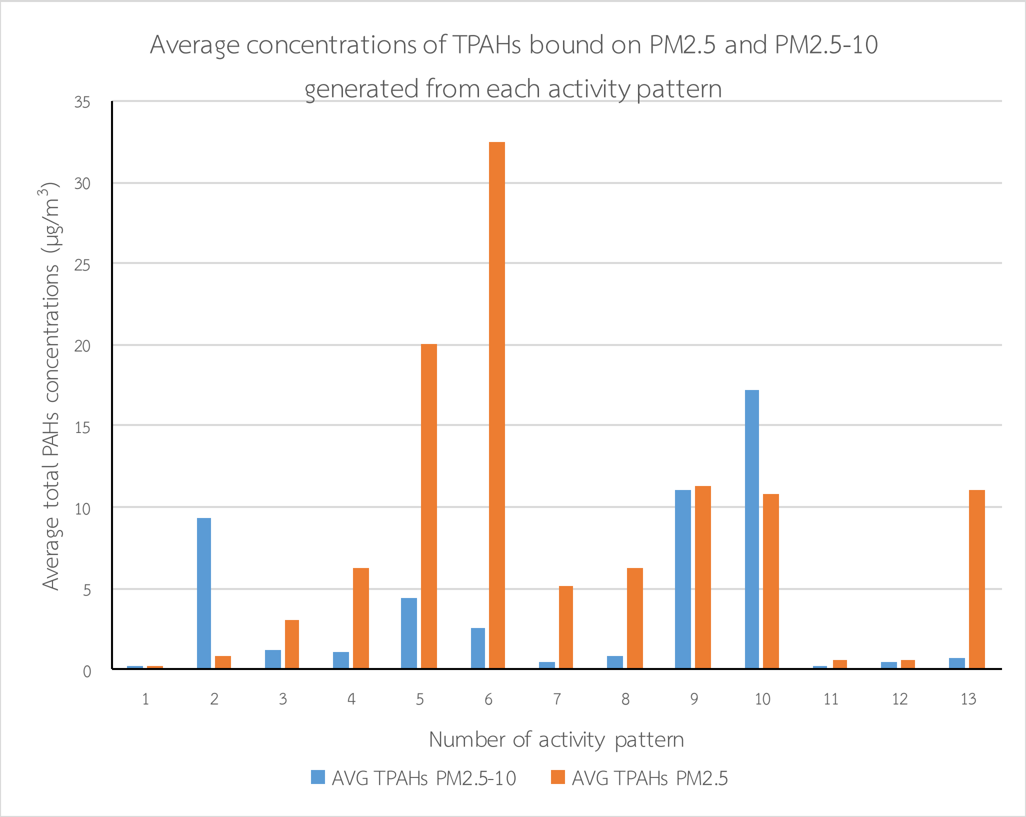


Figure 4.8 Average total PAHs concentrations in $PM_{2.5-10}$ and $PM_{2.5}$ classified by the number of activity pattern

Table 4.18 Average total PAHs concentrations in $PM_{2.5-10}$ and $PM_{2.5}$ classified by the number of activity pattern

Pattern No.	N	$PM_{2.5-10}$			$PM_{2.5}$		
		Min	Max	Average	Min	Max	Average
1	1	0.1835	0.1835	0.1835	0.2669	0.2669	0.2669
2	1	9.3538	9.3538	9.3538	0.8170	0.8170	0.8170
3	1	1.2421	1.2421	1.2421	3.0080	3.0080	3.0080
4	3	0.6610	1.4393	1.0781	0.7172	10.2855	6.2103
5	5	0.2027	9.8818	4.4091	0.3171	50.6031	20.0271
6	11	0.4550	12.6419	2.5086	2.8885	89.9645	32.4384

Pattern No.	N	$PM_{2.5-10}$			$PM_{2.5}$		
		Min	Max	Average	Min	Max	Average
7	2	0.0703	0.9888	0.5296	1.7531	8.4594	5.1062
8	2	0.8054	0.8810	0.8432	5.7590	6.8674	6.3132
9	1	11.0246	11.0246	11.0246	11.3021	11.3021	11.3021
10	1	17.2373	17.2373	17.2373	10.8030	10.8030	10.8030
11	1	0.1676	0.1676	0.1676	0.5715	0.5715	0.5715
12	2	0.3280	0.6696	0.4988	0.5783	0.6007	0.5895
13	2	0.1768	1.2363	0.7065	8.0882	14.0745	11.0814

In contrast, the Pearson's correlation analysis revealed the significant relationship between the concentrations of total 13 PAHs on both two types of particulate matter and their own score of activity patterns considerable as source of particle mass concentrations. The individual total concentrations of PAHs on $PM_{2.5-10}$ as same as $PM_{2.5}$ had the positive correlation with their score of activity patterns at 90 % confidence interval ($PM_{2.5-10}$: r=0.321, p<0.10 and $PM_{2.5}$: r=0.333, p<0.10). The intense relationship between these factors confirmed that the total exposure concentrations of 13 PAHs detected in particulate matter samples were affected by the activities of the workers in burning processes, which also related to the emitted mass concentration of particulate matter directly. The closer to the source of each type of particulate matter, the bigger chance of the workers to receive particle bound PAHs in the air correspondingly.

The Pearson's correlation analysis also confirmed the positive relationship between the concentrations of both $PM_{2.5-10}$ and $PM_{2.5}$ and their exposure concentrations of total 13 PAHs adsorbed on the particles ($PM_{2.5-10}$: r=0.852, p<0.01 and $PM_{2.5}$: r=0.968, p<0.01). The strong positive correlation at 99% confidence interval strengthened that the PAHs detected in the extracted samples were the particle phase PAHs; moreover, the results also proved that these concentrations of total 13 PAHs were really influenced by the worker activity as same as the behavior of particulate matter. The processes of e-waste burning spread out the plume of smoke and thus increase the exposed chance of both particulate matter and the PAHs contained on the surface of the particles to the workers. The pattern of activity that generated the highest total concentration of PAHs on $PM_{2.5-10}$ was the activity number 13th (50% fire mixing, 30% sweeping, and 20% compiling), which contributed from the high mechanical processes composed with the large percent of sweeping activity combined with the highest percent of compiling activity that was considered as the main source of coarse particles in this study; thus, this pattern of activity emitted the great mass concentration of $PM_{2.5-10}$ and obtained the large total concentration of particle phase PAHs compatibly. By the same way, the highest total concentration of PAHs on $PM_{2.5}$ was from the activity number 6th (80% fire mixing, and 20% sweeping), which had the greatest percent of fire mixing process that was weighted as the strongest source of fine particles in this research. This pattern of activity received the highest concentration of $PM_{2.5}$ and also reasonably had the highest total PAHs concentration adsorbed on the surface of fine particles. In addition, all of the statistical analysis results in this part were already summed up in an Appendix B.

Comparing with the previous related research, the overall average total concentrations of 13 PAHs in this study had the clearly higher quantity than the PAHs found in other research. Comparing with the concentrations of total PAHs in $PM_{2.5}$ samples collected in ambient air of Taizhou, a city famous for its e-waste recycling industry in Zhejiang province of China, the concentrations in this study were obviously higher for approximately 741 times in summer and 67 times in winter (the total PAHs concentration in summer and winter was 22.42 and 248.5 ng/m^3; Gu et al., 2010). The concentrations also much higher than the maximum average concentrations of total PAHs measured from the air in another well-known e-waste recycling zone in China for about 1,000 folds (the total PAHs concentration in the study ranged from 15.1 to 17.7 ng/m^3; Luo et al., 2015). These results suggested that the PAHs concentrations investigated from direct burning processes had the strongly greater concentrations than the PAHs in ambient air of e-waste recycling workplaces, which might be lesser due to the effect from the dilution of an airstream though the direction away from open burning sites.

In addition, to consider the dominant types of particle-bound PAHs in this study, the profile graph of each species of PAHs based on the average total concentrations in $PM_{2.5-10}$ and $PM_{2.5}$ classified by each activity pattern were created and shown in Figure 4.9 and Figure 4.10, respectively. Figure 4.9 demonstrates that the dominant species of PAHs bound on $PM_{2.5-10}$ in this study were Pyrene, Benzo(k)fluoranthene, Dibenz(a,h)anthracene, Chrysene, and Benzo(g,h,i)perylene.

Similarly, the major compounds found in the $PM_{2.5}$ samples that summarized in Figure 4.10 were Fluoranthene, Pyrene, Dibenz(a,h)anthracene, and Benzo(g,h,i)perylene, which were the resemble species of PAHs that found in electric wire samples from Alawi et al. research (2018). The profile of PAHs also had the similar trend with the species of PAHs detected in soil from the e-waste recycling site, Guiyu, China in Yu et al. study (2006), which the dominant PAHs were also included Fluoranthene, Pyrene, Chrysene, followed by the group of Benzo(b& k)fluoranthene and Benzo(g,h,i)perylene. The study also supported that these types of PAHs were mainly derived from the incomplete combustion of e-waste (e.g. wire insulations and PVC materials), and the soil from e-waste burning sites contributed the highest total concentrations of PAHs compared with other studied areas.

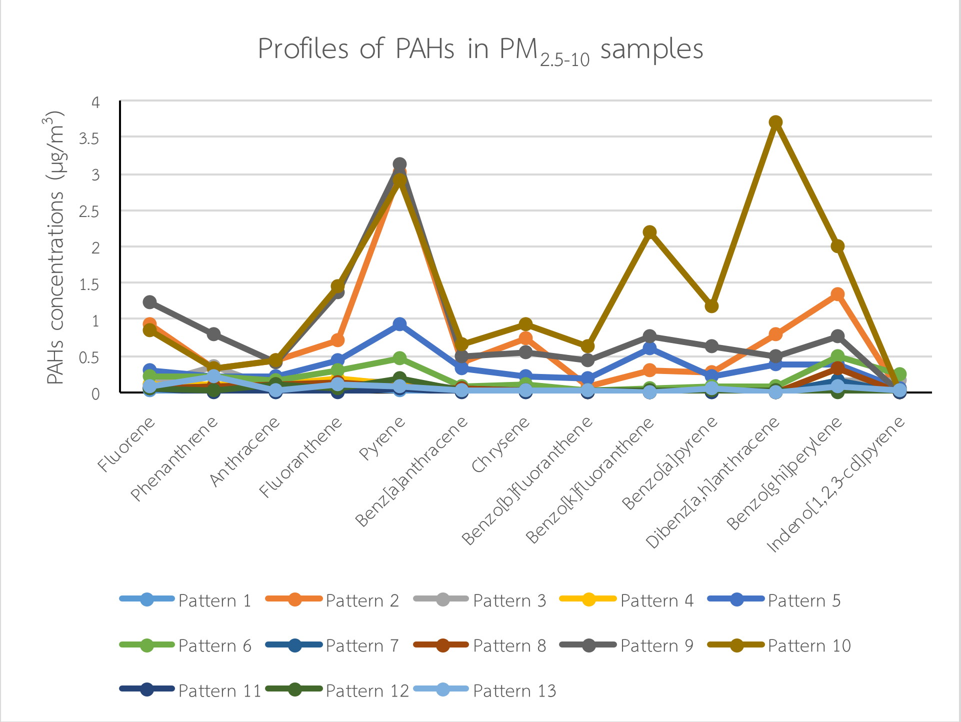


Figure 4.9 Profile of 13 PAHs in $PM_{2.5-10}$ samples

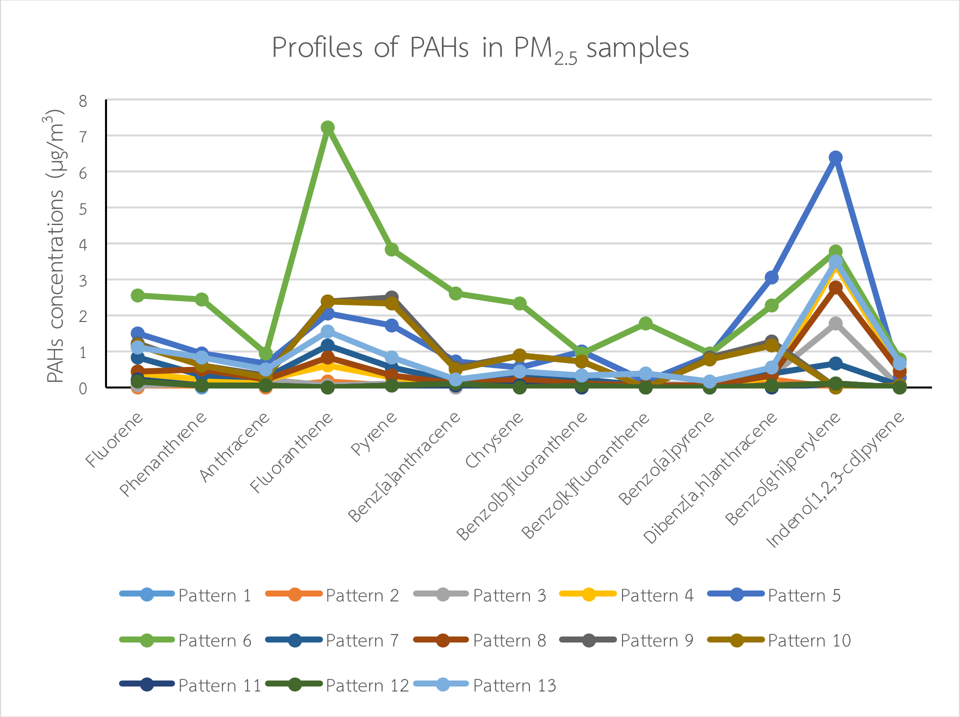


Figure 4.10 Profile of 13 PAHs in $PM_{2.5}$ samples

4.6 Exposure concentration of polycyclic aromatic hydrocarbons of the workers via dermal route

In the dermal dust samples, the total concentrations of 13 PAHs on the particles before burning work ranged from 8.1072 to 253.6118 mg/kg with the average concentration at 95.3894 mg/kg. For the samples of dust after finish burning work, the total concentrations of PAHs adsorbed on the particles varied from 117.5432 to 4,315.9496 mg/kg and the mean concentration was 1,187.9897 mg/kg. Also, the average concentration of 13 PAHs on the dust after hand washing was 309.9614 mg/kg and the range of values varied from 109.1063 to 876.9778 mg/kg. The average total concentrations of 13 species of PAHs from each types of dust collecting activities differentiated by the pattern of activity were summarized in Figure 4.11 and the values of ranges and the average total dermal PAHs concentrations were summarized in Table C6 contained in Appendix C.

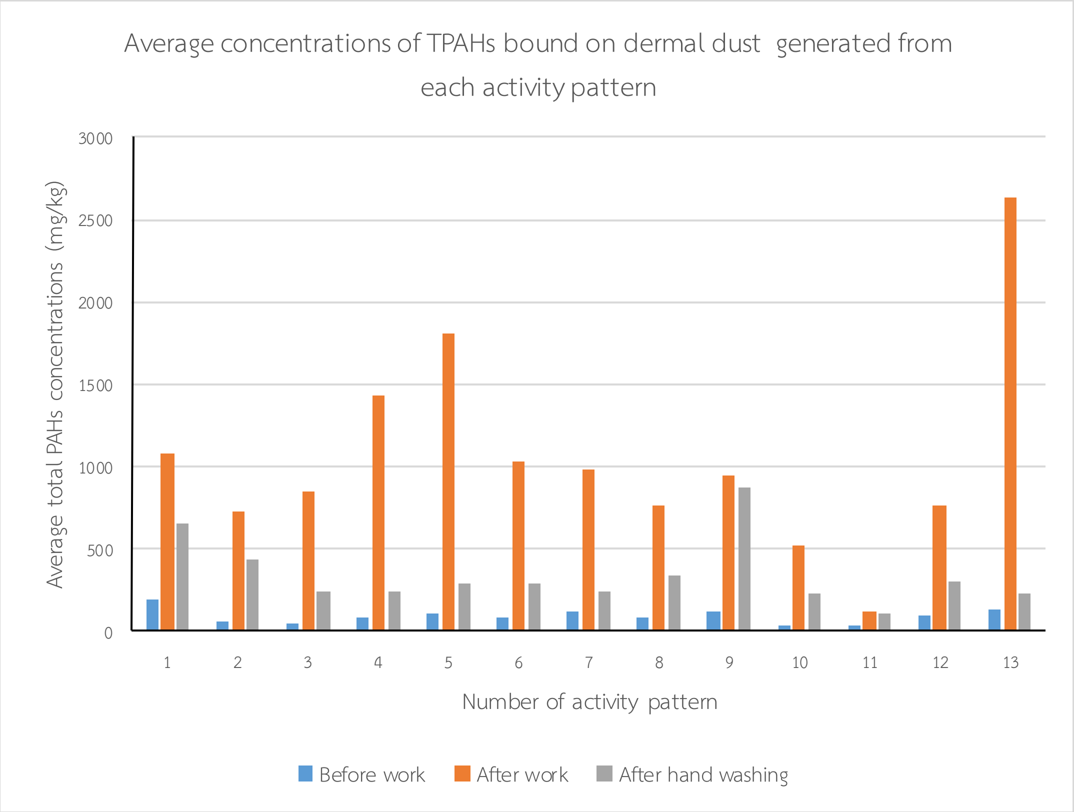


Figure 4.11 Average total PAHs concentrations in each type of dermal dust classified by the number of activity pattern

According to Figure 4.11, the activity pattern number 13th obtained the highest average total PAHs concentrations, which was the resulted from the activity in this pattern that consisted of the most variety and high percentage of overall burning procedure including 80% of fire mixing, 10% of sweeping, and 20% of compiling. This pattern of activity induced the workers to move and use their hands in various way more than some other patterns that had the certain two types of similar activities. Moreover, the personal protective equipment that workers who did this activity used were cotton knitted gloves and even bare hands, so this could create the larger chance for the chemical-contained dust to adsorb on the surface of worker hands and also leaded to the higher opportunity of the PAHs dermal exposure.

