CHAPTER 2

Literature Reviews

2.1 Criteria air pollutions and their health effects

Air pollution is due to the excessive discharge of particulates, fumes and chemicals into the atmosphere and their suspension in the atmosphere for the long period of time. Air pollutant may occur in the form of solid particles, liquid droplets or gases. There are over hundred identified air pollutants. The major categories of those pollutants are following particulate matter (PM), oxides of sulfur (SO_x), oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and ozone (O_3). An air quality index (AQI) is a number used by each agencies to communicate to public how polluted the air currently is or how polluted it is forecast to become. As the AQI increases, an increasingly large percentage of the population is likely to experience increased severe adverse health effects. Different countries have their own air quality indices, corresponding to different national air quality standards [12]. Some of these are the Air Quality Health Index (Canada), the Air Pollution Index (Malaysia) and the Air Quality Index (Thailand).

The Pollution Control Department (PCD) by the Ministry of Natural Sources and Environment of Thailand has been used an air quality in term of AQI value. The index is based on five pollutants regulated by the National Ambient Air Quality Standards (NAAQS). The index is calculated from the concentrations of the following pollutants: Particles with an aerodynamic diameter less than 10 micron (PM_{10}), ground-level ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO). The breakpoints between index values are defined for each pollutant separate and the overall index is defined as the maximum value of the index [13]. Different averaging periods are used for different pollutants as shown in Table 2.1.

Table 2.1 Concentrations of each air pollutants compared to AQI values

AQI	PM_{10} (24h)	O_3 (1hr)	SO_2 (24hr)	NO_2 (1hr)	CO (8hr)
	$\mu g/m^3$	ppb	ppb	ppb	ppb
50	40	51	25	85	4.48
100	120	100	120	170	9.00
200	350	203	305	600	14.84
300	420	405	610	1,202	29.69
400	500	509	802	1,594	40.17
500	600	611	1,000	1,993	50.21

This AQI is divided into five categories with increasing levels of health concern as show in Table 2.2. An AQI value below 50 the air quality is good and no health risk. While, the value over 300 represents hazardous air quality and people should avoid outdoor exercise. People with respiratory tract disorder should stay indoors. Therefore, the AQI value represents a significant step forward in providing people with timely, reliable information about air pollution levels using data collected from ambient air quality monitoring (AQM) stations of Thailand.

Since 1996, there are seven ambient air quality monitoring (AQM) stations in Northern Thailand. According to air pollution problem with low visibility is not only large city but in many small areas, the PCD has been increased the number with nine AQM stations during past of decade [5]. At the present, there are sixteen AQM stations across nine provinces in northern Thailand. The highest number of AQM stations in northern Thailand was located in four different part of Lampang province including Lampang meteorological station (37T), Sop Pad health promotion hospital station (38T), Thasi health promotion hospital station (39T) and Lampang government center station(40T). .

Table 2.2 Thailand Air Quality Index

Values	Description	Color	Health Implication
0-50	Good	Blue	No health risk.
51-100	Moderate	Green	No health risk.
101-200	Unhealthy	Yellow	People with respiratory tract disorder should avoid outdoor exercise. Children and the elderly should not spend an extended period of time outdoors.
201-300	Very Unhealthy	Orange	People with respiratory tract disorder should avoid outdoor activity. Children and the elderly should restrict the time spent outdoors.
> 300	Hazardous	Red	People should avoid outdoor exercise. People with respiratory tract disorder should stay indoors.

2.2 Lampang and air pollution

Lampang is one of the eight provinces of upper northern Thailand, covering an area of 12,534 km^2. Most of the area is covered by forest, while agricultural activities, industrial and residential area cover about 20% as show in Figure 2.1. Lampang consists of mountain-valley topography aligning with north-south hill ridges [14]. Such topographical characteristics restrict horizontal dispersion and enhance the air pollution builup in the area, especially during the dry season when the area is under the influence of a high pressure ridge, cionciding with the northeast monsoon, and associated temperature inversions can trap emissions close to the ground and results tend to accumulate in high levels of air pollutions [15].