The total concentrations of PAHs in the dust collected before burning work, which were the background concentrations on the hands of workers, had no significant relationship with their quantity of dust. It could be possible because the samples were collected before workers directly exposed to the major source of PAHs, which was the burning process, so the obtained concentrations might come from the dust that was accumulated in their house, and the high concentrations found in these background samples probable came from the suspended PAHs bound on the dust that released from pounding activity that used for removing the residue burnt products from the precious metal after burning, which the workers did this activity in the yard of their own homes.

For the samples of dust after finish burning work, the total concentrations of PAHs had significant relationship with their amount of dust at 99% confidence interval ($r=0.832$, $p<0.01$) and also had the strong positive relationship with their own activity scores weighted with the use of personal protective equipment at 99% confidence interval ($r=0.611$, $p<0.01$). The correlation results revealed that the factors that had an impact on the exposure concentrations of PAHs adsorbed on the dust particles were the working activity and the selection of personal protective equipment.

The exposure concentrations of 13 PAHs on the dust after hand washing also had no significant correlation with their masses of dust, which could be the resulted from many related factors that could create the variation and uncertainty including personal hand washing procedure, types of detergent, and the source of water that might be possibly contaminated in the area. However, the concentrations after hand washing was clearly lower than the concentrations after finished working ($p<0.01$), so the results indicated that hand washing was the effective way to reduce the risk from dermal contact of PAHs from e-waste burning process. Figure 4.12 shows the percent reduction of PAHs total concentration varied by the types of detergent, which demonstrated that the type of detergent that influenced the highest percent reduction of total PAHs concentration was soap. PAHs had the ability for fat-soluble (Swedish Chemicals Agency, 2018), so it might be related to the composition of soap that prepared from fatty acid or oil, which could solve and rinse off the PAHs better than other types of detergent.

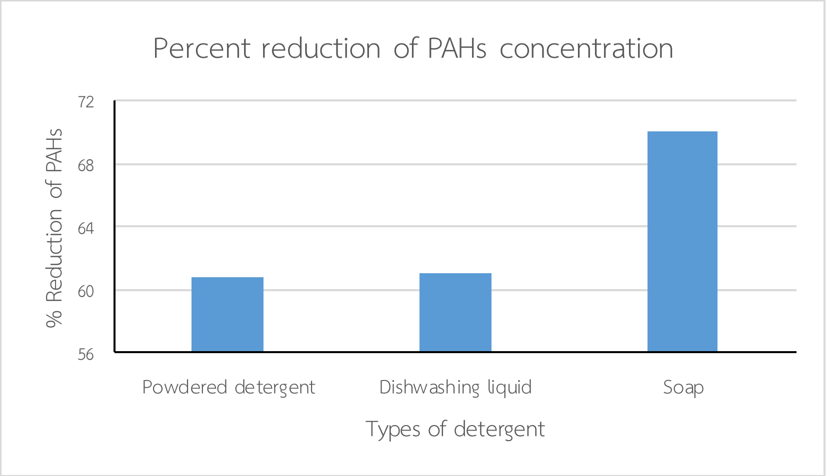


Figure 4.12 Percent reduction of PAHs total concentration varied by the types of detergent

In comparison with the previous study, the total 16 PAHs concentrations on the dust after finish burning work were used to compare. Anna et al. (2013) determined the levels and distribution of polycyclic aromatic hydrocarbons in soil in Guiyu, a major hotspot of e-waste recycling site in China. The results revealed that the highest average total PAHs concentrations were found in combusted residues of wires, cables, and other computer electrical components located at two e-waste open burning sites (18,600 and 10,800 ± 3,940 ng/g), which the concentrations of total PAHs in this study were distinctively higher than those for 64 and 110 times, respectively. Yu et al. (2006) studied about polycyclic aromatic hydrocarbons (PAHs) in soil in the same e-waste recycling site, Guiyu, in Southeast China and the results also suggested that the highest concentrations of a sum of 16 PAHs belonged to the soil from open burning sites compared with area near the open burning sites, the rice field, and the reservoir areas. The obtained total concentrations of PAHs found in the soil was 2065 μg/kg, which was particularly lower than this study for 575 folds.

Regarding to discuss the PAHs profile in the dust samples, the average total concentrations in each type of dust classified by each activity pattern were plotted and demonstrated in Figure 4.13 - 4.15, which summarize the distribution of each species of PAHs based on the average total concentrations in the dust collected before burning work, after burning work, and after hand washing, respectively. From Figure 4.13, the major species of PAHs found in the dust before burning work were

Benzo[k]fluoranthene, while in the dust after burning work shown in Figure 4.14, the main type of PAHs detected in samples was Dibenz(a,h)anthracene followed by Pyrene. Furthermore, Dibenz(a,h)anthracene and Pyrene also contributed the highest concentrations in the dust after hand washing samples correspondingly with the PAHs after working. The species of PAHs found in the dermal dust samples were similar to those detected in particulate matter phase, which could also found in the electrical wire and from soil in e-waste burning sites from other studies as were discussed above.

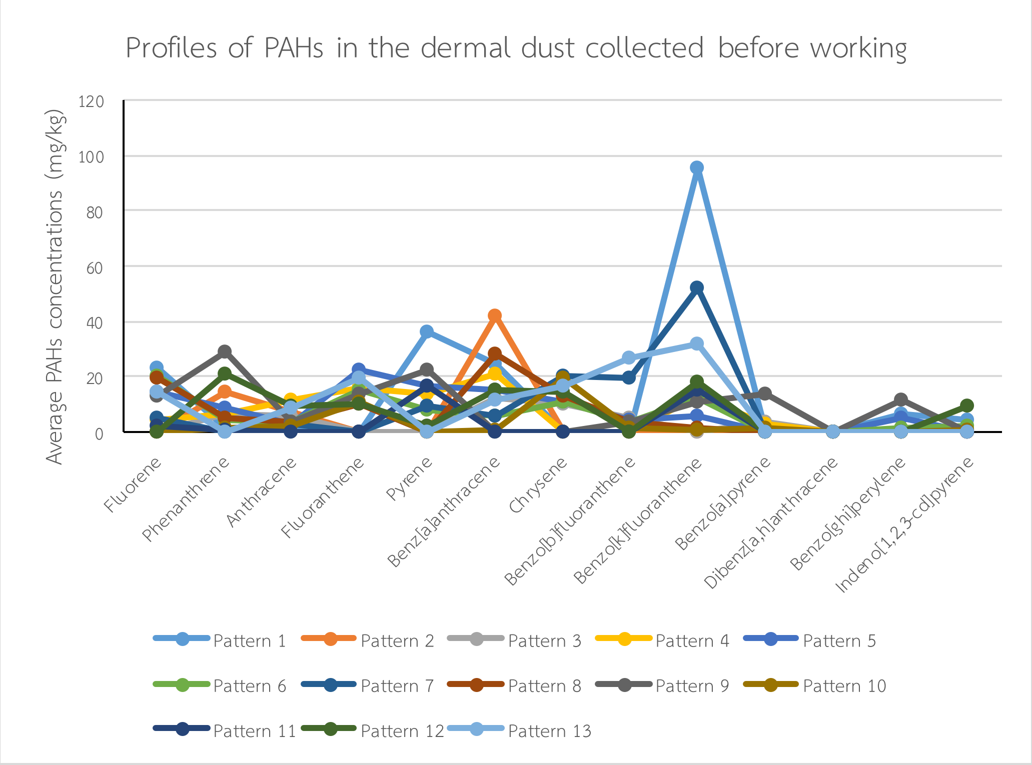


Figure 4.13 Average total PAHs concentrations in the dust before burning work classified by the pattern of activity

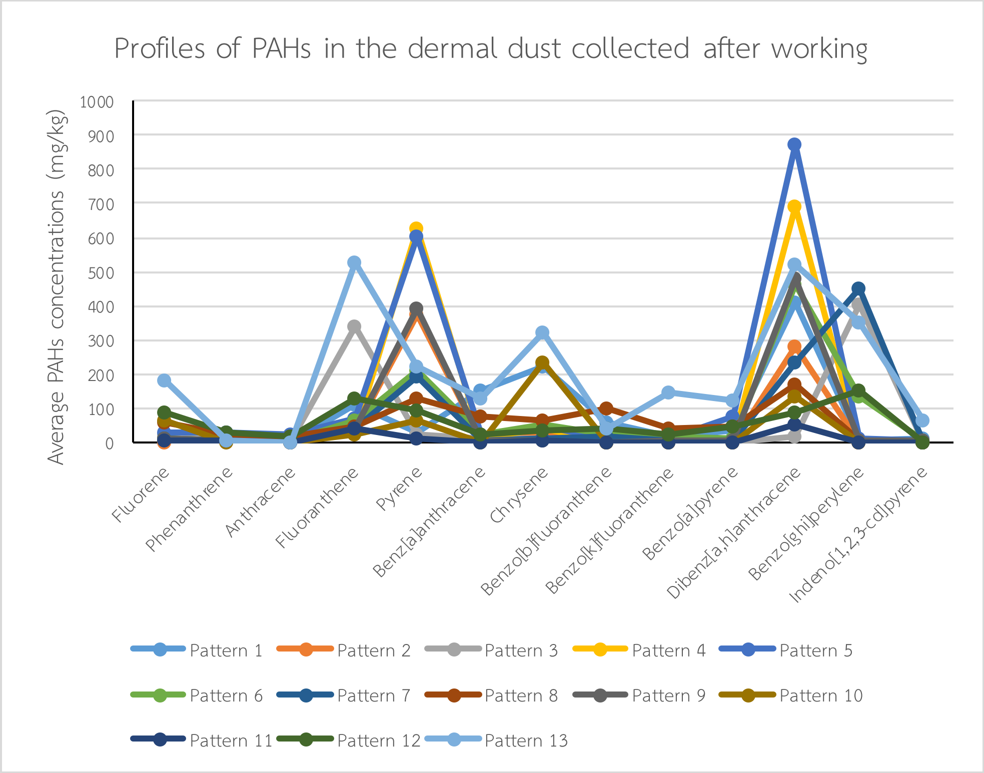


Figure 4.14 Average total PAHs concentrations in the dust after burning work classified by the pattern of activity

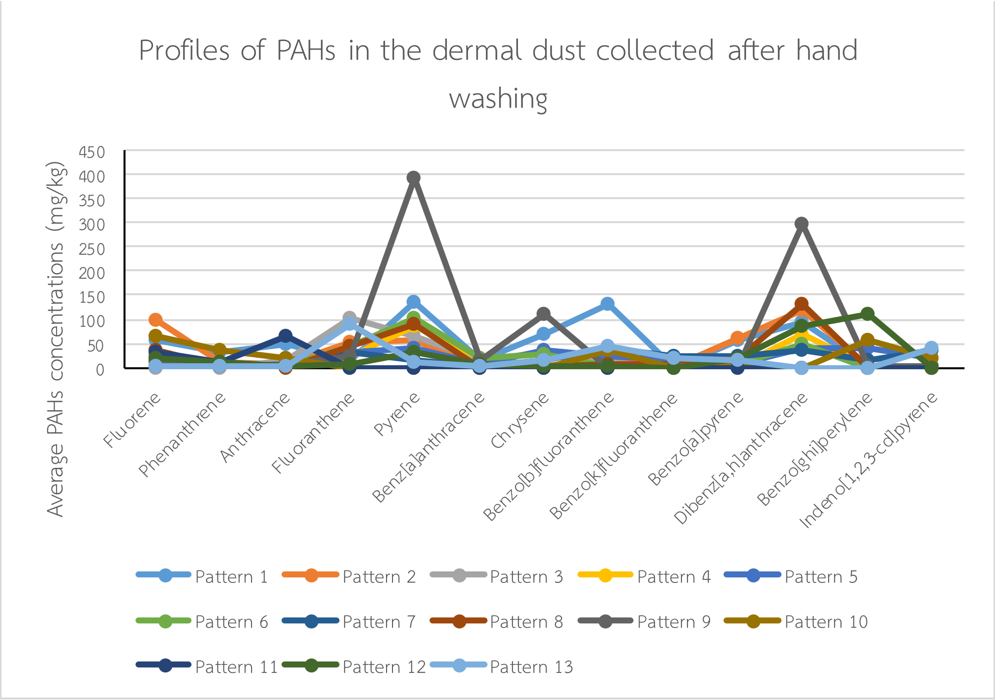


Figure 4.15 Average total PAHs concentrations in the dust after hand washing classified by the pattern of activity

4.7 Health risk assessment of the worker exposed to PAHs via inhalation and dermal adsorption

In order to process the estimation of the probability of adverse health effects in workers who may be exposed to PAHs in contaminated working environment, the human health risk assessment were implemented by following the four steps of framework suggested from United State Environmental Protection Agency (US EPA). Since the limitation of available current data about reference potency values from all types of compounds in PAHs group, in this case BaP equivalence approach were implemented by convert the concentrations of each PAHs to BaP equivalence concentrations using Potency Equivalency Factors (PEFs) with BaP as the index compound.

4.7.1 Health risk assessment via inhalation exposure to PAHs adsorbed on $PM_{2.5\text{-}10}$ and $PM_{2.5}$

The chronic daily intake (CDI) of total BaP equivalent concentrations (t-BaPeq) that were calculated from the concentrations of PAHs adsorbed on $PM_{2.5\text{-}10}$ and $PM_{2.5}$ sampling from the 33 workers who did burning work and had chance to be the inhalation exposure to PAHs at e-waste dismantling site. The results of CDI including the minimum, maximum, and average of t-BaPeq in 95% confidence interval were demonstrated in Table 4.19, which the CDI values of $PM_{2.5\text{-}10}$ ranged from 4.03×10^{-10} to 3.98×10^{-6} mg/kg BW-day with the average CDI of 2.58×10^{-7} mg/kg BW-day (N = 33). For $PM_{2.5}$, the CDI values of $PM_{2.5\text{-}10}$ ranged from 1.55×10^{-9} to 7.50×10^{-6} mg/kg BW-day and the mean CDI was 1.12×10^{-6} mg/kg BW-day (N = 33).

In addition, the minimum, maximum, the average of lifetime cancer risk with 95% confidence interval (95% CI), and % unacceptable risk were summed up in Table 4.20. The life time cancer risk of $PM_{2.5\text{-}10}$ bounded PAHs exposure at 95% confidence interval ranged from 3.44×10^{-7}– 1.98×10^{-5}, and 95% confidence interval cancer risk for PAHs in $PM_{2.5}$ ranged from 2.02×10^{-5} - 6.71×10^{-4}, respectively.

Table 4.19 Chronic daily intake of t-BaPeq for the workers via inhalation route

Types of PM	CDI (mg/kg BW-day)		
	Min	Max	Average
$PM_{2.5-10}$	4.03×10^{-10}	3.98×10^{-6}	2.58×10^{-7}
$PM_{2.5}$	1.55×10^{-9}	7.50×10^{-6}	1.12×10^{-6}

Table 4.20 The lifetime cancer risk of t-BaPeq for the workers via inhalation route

Types of PM	Lifetime cancer risk			95% CI		% Unaccept-able risk
	Min	Max	Average	Lower	Upper	
$PM_{2.5-10}$	1.57×10^{-8}	1.55×10^{-4}	1.01×10^{-5}	3.44×10^{-7}	1.98×10^{-5}	72.73
$PM_{2.5}$	6.03×10^{-8}	2.92×10^{-4}	4.37×10^{-5}	2.02×10^{-5}	6.71×10^{-4}	87.88
Total Inhalation Risk	5.37×10^{-5}	2.93×10^{-4}	5.37×10^{-5}	2.75×10^{-5}	8.00×10^{-5}	90.91

The cancer risks in case of the inhalation exposure to the particle bound PAHs were obviously exceeded the acceptable level of life time cancer risk at 10^{-6} for both of $PM_{2.5-10}$ and $PM_{2.5}$ cases at 72.73 and 87.88 % unacceptable risk, respectively, suggested that the workers who handled e-waste burning work individually had the high opportunity to get adverse health effects from this group of carcinogens that released from the incomplete combustion of the waste. The average lifetime cancer risk posed by $PM_{2.5}$ was greater than those from $PM_{2.5-10}$ for 4.33 times, pointed that the main particulate matter released from the burning processes was fine particles leading to the high concentrations of PAHs adsorbed on the surface of the particles. The total inhalation risk, which was the summation of the cancer risk from both two kinds of PM emitted from combustion of waste varied from 2.75×10^{-5} - 8.00×10^{-5} at 95% confidence interval. The even higher cancer risk and the increased % unacceptable risk indicated the more possibility to pose the severe health consequences to the workers that had to receive both two types of the PM at the same time via their burning activities. Figure 4.16 - 4.18 present the individual lifetime cancer risk of PAHs in each type of particulate matter samples and the total inhalation lifetime cancer risk of PAHs classified by their number of activity pattern, respectively. The activity pattern that received the highest cancer risk of PAHs in coarse particles was pattern number 10th and for fine particles was pattern number 6th, which had the same trends in accordance with the concentrations of both two types of PM and the total PAHs concentrations as the results were discussed previously. At last, the greatest total lifetime cancer risk via inhalation route obtained from pattern of activity number 5th, 6th, and 10th with the values reached the range of 10^{-4}, followed by most of the samples that had the risk in the range of 10^{-5}, while pattern number 1st got the least total inhalation lifetime cancer risk at 10^{-7} level that was considered as under the acceptable safe level.

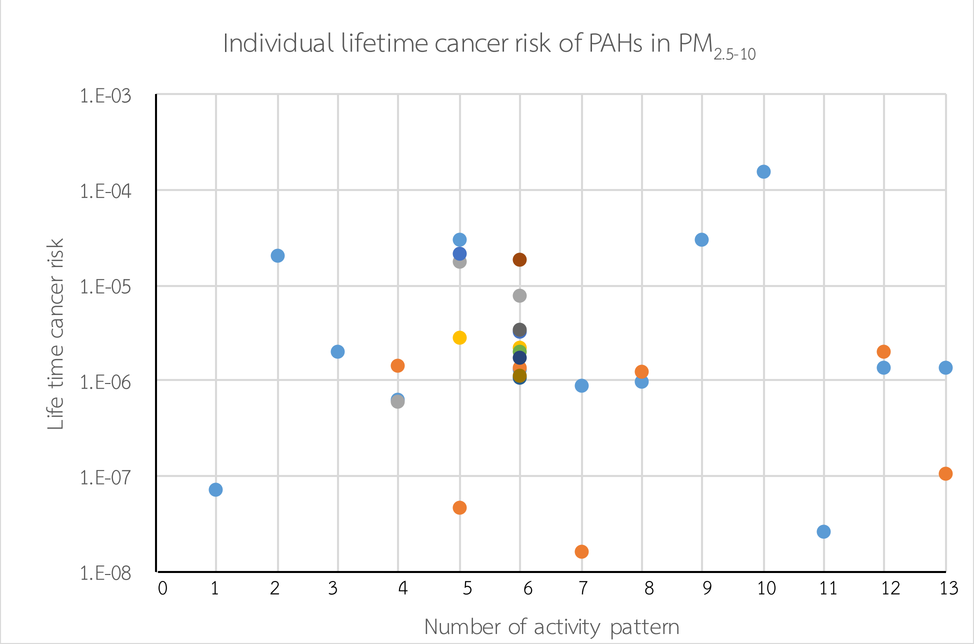


Figure 4.16 Individual lifetime cancer risk of PAHs in $PM_{2.5-10}$ classified by the number of activity pattern

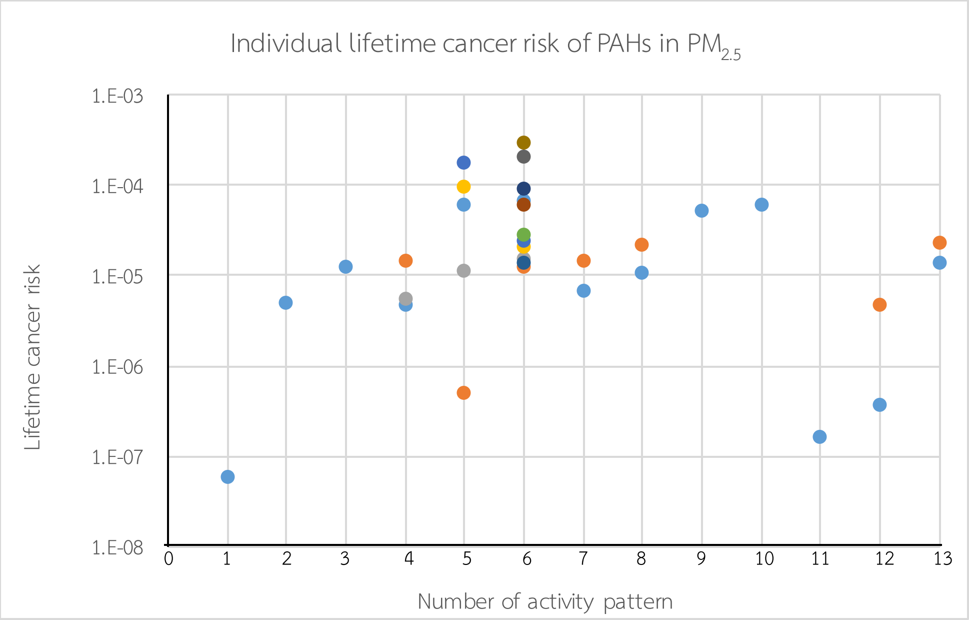


Figure 4.17 Individual lifetime cancer risk of PAHs in $PM_{2.5}$ classified by the number of activity pattern

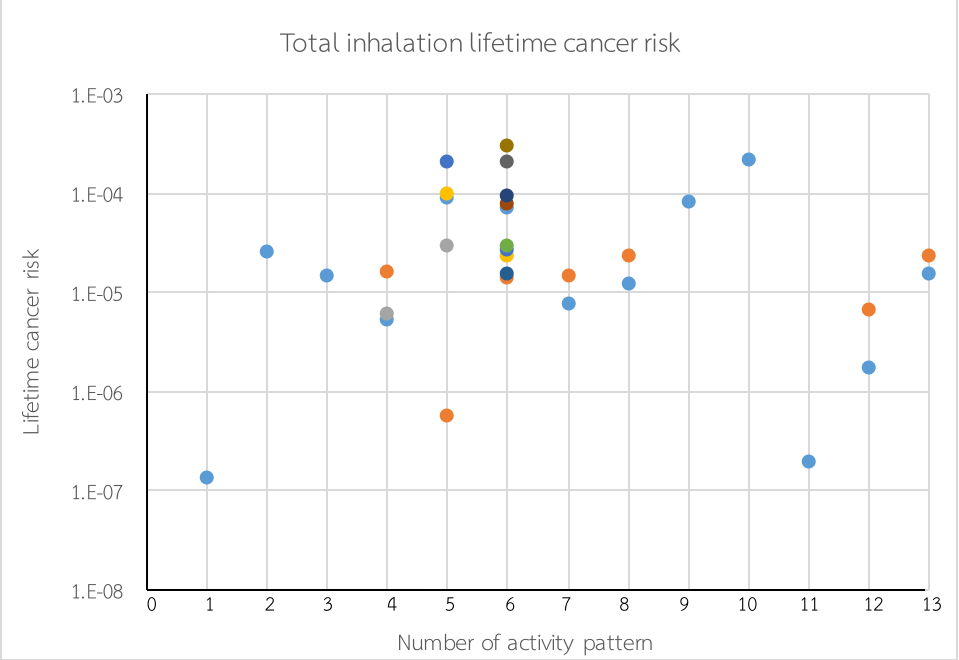


Figure 4.18 Individual total inhalation lifetime cancer risk of PAHs classified by the number of activity pattern

4.7.2 Health risk assessment via dermal exposure to PAHs adsorbed on the dust

The values of chronic daily intake (CDI) of total BaP equivalent concentrations (t-BaPeq) of PAHs adsorbed on the dust collected from the 33 e-waste burning workers were summarized in Table 4.21. The highest average CDI was the CDI calculated from t-BaPeq of the dust after finish burning work, which the values ranged from 4.47×10^{-7} to 3.37×10^{-5} mg/kg BW-day with the average CDI of 8.20×10^{-6} mg/kg BW-day (N = 33). The second highest mean CDI went to the CDI from the dust after hand washing that was 1.26×10^{-6} mg/kg BW-day with the values varied from 2.35×10^{-9} to 5.16×10^{-6} mg/kg BW-day (N = 33). The least mean CDI values was the CDI from the dust before burning work with the minimum CDI 3.04×10^{-10} , maximum CDI 2.66×10^{-7} mg/kg BW-day and the mean CDI 7.89×10^{-8} mg/kg BW-day, respectively (N = 33).

The life time cancer risk had the same trend as the chronic daily intake of the dust exposure. The cancer risk at 95% confidence interval of the workers exposed to PAHs in dermal dust before burning work, after finish burning work, and after hand washing ranged from 1.32×10^{-6}– 2.62×10^{-6}, 1.25×10^{-4} - 2.85×10^{-4}, and 2.07×10^{-5} - 4.22×10^{-5}, respectively. The minimum, maximum, and average of lifetime cancer risk with 95% CI, and % unacceptable risk were summed up in Table 4.22.

Table 4.21 Chronic daily intake of t-BaPeq for the workers via dermal route

Types of dust	CDI (mg/kg BW-day)		
	Min	Max	Average
Before burning work	3.04×10^{-10}	2.66×10^{-7}	7.89×10^{-8}
After finish burning work	4.47×10^{-7}	3.37×10^{-5}	8.20×10^{-6}
After hand washing	2.35×10^{-9}	5.16×10^{-6}	1.26×10^{-6}

Table 4.22 The lifetime cancer risk of t-BaPeq for the workers via dermal route

Types of dust	Lifetime cancer risk			95% CI		% Unaccept-able risk
	Min	Max	Average	Lower	Upper	
Before burning work	7.60×10^{-9}	6.66×10^{-6}	1.97×10^{-6}	1.32×10^{-6}	2.62×10^{-6}	60.61
After finish burning work	1.12×10^{-5}	8.43×10^{-4}	2.05×10^{-4}	1.25×10^{-4}	2.85×10^{-4}	100
After hand washing	5.88×10^{-8}	1.29×10^{-4}	3.14×10^{-5}	2.07×10^{-5}	4.22×10^{-5}	90.91

The results of cancer risk from the dermal contact of PAHs on the dust after burning work ranked the highest mean value and exceed the acceptable level of life time cancer risk (10^{-6}) for 205 times in all samples. The samples of the dust before burning work, which represent the background concentrations of PAHs on the surface of workers' hands, which accumulated from their daily life activities and the living environment. The results might reflect that their usual life style and their living places permitted to the sinking of the PAHs through their body skin, since all of the workers in this study had the e-waste dismantling work places in their residential areas and spent most of the time in the working sites. The washing of hands after work could reduce the average life time cancer risk of PAHs adsorbed on the dust during burning work for 6.25 folds. However, the residue PAHs concentrations were still higher than an acceptable level for the risk of cancer. The water and the sinking species of PAHs in their household might be the related source of PAHs that generated the significant lifetime cancer risk, and were suggested to be investigated in the further study. Figure 4.19 demonstrates the ranges of individual lifetime cancer risk of PAHs adsorbed on each type of dust from workers' hands at 95% CI, which also confirmed that the dermal dust exposure after e-waste burning work generated the highest level of lifetime cancer risk in this study. The washing of hand could reduce a part of risk after working for around ten times but still showed the amount of risk that exceeded acceptable level, so it was necessary for the workers to concern and have awareness to always wash the hands after finished e-waste burning work. The risk from background dust also in the range that higher than the acceptable level; therefore, the sinking and accumulation of PAHs in workers' residential areas should be concerned and monitored for further study.

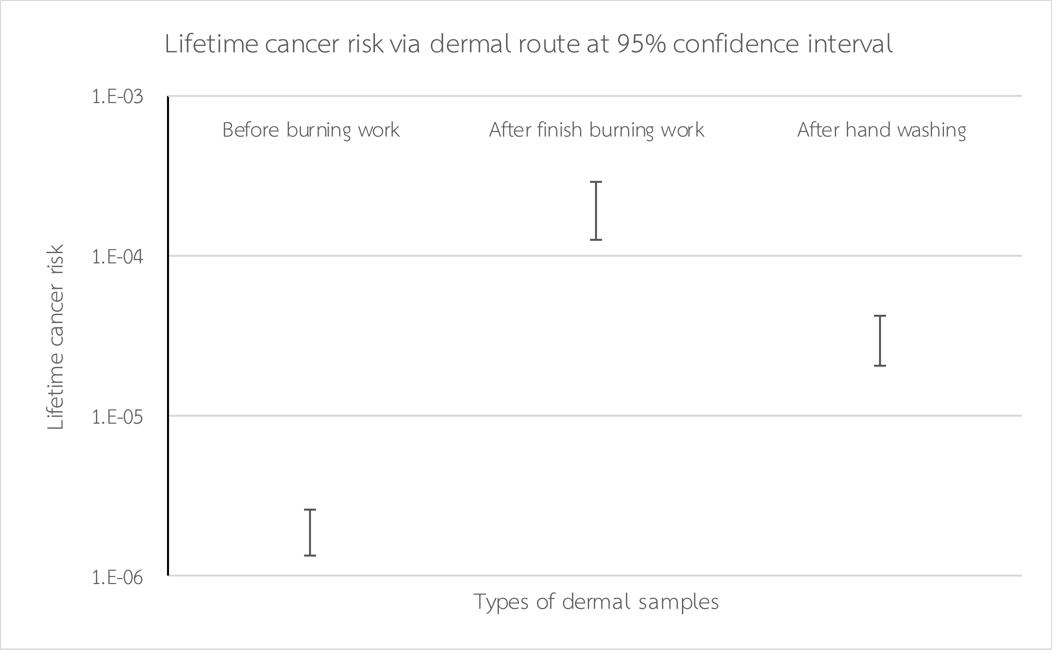


Figure 4.19 Ranges of individual lifetime cancer risk of PAHs from each type of dermal dust at 95% confidence interval

Focusing on the individual lifetime cancer risk of PAHs in the dermal dust after finish working and their related activity pattern, according to Figure 4.20 that sums up the lifetime cancer risk of PAHs in the dust after working classified by the number of activity pattern, the highest lifetime cancer risk belonged to the patterns of burning activity number 4th, 5th, 6th, and 13th. Correspondingly with the masses of dust and total PAHs concentrations, the activity that consisted of the most variety and high percentage of overall burning procedure like activity number 13th induced the workers to move and use their hands in various way more than some other patterns that had the certain two types of similar activities, so the greater chance to expose the PAHs bound on the dust and receive the risk was created. The activity that had high proportion of fire mixing process such as activity number 4th, 5th, and 6th also gained the high level of lifetime cancer risk, which might be the effect from the small size particles that emitted from fire mixing process related to the better ability to adsorbed

PAHs, as discussed in topic 4.5. The higher exposure concentrations of PAHs, the larger opportunity to obtain the risk. Furthermore, the group of workers who received this highest level of risk were those who did not use personal protective equipment during work, so it could create the larger chance for the chemical-contained dust to adsorb on the surface of worker hands and also leaded to the higher opportunity of the PAHs dermal exposure followed by the higher lifetime cancer risk to acquired.

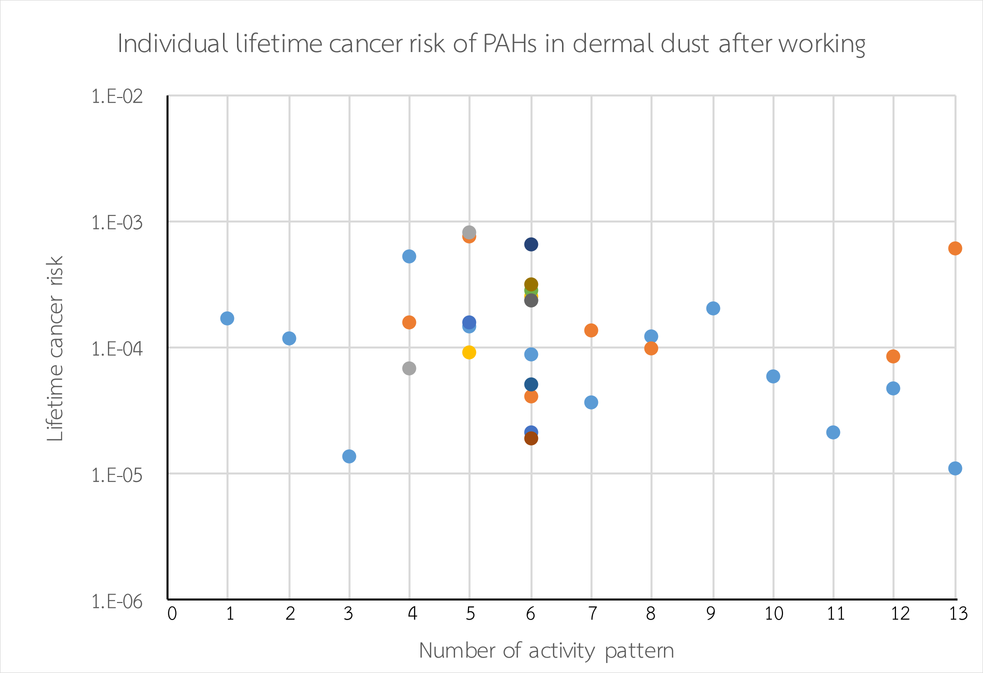


Figure 4.20 Individual lifetime cancer risk of PAHs in the dermal dust after working classified by the number of activity pattern

4.7.3 Multi route of exposure lifetime cancer risk of particle bound PAHs

The values of multi route life time cancer risk in this study came from the combination of inhalation life time cancer risk and dermal life time cancer risk obtained from the e-waste burning workers. The total inhalation cancer risk which was the summation of cancer risk of PAHs from $PM_{2.5-10}$ and $PM_{2.5}$ and the cancer risk of PAHs from the dust after burning work were summed up to calculate the risk of cancer from the multi route of exposure. The multi route cancer risk at 95% confidence interval of the workers exposed to PAHs in this study ranged from 1.74×10^{-4} to 3.74×10^{-4} with the average concentration at 2.59 x 10^{-4}. The minimum, maximum, average of lifetime cancer risk with 95% CI, and % unacceptable risk were shown in Table 4.23.