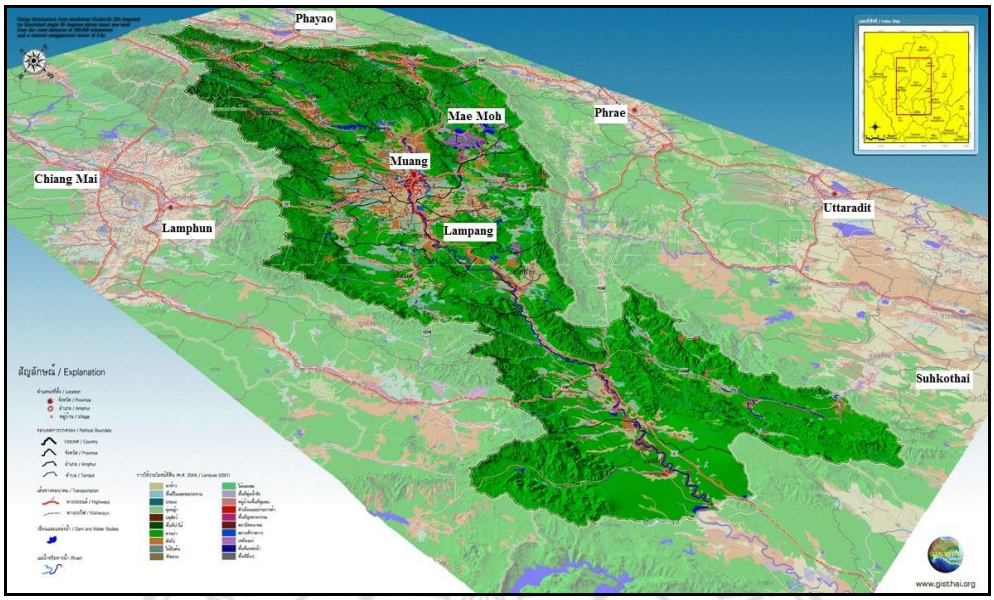


Figure 2.1 Land-use map of Lampang Province [16]

In recent years, the monitoring data reported by PCD illustrates that some criteria pollutants such as SO_2, NO_2 and CO are generally within permitted levels. However, There are air pollution remains a major concern in Lampang. Figure 2.2 shows the maximum 1 hour of O_3 levels were mostly exceeded the standard of 100 ppb/hour in March and April and espeacially in 2015 [4].

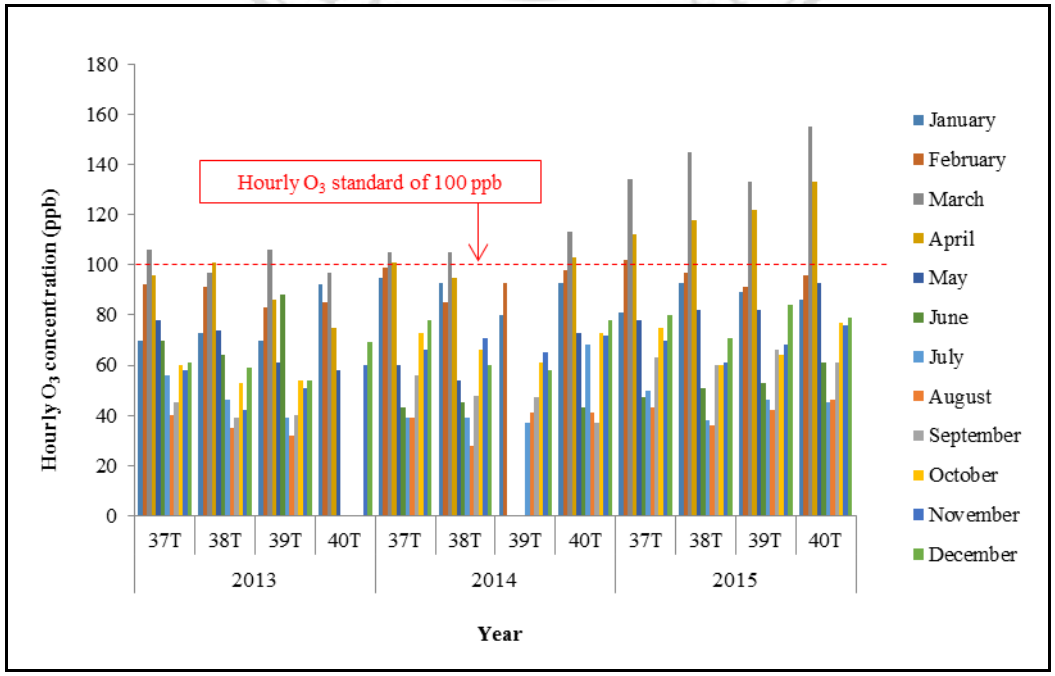


Figure 2.2 Maximum 1 hour of O_3 levels (ppb)