Table 4.23 The lifetime cancer risk of t-BaPeq for the workers via each route of exposure

Route of exposure	Lifetime cancer risk			95% CI		% Unacceptable risk
	Min	Max	Average	Lower	Upper	
Inhalation	5.37 x 10^{-5}	2.93 x 10^{-4}	5.37 x 10^{-5}	2.75 x 10^{-5}	8.00 x 10^{-5}	90.91
Dermal	1.12 x 10^{-5}	8.43 x 10^{-4}	2.05 x 10^{-4}	1.25 x 10^{-4}	2.85 x 10^{-4}	100
Multi (Inhalation + Dermal)	2.20 x 10^{-5}	8.71 x 10^{-4}	2.59 x 10^{-4}	1.74 x 10^{-4}	3.74 x 10^{-4}	100

The results of multi route life time cancer risk in this study were distinctively higher than the acceptable level of cancer risk for 259 times, which clearly indicated to the large possibility of the severe detrimental health burdens posed to the workers who took responsible for burning work of e-waste. Comparing with other study, Huang et al. (2018) evaluated the potential health risk to remote rural populations from the combustion of biomass fuels that suspected to generates abundant polycyclic aromatic hydrocarbons (PAHs) in Tibet, China, which was the place that known to have highly use of biomass fuel, the significant source of PAHs. The median incremental lifetime cancer risk from inhalation and dermal contact combined was 2.4 × 10^{-6} (95% confidence interval: 0.02–12 × 10^{-6}). The results from this study was obviously higher than the previous one for approximately 90 folds, which reflected the large opportunity of the workers to receive the risk of cancer from the severe polluted of PAHs via the working processes of the e-waste burning within the short period of time.

To reduce the risk of cancer from particle bound PAHs exposure via burning activities, the high efficiency of personal protective equipment must be used to decrease the chance of taking in contact with PAHs emitted from burning work. The risk communication is importantly should be applied to inform the potential hazard of

PAHs and other toxic substances that may cause harmful effects on the workers' health. Also the correct procedure to wear the personal protective equipment would be advised via the risk communication activities to enhance the highest protection to the workers. The further implementation of management control and policy is needed to guard against the long term health burdens from the accumulation of PAHs within all of the workers, residential people and environment.

4.7.4 Uncertainty factors in this study

Regarding to the research hypothesis number 1, this thesis was hypothesized that open burning of e-waste might emit PAHs absorbed on particulate matter higher than those absorbed in the dust, which leads to the higher exposure level of PAHs via inhalation route than dermal route. However, the real obtained results showed the inverse outcome, which possibly resulted from the error from uncertainty factors and limitations occurred in this research. The uncertainty factors could be divided into the uncertainties that cause under estimation and uncertainty that cause over estimation, which were discussed as follows.

1. Uncertainty factors that cause under estimation
    1.1 Personal inhalation exposure
    - The impact of wind that dispersed the fume of smoke away from the direction where workers proceeded burning activity
    - The workers moved out of the burning area to keep away from the smoke or to do other activities that were not related to burning work.

    1.2 Personal dermal exposure
    - The use of additional equipment to help moving or picking up the waste instead of using hand directly, which leaded to reduce the exposure level between hands and the waste
2. Uncertainty factors that cause over estimation
    2.1 Personal inhalation exposure
    - The accumulation of suspended particulate matter in landfill area from e-waste burning of other workers that were not the

participants in this research but had to do burning work in the same specified day announced by local authorities.

- The selection of burning location in landfill that was located lower than other area and surrounded by tree leading to the lower dispersion of the smoke the more efficiency to trap the fume of waste in burning area

2.2 Personal dermal exposure

- The accumulation of dust and PAHs from reusing of old gloves
- The adsorption of dust from other sources such as from workers' residential areas that had dismantling site combined together
- The accumulation of PAHs from other sources, including from water supply, from reused clothing and equipment, and from the background concentrations in workers' skin

The results in this study inclined to be more overestimation than underestimation, especially for dermal personal exposure because of the more limitation from complicated and uncontrollable factors such as personal behavior, and the contaminated exposure concentrations from other media sources. This research also had study limitation that probable caused the bias and error in results, which could be divided into three topics, including

1. Observational bias, the recorded data during sampling came from researcher personal observation; thus, it could cause the inaccurate information from the personal estimation for the descriptive data that were unable to measure by any equipment, especially the pattern of activity that had much variety and complexity,
2. Selection bias, due to the very specific group of interested participants and the limitation of time, the groups of workers in this study came from the same dismantling sites in the study area. The participants could not be highly selective and the selection was unable to cover all of the burning sites in the provincial scale, so the details and difference among burning activity might not fully showed up.
3. Information bias the information bias came from the error occurred from face to face interview and questionnaire results. The questions that workers had to

answer were not in their daily life communication, so it could cause the unsure and misunderstanding while replied.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research aimed to study about the emission of PAHs from the open burning of e-waste in Buriram province, Thailand and to estimate the lifetime cancer risk of polycyclic aromatic hydrocarbons (PAHs) that probably occurs to the workers in the e-waste dismantling site from both of inhalation and dermal exposure. The personal inhalation and dermal exposure samples were collected at the e-waste dismantling site in Daeng Yai subdistrict (located in Ban Mai Chaiyaphot district, Buriram province, Thailand) during February to August, 2017, which all the obtained results could be summarized as follows:

5.1.1 Conclusions of inhalation PM concentrations

1. The concentrations of $PM_{2.5-10}$ ranged from 0.0679 to 2.2851 mg/m^3 with the average concentration of 0.4417 mg/m^3 (N = 33). For $PM_{2.5}$, the concentrations ranged from 0.1442 to 17.4300 mg/m^3 and the mean concentration was 2.7736 mg/m^3 (N = 33). The concentrations of PM_{10}, which were the summation of $PM_{2.5}$ and $PM_{2.5-10}$ concentrations, ranged from 0.2321 to 18.3606 mg/m^3 with the average concentration 3.2154 mg/m^3 (N=33).
2. There was the strong positive relationship between $PM_{2.5}$ and PM_{10} mass concentrations at 99% confidence interval ($r=0.995$, $p<0.01$), and the average $PM_{2.5}$ mass concentrations accounted for 74.93 ± 17.94% from PM_{10} mass concentrations.
3. The correlation between quantity of burnt e-waste and the concentrations of $PM_{2.5-10}$ analyzed by Pearson correlation suggested the positive correlation ($r=0.393$, $p<0.05$) between 2 factors above. The same correlation also showed in the $PM_{2.5}$ concentrations, the Pearson correlation between quantity of burnt e-waste and the concentrations of $PM_{2.5}$ had the positive relationship ($r=0.627$, $p<0.01$).
4. The Pearson's correlation showed the positive relationship at 90% confidence interval between $PM_{2.5}$ concentrations and their own total scores of activity patterns that were weight the highest score to fire mixing process followed by sweeping process, pounding, and compiling of the waste, respectively ($r=0.305$, $p<0.10$).
5. $PM_{2.5-10}$ mass concentrations also had the positive correlation with their own total scores of activity patterns that were weight the highest score to the order

of compiling process followed by pounding, sweeping, and fire mixing to the pile of waste at 95% confidence interval ($r=0.397$, $p<0.05$).

5.1.2 Conclusions of dermal dust masses

1. The masses of particulate matter before burning work ranged from 0.00292 - 0.05206 g with the average weight at 0.02011 g (N = 33). For the masses of dust collected after finish burning work, the weight varied from 0.00974 – 0.18540 g, which 0.05923 g was the mean gravimetric mass (N = 33). The masses of dust after hand washing when the work finished varied from 0.00122 – 0.05170 g with the average mass at 0.01569 g (N = 33).
2. The mean gravimetric mass of dust after finish burning work was significantly higher than both of the mean gravimetric mass of dust before burning work and after hand washing at 99% confidence interval ($p<0.01$).
3. The impact of burning activity patterns and the use of personal protective equipment on the gravimetric masses of dermal particulate matter were verified by Pearson's correlation. The obtained results showed the strong positive relationship at 99% confidence interval between the quantity of dust and the total final scores, which were the combination of activity patterns and the use of personal protective equipment ($r=0.562$, $p<0.01$).

5.1.3 Conclusions of inhalation and dermal polycyclic aromatic hydrocarbon concentrations

1. The total concentrations of PAHs on $PM_{2.5-10}$ particles ranged from 0.0703 to 20.9800 $\mu g/m^3$, and the average total concentration was 2.9467 $\mu g/m^3$. For $PM_{2.5}$, the total concentrations of PAHs adsorbed on the particles varied from 0.2669 to 89.9645 $\mu g/m^3$, and the mean concentration was 16.6224 $\mu g/m^3$.
2. The Pearson's correlation analysis revealed the significant relationship between the concentrations of total 13 PAHs on both two types of particulate matter and their own score of activity patterns considerable as source of particle mass concentrations. The individual total concentrations of PAHs on $PM_{2.5-10}$ as same as $PM_{2.5}$ had the positive correlation with their score of activity patterns at 90 % confidence interval ($PM_{2.5-10}$: $r=0.321$, $p<0.10$ and $PM_{2.5}$: $r=0.333$, $p<0.10$).
3. The Pearson's correlation analysis also confirmed the positive relationship between the concentrations of both $PM_{2.5-10}$ and $PM_{2.5}$ and their exposure

concentrations of total 13 PAHs adsorbed on the particles ($PM_{2.5-10}$: r=0.852, p<0.01 and $PM_{2.5}$: r=0.968, p<0.01).

4. According to the distribution of each species of PAHs based on the total concentrations in $PM_{2.5-10}$ and $PM_{2.5}$, the dominant species of PAHs bound on $PM_{2.5-10}$ in this study were Pyrene, Benzo(k)fluoranthene, Dibenz(a,h)anthracene, Chrysene, and Benzo(g,h,i)perylene. Similarly, the major compounds found in the $PM_{2.5}$ samples were Fluoranthene, Pyrene, Dibenz(a,h)anthracene, and Benzo(g,h,i)perylene,

5. In the dermal dust samples, the total concentrations of 13 PAHs on the particles before burning work ranged from 8.1072 to 253.6118 mg/kg with the average concentration at 95.3894 mg/kg. For the samples of dust after finish burning work, the total concentrations of PAHs adsorbed on the particles varied from 117.5432 to 4,315.9496 mg/kg and the mean concentration was 1,187.9897 mg/kg. Also, the average concentration of 13 PAHs on the dust after hand washing was 309.9614 mg/kg and the range of values varied from 109.1063 to 876.9778 mg/kg.

6. For the samples of dust after finish burning work, the total concentrations of PAHs had significant relationship with their amount of dust at 99% confidence interval (r=0.832, p<0.01) and also had the strong positive relationship with their own activity scores weighted with the use of personal protective equipment at 99% confidence interval (r=0.611, p<0.01).

7. The major species of PAHs found in the dust before burning work were Benzo[k]fluoranthene, while in the dust after burning work, the main type of PAHs detected in samples was Dibenz(a,h)anthracene followed by Pyrene, which were similar to the dominant PAHs species found in inhalation samples. Dibenz(a,h)anthracene and Pyrene also contributed the highest concentrations in the dust after hand washing samples correspondingly with the PAHs after working.

5.1.4 Conclusions of inhalation and dermal risk assessment

1. The life time cancer risk of $PM_{2.5-10}$ bounded PAHs exposure at 95% confidence interval ranged from 3.44×10^{-7}– 1.98×10^{-5}, and 95% confidence interval cancer risk for PAHs in $PM_{2.5}$ ranged from 2.02×10^{-5} - 6.71×10^{-4}, respectively.

2. The total inhalation lifetime cancer risk, which was the summation of inhalation life time cancer risk from PAHs bound on both two types of particulate matter, at 95% confidence interval ranged from 2.75×10^{-5} to 8.00×10^{-5} with 90.91% unacceptable risk.

3. The lifetime cancer risk at 95% confidence interval of the workers exposed to PAHs in dermal dust before burning work, after finish burning work, and

after hand washing ranged from 1.32×10^{-6}– 2.62×10^{-6}, 1.25×10^{-4} - 2.85×10^{-4}, and 2.07×10^{-5} - 4.22×10^{-5}, respectively.

4. The multi route cancer risk, which was the combination of total inhalation life time cancer risk and dermal life time cancer risk after finish burning work, at 95% confidence interval ranged from 1.74×10^{-4} to 3.74×10^{-4} with 100% unacceptable risk.

5.2 Recommendations and suggestions

5.2.1 Research recommendations

1. Due to the high level of unacceptable risk, the study area should be extended to another e-waste dismantling sites in provincial scale and national scale, in order to estimate and compare the health risk among the burning workers and to set the plan to protect against the detrimental health consequences and also to control the pollution emitted into the environment.
2. The concentrations of PAHs and other toxic substances in e-waste accumulated within biomarkers in workers' body and another environmental media in the e-waste dismantling sites should be investigated and also find the further reduction plan.
3. The risk communication is necessarily to be implemented to inform the potential hazard of PAHs and other toxic substances that may cause harmful effects on the workers' health and the correct procedure to wear the personal protective equipment to decrease the chance of taking in contact with PAHs emitted from burning work would be advised via the risk communication activities to enhance the highest protection to the workers.

5.2.2 Participant recommendations

1. In order to reduce exposure time, the workers should avoid being covered or close to the fume of e-waste burning smoke and try to use the supportive equipment such as wood sticks and brooms to help collecting and sweeping the waste instead of using the hands directly.
2. The burning workers are necessary to wear the appropriate types of personal protective equipment both for inhalation and dermal exposure protection. The mask must be the type that can filtrate $PM_{2.5}$, for example KN95 and N95 masks, and the gloves are recommended to be rubber cleaning gloves or double layers of sanitary hand gloves, regarding to the results in this study.

3. After finish burning work, workers need to always wash the hands, in order to decrease the contamination and risk from e-waste burning activity, and soap is suggested to be the detergent that workers should use, due to the highest performance in reducing the concentrations of PAHs found in this research.

4. The workers are advised to avoid reusing the gloves. Furthermore, the clothing and also other equipment that have been used in burning work should be cleaned and sun dried.

5.2.3 Policy recommendations

1. The further implementation of management plan and environmental control policy set from research data are required, in order to protect the workers, residential people and environment against the toxicity and effects from the accumulation of PAHs and other hazardous substances released from e-waste dismantling activities.

2. The local government should present the alternative way for workers to reduce e-waste open burning activity, for example providing electrical wire peeling machine to separate the copper from the wire by mechanical process instead of using burning method.

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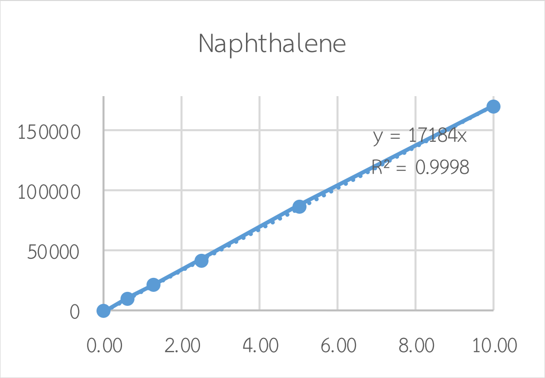
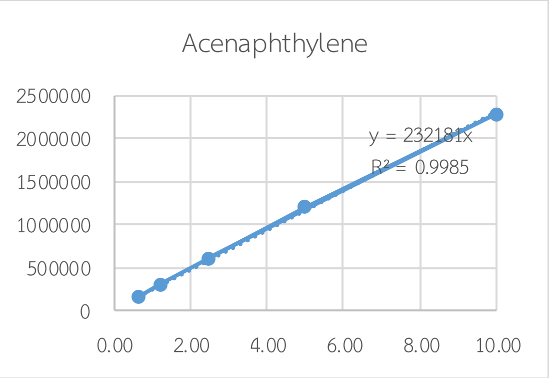
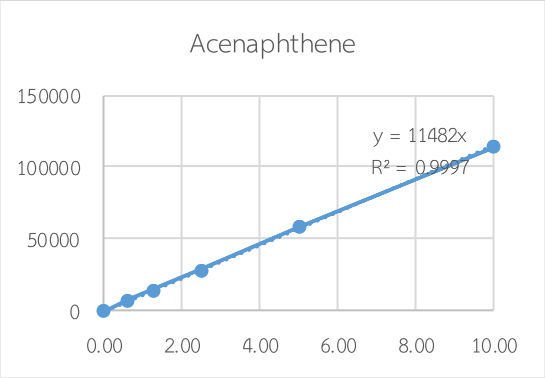
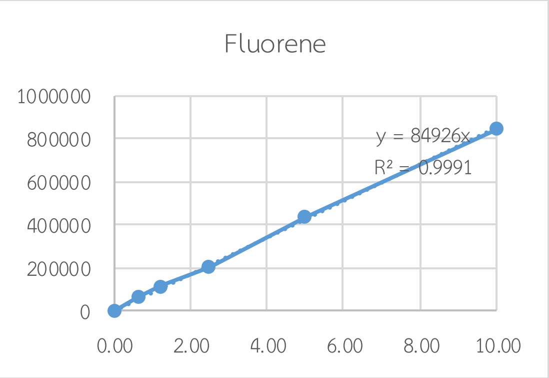
APPENDIX A

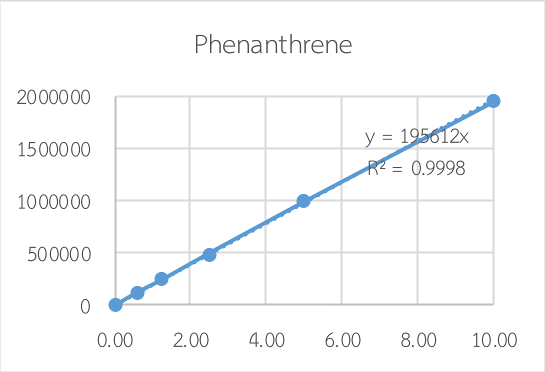
GRAPH PLOTTED OF STANDARD CALIBRATION CURVES

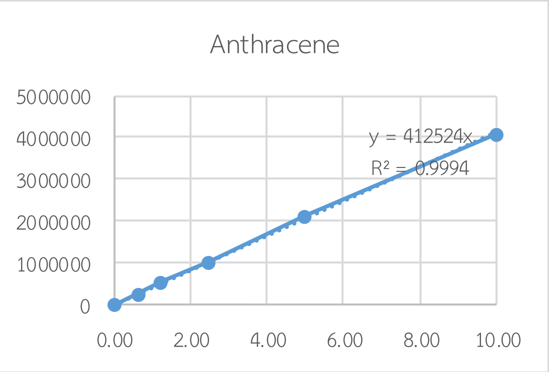


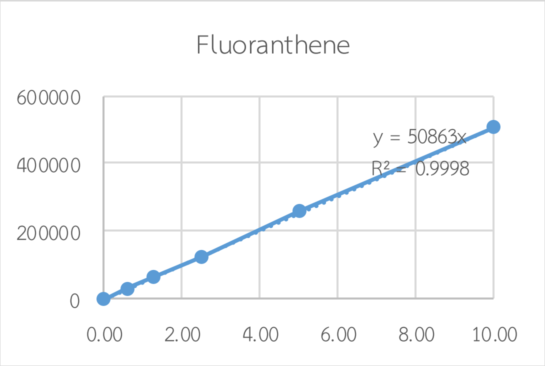


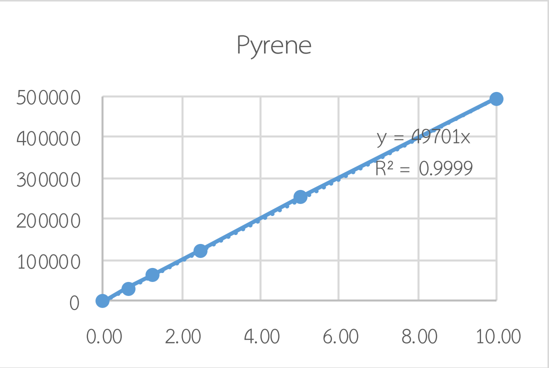


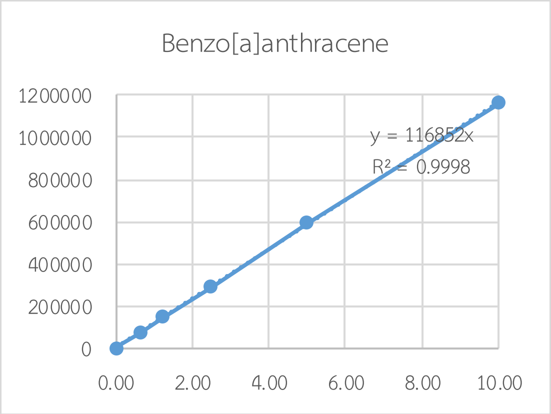


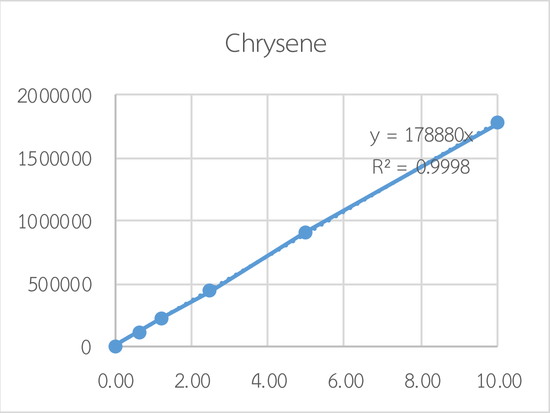









Benzo[a]anthracene
1200000
1000000
800000
600000
400000
200000
0
0.00
2.00
4.00
6.00
8.00
10.00
y = 116852x
R² = 0.9998


Chrysene
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0.00
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4.00
6.00
8.00
10.00
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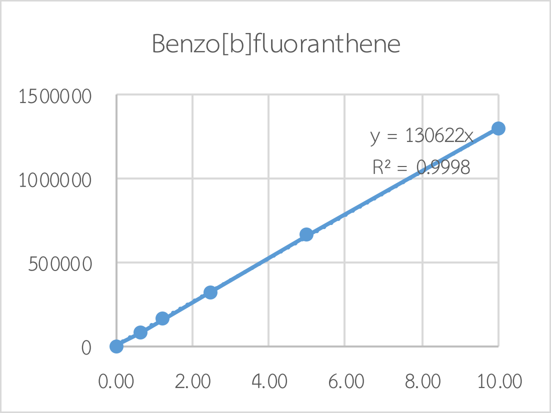
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8.00
10.00
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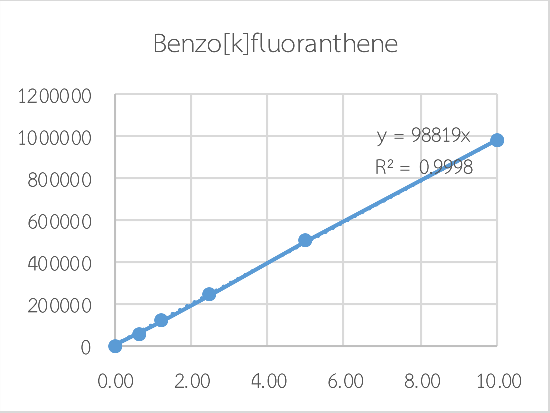
Benzo[k]fluoranthene
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800000
600000
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2.00
4.00
6.00
8.00
10.00
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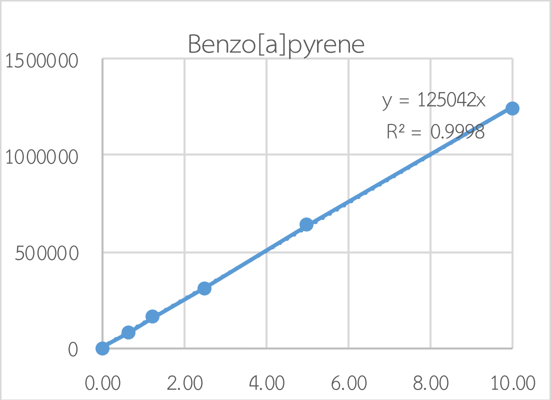
R² = 0.9998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4.00
6.00
8.00
10.00
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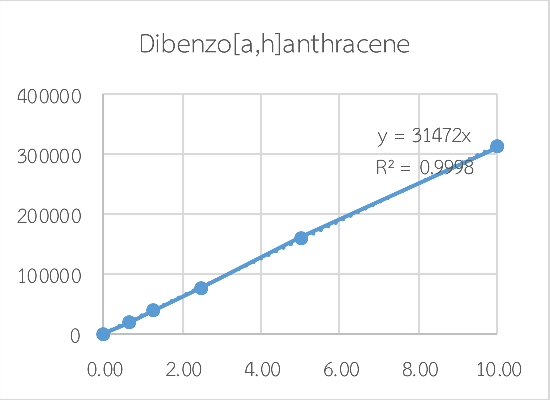
Dibenzo[a,h]anthracene
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300000
200000
100000
0
0.00
2.00
4.00
6.00
8.00
10.00
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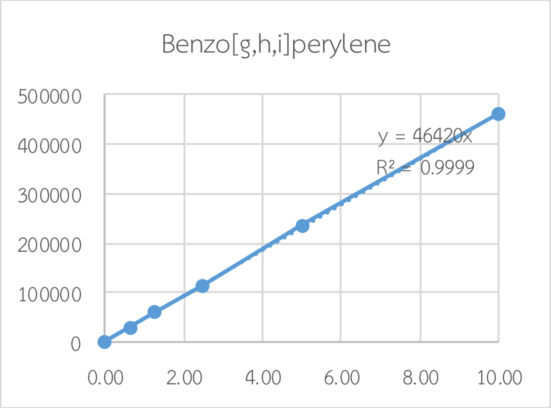
R² = 0.9998


Benzo[g,h,i]perylene
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6.00
8.00
10.00
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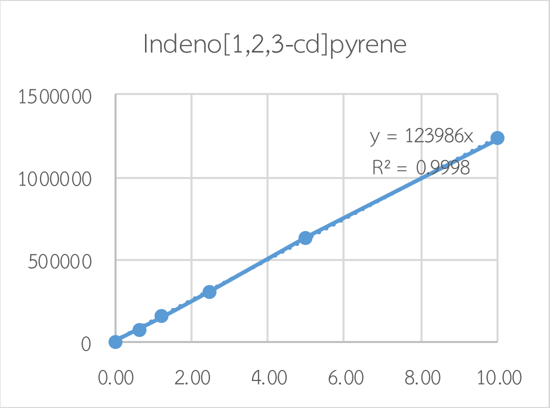
R² = 0.9999


Indeno[1,2,3-cd]pyrene
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0.00
2.00
4.00
6.00
8.00
10.00
y = 123986x
R² = 0.9998

APPENDIX B

STATISTICAL RESULTS FROM SPSS PROGRAM

1. Statistical analysis for exposure concentration of particulate matter of the workers via inhalation

Correlations

		PM2.5	PM10
PM2.5	Pearson Correlation	1	.995**
	Sig. (2-tailed)		.000
	N	33	33
PM10	Pearson Correlation	.995**	1
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		PM2.5_10	amount_of_waste
PM2.5_10	Pearson Correlation	1	.393*
	Sig. (2-tailed)		.024
	N	33	33
amount_of_waste	Pearson Correlation	.393*	1
	Sig. (2-tailed)	.024	
	N	33	33

*. Correlation is significant at the 0.05 level (2-tailed).

Correlations

		PM2.5	amount_of_waste
PM2.5	Pearson Correlation	1	.627**
	Sig. (2-tailed)		.000
	N	33	33
amount_of_waste	Pearson Correlation	.627**	1
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		PM2.5	score_PM2.5
PM2.5	Pearson Correlation	1	.305*
	Sig. (2-tailed)		.084
	N	33	33
score_PM2.5	Pearson Correlation	.305	1
	Sig. (2-tailed)	.084	
	N	33	33

*. Correlation is significant at the 0.10 level (2-tailed).

Correlations

		PM2.5_10	score_PM2.5_10
PM2.5_10	Pearson Correlation	1	.397*
	Sig. (2-tailed)		.022
	N	33	33
score_PM2.5_10	Pearson Correlation	.397*	1
	Sig. (2-tailed)	.022	
	N	33	33

*. Correlation is significant at the 0.05 level (2-tailed).

2. Statistical analysis for amount of dust adsorbed on the workers' hands

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	dust_after_work - dust_before_work	4.591	32	.000
Pair 2	dust_after_work - dust_after_handwashing	5.707	32	.000

Correlations

		dust_after_work	PPE_activity_total_score
dust_after_work	Pearson Correlation	1	.562**
	Sig. (2-tailed)		.001
	N	33	33
PPE_activity_total_score	Pearson Correlation	.562**	1
	Sig. (2-tailed)	.001	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

3. Statistical analysis for exposure concentration of polycyclic aromatic hydrocarbons of the workers via inhalation route

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	TPAHs_PM2.5 - TPAHs_PM2.5_10	3.432	32	.002

Correlations

		TPAHs_PM2.5_10	score_PM2.5_10
TPAHs_PM2.5_10	Pearson Correlation	1	.321*
	Sig. (2-tailed)		.069
	N	33	33
score_PM2.5_10	Pearson Correlation	.321	1
	Sig. (2-tailed)	.069	
	N	33	33

*. Correlation is significant at the 0.10 level (2-tailed).

Correlations

		TPAHs_PM2.5	score_PM2.5
TPAHs_PM2.5	Pearson Correlation	1	.333*
	Sig. (2-tailed)		.059
	N	33	33
score_PM2.5	Pearson Correlation	.333	1
	Sig. (2-tailed)	.059	
	N	33	33

*. Correlation is significant at the 0.10 level (2-tailed).

Correlations

		PM2.5_10	TPAHs_PM2.5_10
PM2.5_10	Pearson Correlation	1	.852**
	Sig. (2-tailed)		.000
	N	33	33
TPAHs_PM2.5_10	Pearson Correlation	.852**	1
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		PM2.5	TPAHs_PM2.5
PM2.5	Pearson Correlation	1	.968**
	Sig. (2-tailed)		.000
	N	33	33
TPAHs_PM2.5	Pearson Correlation	.968**	1
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

4. Statistical analysis for exposure concentration of polycyclic aromatic hydrocarbons of the workers via dermal route

Correlations

		dust_after_work	TPAHs_dust_after_work
dust_after_work	Pearson Correlation	1	.832**
	Sig. (2-tailed)		.000
	N	33	33
TPAHs_dust_after_work	Pearson Correlation	.832**	1
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Correlations

		TPAHs_dust_after_work	PPE_activity_total_score
TPAHs_dust_after_work	Pearson Correlation	1	.611**
	Sig. (2-tailed)		.000
	N	33	33
PPE_activity_total_score	Pearson Correlation	.611**	1
	Sig. (2-tailed)	.000	
	N	33	33

**. Correlation is significant at the 0.01 level (2-tailed).

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	TPAHs_dust_after_work - TPAHs_after_hand_washing	5.219	32	.000

APPENDIX C

TABLES OF RESULT SUMMARY

Table C1 Meteorological data during sampling

Sampling date	Worker no.	Temperature (° C)	Pressure (mmHg)	Humidity (%)	Wind speed (mph)
23 February 2017	1-2	32	759.46	56	5
24 February 2017	3-4	34	759.46	60	5
26 February 2017	6-7	25	762	76	10
16 March 2017	8-9	26	756.92	68	2
19 March 2017	10-13	29	759.46	70	4
20 April 2017	14-17	29	756.92	87	8
23 April 2017	18-21	28	756.92	75	1
11 June 2017	22-25	27	756.92	74	7
19 July 2017	26-29	28	756.92	77	10
1 August 2017	30-33	29	754.38	77	11

Table C2 Particulate matter raw masses and related sampling data

Worker No.	Avg flow rate (m^3/min)	Avg sampling time (min)	volume of air (m^3)	$PM_{2.5-10}$			$PM_{2.5}$		
				Filter masses before sampling (mg)	Filter masses after sampling (mg)	$PM_{2.5-10}$ masses (mg)	Filter masses before sampling (mg)	Filter masses after sampling (mg)	$PM_{2.5}$ masses (mg)
1	0.003026	106	0.3208	26.6893	26.7739	0.0845	180.9916	181.2472	0.2555
2	0.003004	106	0.3184	25.5743	25.6294	0.0551	183.1774	183.3843	0.2069
3	0.003022	56	0.1692	25.4306	25.5546	0.1240	193.0558	193.0928	0.0370
4	0.003006	53	0.1593	24.4682	24.5773	0.1091	172.7322	172.9707	0.2386
5	0.003035	55	0.1669	25.2394	25.2697	0.0303	158.4493	158.6712	0.2219
6	0.002989	101	0.3019	26.2336	26.2641	0.0305	173.4656	173.5340	0.0683
7	0.003005	98	0.2945	25.9035	25.9440	0.0405	223.9459	224.0184	0.0726
8	0.002996	73	0.2187	26.2485	26.3311	0.0826	224.3088	224.3996	0.0908
9	0.002991	70	0.2093	26.0170	26.0529	0.0359	227.1242	227.3195	0.1953
10	0.002987	98	0.2927	26.5869	26.6126	0.0257	234.9116	234.9538	0.0422
11	0.002989	103	0.3078	26.1448	26.2174	0.0725	219.2064	219.5239	0.3175
12	0.002945	103	0.3033	25.9107	25.9313	0.0206	235.0492	235.2514	0.2023
13	0.002980	96	0.2861	27.3935	27.4175	0.0240	226.7931	226.9176	0.1245

Worker No.	Avg flow rate (m^3/min)	Avg sampling time (min)	volume of air (m^3)	$PM_{2.5-10}$			$PM_{2.5}$		
				Filter masses before sampling (mg)	Filter masses after sampling (mg)	$PM_{2.5-10}$ masses (mg)	Filter masses before sampling (mg)	Filter masses after sampling (mg)	$PM_{2.5}$ masses (mg)
14	0.003019	126	0.3804	26.7306	26.7782	0.0476	221.7326	222.0905	0.3579
15	0.003013	126	0.3796	26.6189	26.6700	0.0511	220.9474	221.2117	0.2643
16	0.003020	121	0.3654	26.0614	26.1002	0.0388	221.0815	221.2452	0.1637
17	0.002970	121	0.3593	26.4166	26.4532	0.0366	217.4939	217.6314	0.1375
18	0.003014	94	0.2833	25.8483	26.0017	0.1534	215.5423	215.7861	0.2438
19	0.003021	87	0.2628	25.6340	26.2345	0.6005	204.0032	204.3367	0.3334
20	0.002993	88	0.2633	26.5104	26.6424	0.1320	218.0100	218.4334	0.4233
21	0.003017	87	0.2625	25.6846	26.1931	0.5085	185.0035	185.3072	0.3037
22	0.002957	87	0.2573	26.8959	26.9987	0.1028	194.0225	194.2162	0.1937
23	0.003020	87	0.2627	26.9621	27.0483	0.0862	196.5667	196.7038	0.1371
24	0.002954	79	0.2333	26.7432	26.7608	0.0176	182.2447	182.3067	0.0620
25	0.003026	86	0.2603	26.7867	26.8248	0.0381	197.1102	197.2998	0.1897
26	0.003040	75	0.2280	26.0075	26.0703	0.0628	202.0125	202.1840	0.1715
27	0.003036	73	0.2216	26.0610	26.1254	0.0644	235.6948	236.0061	0.3113

Worker No.	Avg flow rate (m^3/min)	Avg sampling time (min)	volume of air (m^3)	$PM_{2.5-10}$			$PM_{2.5}$		
				Filter masses before sampling (mg)	Filter masses after sampling (mg)	$PM_{2.5-10}$ masses (mg)	Filter masses before sampling (mg)	Filter masses after sampling (mg)	$PM_{2.5}$ masses (mg)
28	0.002925	61	0.1784	26.1845	26.3506	0.1660	208.2406	211.3505	3.1099
29	0.003005	64	0.1923	25.3975	25.5107	0.1132	208.2931	211.5231	3.2300
30	0.003038	63	0.1914	26.5645	26.6403	0.0758	229.1579	231.5532	2.3953
31	0.003040	63	0.1915	26.2689	26.4015	0.1326	222.6879	224.5319	1.8440
32	0.003072	62	0.1905	26.3787	26.5218	0.1431	207.2055	208.6720	1.4665
33	0.003055	61	0.1864	24.8097	24.9349	0.1251	196.0165	197.3372	1.3207

Table C3 Concentrations of each species of PAHs bound on PM$_{2.5-10}$ samples

Worker no.	PAHs bound on PM$_{2.5-10}$ concentrations (µg/m^3)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
1	0.0570	0.0906	0.0767	0.1706	0.0864	0.0333	0.0193	ND	ND	0.0176	ND	0.3295	ND
2	0.0594	0.0545	0.1062	0.0941	0.0649	0.0477	0.0302	ND	ND	0.0235	ND	0.3248	ND
3	0.9256	0.3356	0.4451	0.7187	3.0004	0.4133	0.7463	0.0631	0.3006	0.2655	0.7931	1.3466	ND
4	0.1862	0.1098	0.2588	0.5719	1.5294	0.8225	0.2330	0.3411	1.3158	0.4358	0.7951	0.2013	0.1253
5	0.1494	0.4172	0.0565	0.1465	0.1274	0.0503	0.0295	0.0562	ND	0.0967	ND	0.0936	0.0131
6	0.0688	0.0068	0.0141	0.0066	0.0489	0.0081	0.0023	ND	ND	ND	ND	0.0470	ND
7	0.0749	0.1187	0.0710	0.1745	0.0710	0.0247	0.0195	0.0163	ND	0.0174	ND	0.0581	0.0149
8	0.1006	0.3587	0.0578	0.1635	0.1193	0.0505	0.0222	0.0251	ND	0.0447	ND	0.1459	0.1538
9	0.0816	0.1620	0.0982	0.1422	0.1053	0.0680	0.0415	ND	ND	0.0455	ND	0.2445	ND
10	0.0212	0.0073	0.0021	0.0413	0.0259	0.0157	0.0020	0.0096	ND	ND	ND	0.0583	ND
11	0.0571	0.0718	0.0792	0.1136	0.0692	0.0292	0.0186	ND	ND	0.0261	ND	0.2198	ND
12	0.0033	0.0064	0.0014	0.0045	0.0055	0.0018	0.0030	ND	ND	ND	ND	0.0445	ND
13	0.0193	0.0076	0.0020	0.0421	0.0227	0.0155	0.0020	0.0096	ND	ND	ND	0.0561	ND
14	0.0218	0.0157	0.0045	0.0406	0.1546	0.0403	0.0375	0.0408	0.0317	0.0118	0.0248	0.0308	ND
15	0.0353	0.0076	0.0059	0.0339	0.2714	0.0884	0.0846	0.1338	0.3220	0.0440	0.1028	ND	0.0179
16	0.0878	0.0404	0.1885	0.1044	0.1876	0.0026	0.0038	ND	ND	0.0283	ND	ND	0.0263
17	0.0108	0.0117	0.0020	0.0093	0.1595	0.0323	0.0102	0.0193	0.0330	ND	0.0401	ND	ND
18	0.1255	0.1282	0.1203	0.2611	0.1180	0.0340	0.0333	ND	0.0213	0.0421	ND	0.4058	0.1497

Worker no.	PAHs bound on PM$_{2.5-10}$ concentrations (µg/m^3)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
19	1.2376	0.8023	0.4169	1.3547	3.1218	0.4937	0.5330	0.4417	0.7565	0.6299	0.4762	0.7603	ND
20	0.1327	0.1861	0.1015	0.2394	0.0556	0.0366	0.0296	ND	ND	0.0591	ND	0.1259	0.0129
21	0.8420	0.3182	0.4240	1.4455	2.9124	0.6536	0.9370	0.6175	2.2008	1.1729	3.7077	2.0057	ND
22	0.1431	0.1188	0.2049	0.2209	0.1653	0.0310	0.0362	ND	ND	0.0429	ND	0.9057	0.3995
23	0.0776	0.0836	0.1126	0.1528	0.1056	0.0364	0.0250	ND	ND	0.0203	ND	0.5203	ND
24	0.0495	0.0030	0.0047	0.0052	0.0400	0.0049	0.0014	ND	ND	ND	ND	0.0589	ND
25	0.0998	0.0390	0.0286	0.2061	0.5955	0.1719	0.1357	0.1955	0.7164	0.0735	0.4140	ND	0.0359
26	0.0833	0.2001	0.0961	0.1796	0.1218	0.0484	0.0240	0.0487	ND	0.0305	ND	0.2016	0.2717
27	0.0946	0.2905	0.0983	0.1709	0.1194	0.0486	0.0230	0.0245	ND	0.0381	ND	0.1794	0.1690
28	1.2801	0.7819	0.4865	1.3925	3.7133	0.4643	0.6683	0.1163	0.2502	0.3479	0.7285	1.1370	1.2753
29	0.1852	0.1626	0.2444	0.3200	0.2113	0.0450	0.0513	ND	ND	0.0562	0.1017	1.1521	0.5149
30	0.1170	0.1043	0.1854	0.1912	0.1543	0.0483	0.0325	ND	ND	0.0279	ND	1.1973	ND
31	0.3175	0.6156	0.1988	0.4136	0.1261	0.0263	0.0342	ND	ND	0.1864	ND	0.3367	0.0682
32	0.7885	0.3000	0.5667	0.9214	2.3998	0.6390	0.6448	0.3570	0.9470	0.2998	0.7409	1.2770	ND
33	0.2561	0.3984	0.1543	0.4580	0.1438	0.0297	0.0396	ND	ND	0.1092	ND	0.1514	0.0125

Table C4 Concentrations of each species of PAHs bound on PM$_{2.5}$ samples

Worker no.	PAHs bound on PM$_{2.5}$ concentrations (µg/m^3)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
1	0.6737	0.6173	0.3178	1.2988	0.6055	0.1357	0.3482	0.1460	0.0949	0.0490	0.0891	1.6606	0.8309
2	0.2376	0.3533	0.1406	0.3556	0.0559	0.0447	0.0613	0.0201	ND	0.0256	0.5339	3.9303	ND
3	0.0152	0.0302	0.0214	0.1334	0.0483	0.0745	0.0581	0.1531	ND	0.0726	0.1908	ND	0.0195
4	1.7765	0.8615	0.6678	3.3316	2.3333	0.8432	0.8256	0.8396	ND	1.0075	1.7792	0.0504	0.1819
5	2.1641	1.5535	0.6993	3.0025	1.6570	0.4150	0.7864	0.5758	0.6467	0.3182	0.6162	1.6398	ND
6	0.1538	0.0085	0.0117	0.0127	0.0348	0.0444	ND	0.0106	ND	ND	0.0111	0.0295	ND
7	0.0516	0.0256	0.0388	0.0326	0.0383	0.0108	0.0029	0.0697	0.0783	0.0128	0.1580	0.1887	0.0091
8	0.0747	0.0883	0.2305	0.0488	0.1019	0.0214	0.0165	0.1141	0.1086	0.0469	0.3546	1.7817	0.0201
9	1.3839	0.5940	0.4983	2.0993	1.0492	0.2328	0.5249	0.2285	0.1392	0.0912	0.2508	1.3672	ND
10	0.0922	0.0068	0.0204	0.0389	0.0589	0.0081	0.0013	0.0120	ND	ND	ND	0.0285	ND
11	1.2313	0.3821	0.7366	1.0737	1.0806	0.3356	0.3531	0.4043	ND	0.6822	0.9829	ND	ND
12	0.2677	0.0684	0.0204	0.2793	0.0613	0.0957	0.0917	0.2246	ND	0.0415	0.5478	ND	0.0548
13	0.0936	0.1015	0.2738	0.0863	0.0496	0.0406	0.1011	0.1064	0.0716	0.0569	0.4599	5.3212	1.3257
14	0.9952	0.7394	0.3167	1.3305	0.7471	0.1820	0.3402	0.4362	0.2909	ND	0.3385	0.8270	ND
15	0.2862	0.5061	0.1235	0.2326	0.0423	0.0304	0.0491	0.0457	0.0197	0.0357	0.3633	1.1539	ND
16	0.1866	0.0198	0.0604	0.0126	0.0443	0.0580	0.0083	0.0051	ND	ND	ND	0.1832	ND
17	0.1356	0.0647	0.0110	0.0211	0.0250	0.1460	0.0143	0.0525	0.0411	0.0082	0.0812	ND	ND
18	0.8853	0.4172	0.3789	1.3609	0.6146	0.1547	0.3745	0.1628	0.1114	0.0575	0.4179	3.9159	1.4338

Worker no.	PAHs bound on $PM_{2.5}$ concentrations (µg/m^3)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
19	1.2409	0.5922	0.3007	2.3906	2.5068	0.5413	0.8773	0.7234	ND	0.8435	1.2524	0.0110	0.0219
20	1.3813	0.8202	0.3584	2.3701	1.4257	0.6337	0.4049	0.1853	0.5642	0.1342	0.3535	ND	0.0584
21	1.1658	0.5834	0.2458	2.3752	2.3113	0.5121	0.9073	0.6959	ND	0.7642	1.1829	ND	0.0592
22	0.9420	0.6736	0.3599	1.1974	0.5144	0.0720	0.2468	0.0661	0.0406	0.0678	0.4460	3.9335	1.5162
23	0.2269	0.1604	0.2695	0.4312	0.1089	0.0852	0.0652	0.0273	ND	0.0180	0.2034	6.0319	ND
24	0.2062	0.0604	0.0216	0.0201	0.0644	0.0232	0.0437	0.0190	0.0177	ND	ND	0.0951	ND
25	0.5535	0.2272	0.0879	0.7263	0.2639	0.1444	0.1502	0.2495	ND	ND	0.3442	ND	0.0511
26	0.5967	1.1097	0.3085	0.4435	0.0954	0.0754	0.0750	0.2328	ND	0.0883	0.8116	4.7408	ND
27	2.2625	1.7769	1.0526	1.4994	1.1306	0.5697	0.2179	1.2484	ND	0.3677	0.0794	21.9285	ND
28	8.3774	7.4712	2.8065	20.8964	12.0283	6.9239	8.0223	1.5949	2.7916	1.4486	1.5580	0.7297	0.8054
29	6.0381	6.5376	1.9271	20.1352	11.1764	7.4736	9.9844	2.4914	6.0902	3.4782	8.4404	4.2416	1.9504
30	3.8203	4.2462	1.2026	19.6659	8.6492	9.7313	3.4840	1.8427	5.0259	3.1059	7.0517	3.2079	3.4559
31	2.9409	2.3145	1.8733	2.2654	1.6861	1.4656	0.3608	2.2516	ND	0.9555	5.1680	29.3213	ND
32	2.1741	1.4202	0.5438	3.9247	4.3998	1.0651	1.4153	1.5994	0.9383	2.5873	8.0034	2.6081	1.2389
33	2.2093	2.7259	0.9868	10.7365	5.4587	2.6377	2.6051	1.7110	4.6811	1.0108	4.4322	0.8531	0.6942

Table C5 Total concentrations of PAHs bound on $PM_{2.5-10}$ and $PM_{2.5}$ samples

Worker no.	Total PAHs concentrations (µg/m^3)		Worker no.	Total PAHs concentrations (µg/m^3)	
	$PM_{2.5-10}$	$PM_{2.5}$		$PM_{2.5-10}$	$PM_{2.5}$
1	0.8810	6.8674	18	1.4393	10.2855
2	0.8054	5.7590	19	11.0246	11.3021
3	9.3538	0.8170	20	0.9794	8.6899
4	6.9259	14.4982	21	17.2373	10.8030
5	1.2363	14.0745	22	2.2684	10.0764
6	0.2027	0.3171	23	1.1342	7.6281
7	0.6610	0.7172	24	0.1676	0.5715
8	1.2421	3.0080	25	2.7120	2.7983
9	0.9888	8.4594	26	1.3056	8.5776
10	0.1835	0.2669	27	1.2564	32.1336
11	0.6845	7.2624	28	12.6419	75.4541
12	0.0703	1.7531	29	3.0446	89.9645
13	0.1768	8.0882	30	2.0582	74.4894
14	0.4550	6.5438	31	2.3233	50.6031
15	1.1477	2.8885	32	9.8818	31.9186
16	0.6696	0.5783	33	1.7531	40.7424
17	0.3280	0.6007			

Table C6 Concentrations of each species of PAHs bound on dermal dust collected before working

Pattern No.	N	Before working (mg/kg)			After working (mg/kg)			After hand washing (mg/kg)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
1	1	192.6719	192.6719	192.6719	1,082.2926	1,082.2926	1,082.2926	656.7977	656.7977	656.7977
2	1	64.1432	64.1432	64.1432	731.5646	731.5646	731.5646	435.2314	435.2314	435.2314
3	1	44.3653	44.3653	44.3653	846.8015	846.8015	846.8015	244.2190	244.2190	244.2190
4	3	13.1430	161.1032	90.1029	535.8798	2,819.8013	1,435.6863	113.9723	367.3825	244.3718
5	5	51.7005	191.2419	107.7516	765.5364	3,412.3534	1,806.0517	124.6013	430.2586	287.2588
6	11	22.2084	253.6118	88.5097	445.3687	3,068.9263	1,031.0008	144.8623	455.3216	295.0177
7	2	96.7185	135.3623	116.0404	856.0557	1,111.6668	983.8613	191.4463	302.6545	247.0504
8	2	71.0311	100.9129	85.9720	690.2763	835.1885	762.7324	174.8886	511.5996	343.2441
9	1	121.5897	121.5897	121.5897	945.7377	945.7377	945.7377	876.9778	876.9778	876.9778
10	1	40.7466	40.7466	40.7466	518.7858	518.7858	518.7858	233.6115	233.6115	233.6115
11	1	36.0134	36.0134	36.0134	117.5432	117.5432	117.5432	109.1063	109.1063	109.1063
12	2	8.1072	194.9039	101.5055	743.2617	784.4287	763.8452	187.2752	420.7879	304.0315
13	2	109.7622	148.8493	129.3057	945.7812	4,315.9496	2,630.8654	148.6057	320.9207	234.7632

Table C7 Concentrations of each species of PAHs bound on dermal dust collected before working

Worker no.	Concentrations of PAHs on dermal dust collected before working (mg/kg)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
1	27.7396	10.1675	6.7220	ND	ND	53.4513	ND	2.8325	ND	ND	ND	ND	ND
2	11.3511	ND	0.3708	21.1539	ND	2.5689	26.7128	5.1336	3.7398	ND	ND	ND	ND
3	ND	14.3971	7.4447	ND	ND	42.3014	ND	ND	ND	ND	ND	ND	ND
4	ND	ND	ND	39.8355	ND	56.5927	ND	ND	ND	ND	ND	6.5929	ND
5	14.2112	ND	11.3831	39.1221	ND	5.5031	7.8456	18.0787	13.6185	ND	ND	ND	ND
6	26.9703	34.3876	5.5212	22.4462	18.8500	7.6267	13.7114	13.5789	29.4427	ND	ND	18.7070	ND
7	ND	13.6109	24.2570	48.8246	ND	33.9606	ND	ND	32.4972	7.9529	ND	ND	ND
8	ND	6.8742	6.0939	ND	ND	12.3114	10.2324	5.0632	ND	3.7902	ND	ND	ND
9	ND	ND	5.9822	ND	ND	ND	ND	38.6530	52.0834	ND	ND	ND	ND
10	23.4350	1.6850	0.6115	ND	36.3253	24.3979	ND	ND	95.3746	ND	ND	6.2925	4.5503
11	30.1698	11.8689	5.5995	42.5658	ND	ND	ND	2.4726	2.8263	ND	ND	5.4244	ND
12	10.6337	0.9139	0.4236	ND	18.9698	11.3544	40.8415	ND	52.2253	ND	ND	ND	ND
13	14.2354	ND	6.2356	ND	ND	17.7342	25.1720	35.7389	49.7332	ND	ND	ND	ND
14	51.3148	7.0231	4.1368	52.7840	30.2715	18.5864	42.2491	ND	47.2461	ND	ND	ND	ND
15	5.4278	1.0979	0.5312	5.2612	ND	9.9237	ND	0.1217	0.1986	ND	ND	ND	0.6270
16	ND	40.7147	17.6853	19.9489	ND	30.4569	29.5287	ND	36.9335	ND	ND	ND	19.6359
17	0.5857	2.0695	0.9685	ND	4.4835	ND	ND	ND	ND	ND	ND	ND	ND
18	9.7627	4.4842	5.2313	ND	39.0779	28.2114	ND	ND	6.9928	ND	ND	ND	2.3022

Worker no.	Concentrations of PAHs on dermal dust collected before working (mg/kg)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
19	12.7832	28.7205	3.6208	14.0464	22.2801	ND	ND	3.7360	10.8788	13.9612	ND	11.5626	ND
20	57.1483	4.1902	2.8526	ND	ND	1.8996	8.2178	30.1723	28.0275	ND	ND	5.1097	5.9721
21	ND	1.6090	2.0304	11.0741	ND	1.1132	19.9528	1.7935	0.9393	1.5063	ND	ND	0.7279
22	12.4860	ND	7.9546	34.6840	ND	14.5542	ND	1.4847	2.4492	0.7570	ND	4.7394	0.5881
23	2.5540	2.5441	6.3693	ND	1.6756	ND	ND	ND	ND	ND	ND	ND	ND
24	2.1663	0.8840	0.4185	ND	17.0336	ND	ND	ND	15.5109	ND	ND	ND	ND
25	4.9619	2.0846	0.3729	8.0682	34.4022	0.6757	1.3454	ND	ND	ND	ND	ND	ND
26	17.6461	4.2550	2.1284	ND	33.2928	16.1758	35.9924	ND	52.1966	ND	ND	ND	ND
27	2.5309	0.9505	1.8503	ND	8.9137	2.5022	0.4184	ND	ND	3.1992	ND	ND	18.8409
28	24.2722	3.0517	0.6698	5.5485	ND	ND	8.0759	ND	ND	ND	ND	ND	ND
29	4.2756	ND	9.0762	ND	5.2756	ND	1.1397	3.3093	ND	ND	ND	ND	ND
30	17.3273	9.1048	2.1746	25.6078	ND	2.7483	27.8318	ND	ND	ND	ND	ND	ND
31	21.8272	1.5454	0.1703	24.3547	ND	ND	3.8029	ND	ND	ND	ND	ND	ND
32	19.0770	7.4650	7.2675	19.3604	30.4705	12.9614	34.1010	10.1807	ND	ND	ND	ND	ND
33	3.2553	3.3387	6.4010	ND	9.2135	ND	ND	ND	ND	ND	ND	ND	ND

Table C8 Concentrations of each species of PAHs bound on dermal dust collected after working

Worker no.	Concentrations of PAHs on dermal dust collected after working (mg/kg)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
1	37.3983	ND	0.3829	2.8764	83.5299	123.8579	63.2754	111.3052	20.0976	19.4537	216.0221	10.4708	1.6062
2	77.9119	40.2021	30.7223	87.6134	169.1959	27.3688	67.8610	81.2954	55.1689	74.9511	120.3130	2.5849	ND
3	ND	6.6872	1.9329	35.8657	374.5196	5.4649	22.2822	0.8606	1.3899	0.4285	282.1331	ND	ND
4	98.6059	91.5901	87.4537	52.9664	74.7001	17.2109	56.1649	3.7032	ND	266.0874	25.1004	28.1623	4.6274
5	12.4857	5.2612	4.2137	433.6655	26.4693	4.2447	13.7257	4.7748	ND	1.2449	24.3869	415.3087	ND
6	4.7234	2.8337	1.8497	44.1774	1171.0061	1.8219	10.1332	7.3109	16.2302	7.7283	1935.6671	ND	0.9892
7	ND	2.5884	4.1689	55.5772	1417.0904	1.5159	4.6833	0.2404	42.9344	12.9616	1275.3546	0.8882	1.7980
8	22.3355	5.4000	3.8983	338.4955	22.9053	12.5806	11.4595	3.2754	ND	2.0605	19.4625	404.9282	ND
9	2.3992	0.6679	0.1049	15.9848	55.4096	0.1067	7.2381	30.4574	9.7738	3.6958	87.6190	898.2096	ND
10	13.9361	26.5216	1.1378	108.5473	25.7415	154.1960	223.6146	57.4210	15.1598	35.9642	407.8881	2.5966	9.5679
11	15.7045	10.4940	6.4834	150.9132	67.8959	28.8077	18.9437	48.6836	55.3432	18.1373	144.6488	ND	18.5496
12	18.1331	5.8352	10.6142	67.5576	325.9090	13.9000	15.5844	2.9628	5.4008	5.5438	381.6542	1.6197	1.3409
13	349.4094	ND	ND	624.5572	416.7375	252.8520	629.9076	73.8100	292.4045	241.0235	1020.5886	290.0277	124.6316
14	0.6188	0.8629	0.2103	14.6976	1.2888	7.4523	2.1030	3.0632	5.6692	3.0230	102.3591	792.3821	30.4334
15	8.2156	ND	0.6207	72.2447	195.6499	1.6518	11.1653	9.0527	15.1868	2.4668	601.2829	ND	ND
16	80.3115	13.7418	9.6018	215.2973	32.2092	14.3296	7.5443	7.4309	ND	11.4937	89.7557	302.7129	ND
17	89.3329	46.2160	26.7726	42.8404	153.4722	29.7029	59.3683	72.6760	44.2329	85.8593	86.7780	2.6268	3.3834
18	17.5082	3.6426	0.5682	17.2365	330.2009	8.3989	9.9665	3.2648	2.4185	1.3523	554.6202	ND	2.2003

Worker no.	Concentrations of PAHs on dermal dust collected after working (mg/kg)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
19	10.6381	5.0700	1.7295	40.6528	392.6067	2.4504	2.4688	0.4564	3.8533	2.9284	477.3925	3.1426	2.3482
20	7.7921	ND	1.3745	35.2342	258.6128	1.5117	4.4362	10.2431	6.1377	2.1086	512.3175	ND	ND
21	66.6645	0.1876	0.0199	25.4809	62.8567	0.1033	231.1858	ND	ND	ND	132.2873	ND	ND
22	1.7950	2.2369	0.2058	20.8448	27.4102	0.8744	0.1715	ND	ND	1.4467	36.1921	439.2086	ND
23	15.1896	4.7003	3.3844	12.3043	124.4933	30.5880	106.7848	0.8931	0.7588	ND	236.7830	ND	ND
24	2.5783	2.7454	0.1896	41.5904	13.8819	0.6563	4.7906	ND	ND	ND	51.1106	ND	ND
25	9.0440	4.4873	3.3335	39.5206	1465.1929	1.9657	9.8285	5.1766	11.6210	10.0598	1850.9184	0.7667	0.4385
26	25.7463	18.0933	10.1664	73.2504	66.2086	21.2036	11.3397	97.6155	46.9663	25.2006	526.9023	ND	0.4757
27	31.6819	4.0365	0.1994	12.4742	15.3634	1.8322	0.3776	8.9749	ND	29.7077	114.8424	225.8786	ND
28	11.1542	5.1262	2.3769	208.4674	89.8020	166.2480	465.5647	4.9985	5.0859	5.7260	25.3607	ND	ND
29	22.0138	17.9944	2.6505	24.3563	92.2768	51.7394	57.4770	55.2754	33.9066	11.0529	607.4721	ND	8.6355
30	7.5748	ND	1.0991	51.6173	350.2141	0.9838	9.9779	20.0235	18.3464	9.1911	623.2964	ND	ND
31	19.7792	33.4838	6.2709	192.6608	46.7794	82.5052	104.0766	51.6941	16.6183	80.0842	164.4979	13.4317	29.6427
32	18.8755	7.8630	3.9264	23.8125	262.8976	21.6336	49.8338	ND	ND	ND	376.6942	ND	ND
33	12.9505	6.8080	5.3945	44.3636	1140.6471	0.3235	17.2957	12.6980	28.8635	31.0788	1766.7899	0.9340	0.7791

Table C9 Concentrations of each species of PAHs bound on dermal dust collected after hand washing

Worker no.	Concentrations of PAHs on dermal dust collected after hand washing (mg/kg)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
1	54.2602	5.7625	0.6971	77.1790	167.3457	ND	5.8510	8.2607	11.0392	17.0332	164.1709	ND	ND
2	18.8356	2.1335	ND	9.1509	15.7406	1.2087	0.1275	7.8738	ND	20.3823	99.4359	ND	ND
3	99.0390	11.5390	5.7524	52.9381	55.3421	ND	2.7189	19.0059	2.8845	60.3188	119.7025	3.0651	2.9251
4	2.3048	1.0156	2.2972	4.5338	10.5201	8.8155	161.4087	18.1436	4.4712	ND	14.0392	ND	ND
5	0.6909	2.2250	1.8341	138.3442	5.5114	ND	ND	ND	ND	ND	ND	ND	ND
6	6.8287	15.0179	1.9900	11.2122	10.9964	3.1940	4.4414	3.8714	10.3750	9.9441	67.9866	196.3486	88.0524
7	12.7100	5.0028	4.6029	25.3504	137.7475	56.3834	ND	2.6165	ND	ND	ND	7.3472	ND
8	ND	ND	16.9925	101.3977	66.9545	16.2039	30.8322	11.8383	ND	ND	ND	ND	ND
9	ND	5.0202	1.2490	33.9122	15.4842	3.5558	3.6134	ND	ND	4.9154	75.9928	28.9957	18.7077
10	57.2599	30.0948	47.9104	14.8144	136.8748	14.5199	70.5420	130.8431	ND	56.0838	92.9096	3.5770	1.3680
11	10.1901	3.5538	3.5209	9.1039	173.8570	42.3296	152.0879	ND	ND	ND	ND	ND	ND
12	2.9020	0.8587	0.4049	31.3012	11.9387	4.5868	23.4360	83.9508	47.0217	42.8661	ND	ND	53.3876
13	3.8988	1.1510	0.5128	37.5739	14.3618	5.1162	27.5697	88.2864	38.1020	26.8025	ND	ND	77.5458
14	9.3204	ND	2.3414	36.1042	196.4758	1.2793	3.1719	8.6198	4.7111	2.9601	ND	ND	ND
15	42.9372	4.3379	0.5246	53.9221	133.4097	ND	3.9453	8.2797	7.5833	14.4987	185.8832	ND	ND
16	ND	17.2046	8.9736	ND	41.5813	9.5854	8.8950	5.6883	ND	5.6727	89.6743	ND	ND
17	39.2581	3.9285	0.3602	14.8049	24.3513	1.9974	0.7983	3.5345	ND	30.8602	80.6044	220.2901	ND
18	6.7609	1.3176	0.1041	17.8602	25.2296	0.6152	1.8259	ND	ND	ND	60.2587	ND	ND

Worker no.	Concentrations of PAHs on dermal dust collected after hand washing (mg/kg)												
	Fle	Phe	Ant	Fla	Pyr	BaA	Chr	BbF	BkF	BaP	DahA	BghiP	IcdP
19	12.6337	4.2799	7.6185	25.4620	393.6960	14.5006	111.4647	ND	3.0512	1.6344	298.0967	3.3353	1.2048
20	4.0790	1.8437	0.3010	10.4406	42.5394	0.8994	1.4468	ND	ND	ND	83.3123	ND	ND
21	62.9469	36.4730	19.9100	ND	ND	ND	ND	36.4893	ND	2.5542	ND	57.5514	17.6867
22	15.2702	3.5940	3.5512	6.4639	215.4899	23.0656	30.1634	2.8277	ND	ND	ND	ND	ND
23	52.8843	5.0138	0.9517	33.3204	92.5728	ND	2.6516	13.6879	3.9760	14.3948	147.9293	ND	ND
24	31.9787	12.6672	64.4605	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
25	30.2313	21.7965	13.3438	101.6098	55.0155	22.4826	12.2499	85.3610	52.3070	18.7073	ND	ND	1.2018
26	5.4032	13.7726	1.5879	10.7689	13.2313	3.0771	4.0639	1.2893	4.1581	6.5513	46.6370	ND	40.5565
27	59.6346	7.3158	2.7171	43.5144	75.8400	ND	2.2138	13.4434	2.6041	18.8317	ND	1.2836	0.6258
28	35.4321	3.3926	0.3441	13.7377	24.2154	1.7527	0.7912	8.4589	ND	27.1951	67.3176	ND	ND
29	42.6643	5.1786	ND	ND	214.7492	ND	31.4785	ND	ND	ND	76.2299	ND	ND
30	1.8662	ND	0.6377	39.8135	18.9991	123.1769	73.7841	8.8942	58.7383	ND	76.3810	ND	ND
31	34.7679	3.3559	0.4193	9.2412	103.4650	ND	6.0833	5.5722	1.0166	1.3095	74.3468	ND	ND
32	ND	24.1913	1.1339	29.0212	19.1889	ND	ND	6.5516	ND	ND	44.5144	ND	ND
33	16.4667	8.0404	26.5221	276.3536	23.2251	ND	ND	ND	ND	ND	ND	ND	ND

Table C10 Total concentrations of PAHs bound on dermal dust samples

Worker no.	Total concentrations of PAHs bound on the dermal dust (mg/kg)		
	Before working	After working	After hand washing
1	100.9129	690.2763	511.5996
2	71.03105	835.1885	174.8886
3	64.14318	731.5646	435.2314
4	103.0211	806.3726	227.5498
5	109.7622	945.7812	148.6057
6	191.2419	3204.471	430.2586
7	161.1032	2819.801	251.7606
8	44.3653	846.8015	244.219
9	96.71854	1111.667	191.4463
10	192.6719	1082.293	656.7977
11	100.9274	584.6048	394.6431
12	135.3623	856.0557	302.6545
13	148.8493	4315.95	320.9207
14	253.6118	964.1636	264.9841
15	23.18909	917.5372	455.3216
16	194.9039	784.4287	187.2752
17	8.107192	743.2617	420.7879
18	96.06249	951.378	113.9723
19	121.5897	945.7377	876.9778
20	143.5901	839.7684	144.8623
21	40.74657	518.7858	233.6115
22	79.69727	530.386	300.4259
23	13.14302	535.8798	367.3825
24	36.01336	117.5432	109.1063
25	51.91086	3412.353	414.3065
26	161.6872	923.1686	151.0969
27	39.20605	445.3687	228.0244

Worker no.	Total concentrations of PAHs bound on the dermal dust (mg/kg)		
	Before working	After working	After hand washing
28	41.6181	989.9105	182.6375
29	23.07648	984.8507	370.3005
30	84.79463	1092.324	402.291
31	51.70047	841.5248	239.5778
32	140.8834	765.5364	124.6013
33	22.20843	3068.926	350.6078

Table C11 Chronic daily intake (CDI) and lifetime cancer risk (LCR) from each route of exposure

Worker no.	Inhalation route				Dermal route					
	PM$_{2.5-10}$		PM$_{2.5}$		Before working		After working		After hand washing	
	CDI (mg/kg BW-day)	LCR	CDI (mg/kg BW-day)	LCR	CDI (mg/kg BW-day)	LCR	CDI (mg/kg BW-day)	LCR	CDI (mg/kg BW-day)	LCR
1	2.51E-08	9.802E-07	2.8E-07	1.092E-05	1.106E-07	2.764E-06	5.053E-06	0.0001263	3.539E-06	8.847E-05
2	3.12E-08	1.216E-06	5.716E-07	2.229E-05	2.673E-08	6.682E-07	3.933E-06	9.834E-05	2.23E-06	5.575E-05
3	5.24E-07	2.042E-05	1.297E-07	5.059E-06	7.208E-08	1.802E-06	4.739E-06	0.0001185	3.051E-06	7.628E-05
4	7.71E-07	3.006E-05	1.539E-06	6.002E-05	1.163E-07	2.909E-06	5.969E-06	0.0001492	3.802E-07	9.504E-06
5	3.48E-08	1.359E-06	3.562E-07	1.389E-05	5.652E-08	1.413E-06	4.467E-07	1.117E-05	2.353E-09	5.883E-08
6	1.20E-09	4.69E-08	1.317E-08	5.135E-07	8.752E-08	2.188E-06	3.073E-05	0.0007681	1.429E-06	3.572E-05
7	1.59E-08	6.202E-07	1.212E-07	4.726E-06	2.427E-07	6.069E-06	2.108E-05	0.0005271	1.01E-07	2.525E-06
8	5.00E-08	1.948E-06	3.172E-07	1.237E-05	1.15E-07	2.875E-06	5.59E-07	1.398E-05	6.964E-08	1.741E-06
9	2.26E-08	8.798E-07	1.717E-07	6.698E-06	1.302E-07	3.254E-06	1.489E-06	3.722E-05	1.19E-06	2.976E-05
10	1.86E-09	7.258E-08	1.546E-09	6.028E-08	1.836E-07	4.591E-06	6.869E-06	0.0001717	2.414E-06	6.034E-05
11	3.24E-08	1.266E-06	1.75E-06	6.826E-05	1.463E-08	3.657E-07	3.601E-06	9.002E-05	1.208E-07	3.02E-06
12	4.03E-10	1.573E-08	3.685E-07	1.437E-05	9.693E-08	2.423E-06	5.562E-06	0.000139	8.843E-07	2.211E-05
13	2.66E-09	1.039E-07	6.071E-07	2.368E-05	1.925E-07	4.813E-06	2.434E-05	0.0006086	8.686E-07	2.172E-05
14	3.50E-08	1.366E-06	3.213E-07	1.253E-05	1.024E-07	2.561E-06	1.682E-06	4.204E-05	6.724E-08	1.681E-06
15	1.95E-07	7.605E-06	4.036E-07	1.574E-05	1.742E-08	4.356E-07	9.573E-06	0.0002393	3.191E-06	7.978E-05
16	3.52E-08	1.371E-06	9.548E-09	3.724E-07	1.67E-07	4.174E-06	1.934E-06	4.835E-05	1.756E-06	4.389E-05

Worker no.	Inhalation route				Dermal route					
	PM$_{2.5-10}$		PM$_{2.5}$		Before working		After working		After hand washing	
	CDI (mg/kg BW-day)	LCR	CDI (mg/kg BW-day)	LCR	CDI (mg/kg BW-day)	LCR	CDI (mg/kg BW-day)	LCR	CDI (mg/kg BW-day)	LCR
17	5.13E-08	2.002E-06	1.196E-07	4.663E-06	3.042E-10	7.604E-09	3.414E-06	8.536E-05	2.067E-06	5.167E-05
18	3.59E-08	1.402E-06	3.716E-07	1.449E-05	4.462E-08	1.115E-06	6.457E-06	0.0001614	6.988E-07	1.747E-05
19	7.68E-07	2.995E-05	1.326E-06	5.172E-05	2.664E-07	6.659E-06	8.198E-06	0.0002049	5.161E-06	0.000129
20	5.73E-08	2.235E-06	5.504E-07	2.146E-05	1.378E-07	3.446E-06	1.043E-05	0.0002606	1.685E-06	4.212E-05
21	3.98E-06	0.0001551	1.58E-06	6.161E-05	3.971E-08	9.927E-07	2.436E-06	6.091E-05	1.599E-07	3.998E-06
22	8.27E-08	3.225E-06	6.171E-07	2.407E-05	5.729E-08	1.432E-06	8.511E-07	2.128E-05	6.392E-08	1.598E-06
23	1.50E-08	5.832E-07	1.437E-07	5.603E-06	8.153E-10	2.038E-08	2.792E-06	6.979E-05	1.901E-06	4.753E-05
24	6.62E-10	2.584E-08	4.267E-09	1.664E-07	2.681E-08	6.702E-07	8.727E-07	2.182E-05	1.173E-08	2.932E-07
25	4.49E-07	1.753E-05	2.933E-07	1.144E-05	2.427E-09	6.069E-08	3.371E-05	0.0008427	6.383E-07	1.596E-05
26	5.17E-08	2.017E-06	7.153E-07	2.79E-05	1.468E-07	3.67E-06	1.149E-05	0.0002871	1.174E-06	2.936E-05
27	2.74E-08	1.07E-06	3.604E-07	1.406E-05	7.651E-08	1.913E-06	2.109E-06	5.272E-05	2.957E-07	7.392E-06
28	4.69E-07	1.829E-05	1.561E-06	6.086E-05	1.759E-09	4.397E-08	7.851E-07	1.963E-05	1.398E-06	3.494E-05
29	8.79E-08	3.428E-06	5.339E-06	0.0002082	6.64E-09	1.66E-07	9.515E-06	0.0002379	1.152E-06	2.881E-05
30	2.89E-08	1.129E-06	7.495E-06	0.0002923	1.265E-08	3.163E-07	1.285E-05	0.0003214	1.943E-06	4.857E-05
31	7.28E-08	2.839E-06	2.445E-06	9.537E-05	1.246E-09	3.116E-08	3.765E-06	9.412E-05	1.091E-06	2.727E-05
32	5.33E-07	2.077E-05	4.69E-06	0.0001829	4.772E-08	1.193E-06	6.461E-06	0.0001615	7.701E-07	1.925E-05
33	4.32E-08	1.684E-06	2.368E-06	9.237E-05	1.197E-09	2.993E-08	2.706E-05	0.0006764	8.841E-09	2.21E-07

Table C12 Multi route of exposure lifetime cancer risk

Worker no.	Route of exposure		
	Total inhalation risk	Dermal risk (After working)	Total multi route of exposure risk
1	1.19E-05	0.0001263	0.0001382
2	2.351E-05	9.834E-05	0.0001218
3	2.548E-05	0.0001185	0.000144
4	9.008E-05	0.0001492	0.0002393
5	1.525E-05	1.117E-05	2.642E-05
6	5.604E-07	0.0007681	0.0007687
7	5.346E-06	0.0005271	0.0005325
8	1.432E-05	1.398E-05	2.83E-05
9	7.578E-06	3.722E-05	4.48E-05
10	1.329E-07	0.0001717	0.0001719
11	6.953E-05	9.002E-05	0.0001595
12	1.439E-05	0.000139	0.0001534
13	2.378E-05	0.0006086	0.0006324
14	1.39E-05	4.204E-05	5.594E-05
15	2.335E-05	0.0002393	0.0002627
16	1.744E-06	4.835E-05	5.009E-05
17	6.664E-06	8.536E-05	9.202E-05
18	1.589E-05	0.0001614	0.0001773
19	8.167E-05	0.0002049	0.0002866
20	2.37E-05	0.0002606	0.0002843
21	0.0002167	6.091E-05	0.0002776
22	2.729E-05	2.128E-05	4.857E-05
23	6.186E-06	6.979E-05	7.598E-05
24	1.923E-07	2.182E-05	2.201E-05
25	2.896E-05	0.0008427	0.0008717
26	2.991E-05	0.0002871	0.0003171
27	1.513E-05	5.272E-05	6.784E-05
28	7.915E-05	1.963E-05	9.878E-05
29	0.0002116	0.0002379	0.0004495

Worker no.	Route of exposure		
	Total inhalation risk	Dermal risk (After working)	Total multi route of exposure risk
30	0.0002934	0.0003214	0.0006148
31	9.821E-05	9.412E-05	0.0001923
32	0.0002037	0.0001615	0.0003652
33	9.405E-05	0.0006764	0.0007705

PPENDIX D

QUESTIONNAIRE USED IN THIS RESEARCH

ชุดที่……………
ชื่อผู้สัมภาษณ์………………………………
วันที่สัมภาษณ์………………………………

แบบประเมินความเสี่ยง และเฝ้าระวังด้านสุขภาพ
ของผู้ประกอบอาชีพคัดแยกขยะอิเล็กทรอนิกส์ จังหวัดบุรีรัมย์

แบบสอบถามนี้จัดทำขึ้นสำหรับใช้ในโครงการ “การประเมินความเสี่ยง และการเฝ้าระวังด้านสุขภาพของผู้ประกอบอาชีพคัดแยกขยะอิเล็กทรอนิกส์ จังหวัดบุรีรัมย์” โดยมีวัตถุประสงค์เพื่อสำรวจข้อมูลพื้นฐานของชุมชนคัดแยกขยะอิเล็กทรอนิกส์ในจังหวัดบุรีรัมย์ ทั้งนี้ คณะผู้วิจัยจะเก็บข้อมูลของท่านเป็นความลับและจะนำเสนอผลการศึกษาในภาพรวมเท่านั้น

<u>ตอนที่ 1</u> ข้อมูลส่วนบุคคล (เน้นสัมภาษณ์หัวหน้าครัวเรือน)

1.1 รหัสผู้ตอบแบบสอบถาม..

1.2 เพศ ☐ ชาย ☐ หญิง

1.3 อายุ..................ปี

1.4 น้ำหนัก................................กิโลกรัม

1.5 ท่านอาศัยอยู่ที่นี่เป็นระยะเวลา ....ปี

1.6 จำนวนสมาชิกในครอบครัว.................................คน จำนวนเด็กที่มีอายุต่ำกว่า 12 ปี.......................คน

1.7 อาชีพหลักของครอบครัว คือ..

1.8 การศึกษาสูงสุด

☐ ไม่ได้เรียน ☐ ประถมศึกษา ☐ มัธยมศึกษา/ปวช
☐ อนุปริญญา/ปวส. ☐ ปริญญาตรีหรือสูงกว่า

<u>ตอนที่ 2</u> ข้อมูลด้านการประกอบอาชีพ

2.1 ท่านประกอบอาชีพคัดแยกขยะอิเล็กทรอนิกส์รวมทั้งสิ้นเป็นเวลา.............................ปี.........................เดือน

2.2 จำนวนสมาชิกในครอบครัวที่ทำงานคัดแยกขยะอิเล็กทรอนิกส์.........................คน ชาย.................คน หญิง ....คน

2.3 ลักษณะการทำงานคัดแยกขยะอิเล็กทรอนิกส์ของท่าน (ตอบได้มากกว่า 1 ข้อ)

☐ รับซื้อขยะอิเล็กทรอนิกส์จากบ้านเรือน/ ร้านขายของเก่าแล้วนำมาคัดแยกชิ้นส่วน
☐ รับซื้อเศษวัสดุที่ได้จากการคัดแยกขยะอิเล็กทรอนิกส์
☐ รับจ้างคัดแยกชิ้นส่วนขยะอิเล็กทรอนิกส์ ได้รับค่าจ้าง......................บาทต่อวัน
☐ อื่นๆ ระบุ..

2.4 ใน 1 วัน ท่านใช้เวลาทำงานคัดแยกขยะอิเล็กทรอนิกส์จำนวน................ชั่วโมง

2.5 ใน 1 สัปดาห์ ท่านใช้เวลาทำงานคัดแยกขยะอิเล็กทรอนิกส์จำนวน................วัน

2.6 ท่านมีวันหยุดพักผ่อนหรือไม่ ☐ ไม่มี ☐ มี ....วันต่อสัปดาห์ ☐ ไม่แน่นอน

2.7 ท่านคิดว่าจะประกอบอาชีพคัดแยกขยะอิเล็กทรอนิกส์จนถึงอายุ....................ปี

2.8 ท่านทราบหรือไม่ว่าในขยะอิเล็กทรอนิกส์มีสารอันตรายซึ่งอาจส่งผลกระทบต่อสุขภาพของผู้ทำงาน

☐ ไม่ทราบ ☐ ทราบ จากช่องทาง...

2.9 ในระหว่างทำงาน ท่านมีการสวมอุปกรณ์ป้องกันอันตรายส่วนบุคคลหรือไม่

☐ ไม่มี (ข้ามไปข้อ 2.11) ☐ มี สวมใส่เป็นบางครั้ง ☐ มี สวมใส่ทุกครั้ง

2.10 หากมีการสวมใส่อุปกรณ์ป้องกันอันตรายส่วนบุคคล อุปกรณ์ที่ท่านใช้ ได้แก่ (ตอบได้มากกว่า 1 ข้อ)

☐ ถุงมือ ชนิด ☐ ผ้า  ☐ หน้ากากป้องกันฝุ่น ชนิด ☐ หน้ากากผ้า 

☐ ยาง  ☐ หน้ากากอนามัย 

☐ หน้ากากป้องกันฝุ่นละออง

☐ แว่นตานิรภัย ☐ รองเท้านิรภัยหรือรองเท้าหุ้มส้นที่ปิดมิดชิด

☐ เสื้อแขนยาว ☐ กางเกงขายาว

2.11 ขยะอิเล็กทรอนิกส์ที่ท่านรับซื้อและคัดแยกในแต่ละครั้งได้แก่อะไรบ้าง โปรดระบุ

☐ โทรทัศน์ จำนวน...............เครื่อง ☐ ตู้เย็น จำนวน...............เครื่อง

☐ เครื่องซักผ้า จำนวน...............เครื่อง ☐ คอมพิวเตอร์ จำนวน...............เครื่อง

☐ เครื่องปรับอากาศ จำนวน...............เครื่อง ☐ อื่นๆ..................จำนวน...............เครื่อง

☐ อื่นๆ...................... จำนวน...............เครื่อง ☐ อื่นๆ..................จำนวน...............เครื่อง

2.12 ในหนึ่งเดือน ท่านรับซื้อและคัดแยกขยะอิเล็กทรอนิกส์เป็นจำนวน........................ครั้ง

2.13 วัสดุที่คัดแยกได้จากขยะอิเล็กทรอนิกส์ได้แก่อะไรบ้าง โปรดระบุ

☐ เหล็ก จำนวน...............กิโลกรัม ☐ ทองแดง จำนวน..............กิโลกรัม

☐ อะลูมิเนียม จำนวน...............กิโลกรัม ☐ ทองเหลือง จำนวน..............กิโลกรัม

☐ พลาสติก จำนวน...............กิโลกรัม ☐ อื่นๆ................จำนวน...............กิโลกรัม

☐ อื่นๆ.................... จำนวน...............กิโลกรัม ☐ อื่นๆ................จำนวน...............กิโลกรัม

2.14 ท่านขายวัสดุที่คัดแยกได้จากขยะอิเล็กทรอนิกส์ที่ใด

☐ ร้านค้าในพื้นที่ ☐ ร้านค้านอกพื้นที่ ระบุ.................................. ☐ อื่นๆ ระบุ.........................

2.15 ท่านมีการเผาสายไฟหรือวัสดุอื่นๆ เพื่อให้ได้วัสดุมีค่าหรือไม่

☐ ไม่มี ☐ มี ทำการเผา..............ครั้งต่อเดือน ครั้งละประมาณ................กิโลกรัม

****

ขอขอบคุณทุกท่านที่ให้ความร่วมมือในการให้ข้อมูลตามความเป็นจริง

VITA

Name: Miss Sarasanant Bungadaeng

Date of Birth: April 29, 1993

Nationality: Thai

Educational background: 2011-2014, Bachelor's degree of Science, Department of Environmental Science, Faculty of Science, Chulalongkorn University, Bangkok, Thailand

Current address: 96/5 Petchburi Road, Ratchathewi, Bangkok, 10400 Thailand

Contact information: Sarasanant.b@gmail.com

Publication:

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