A significant increase of maximum 24 hour of PM_{10} levels are almost exceeded the standard of 120 µg/m^3/day. High PM_{10} levels were found at every AQM stations easpeacially in January, February, March and April as show in Figure 2.3. As the results, the PCD has provided that AQI value is usually based on O_3 and PM_{10} levels which pose the greatest threat to human health effects [4].

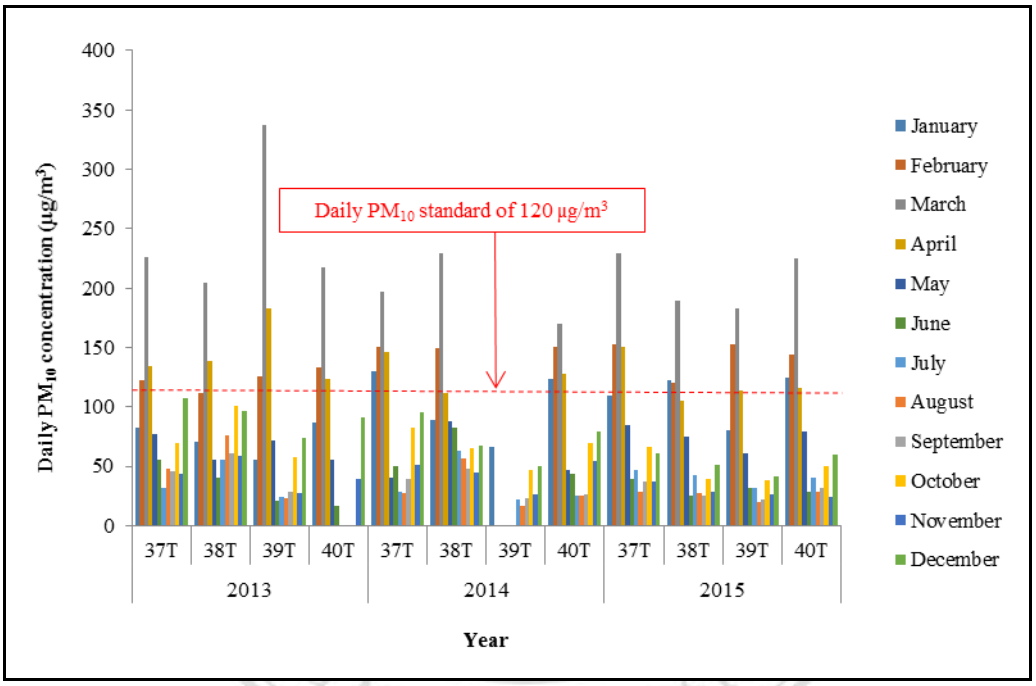


Figure 2.3 Maximum 24 hour of PM_{10} levels (µg/m^3)

The air pollutant emission sources differ for each area in Lampang. In general, major sources of urban air include transport, industry and construction. Whereas, the major sources of suburban area were include biomass burning, forest fires and ceramic factory [9]. However, some important areas such as Hangchat district, it has been examined that the rice straw burning is one of the main emission sources in the area [14]. In addition, Mae Moh district has been experienced to severe air pollution problems where the coal fired power plant is thought as the main source of pollutants in the area [17].

2.3 Mae Moh basin and its air pollution

The Mae Moh basin is situated in the Mae Moh District of Lampang Province. It is distributed in the area of about 135 square kilometers and 7 kilometres in east-west and 16 kilometres in north-south [1]. The basin floor is about 320-340 meters above mean sea level. It is surrounded by high mountain ranges [18]. Since the abundant lignite resources found in the basin are predominantly low rank coal, the utilization processes are mostly conventional combustion to generate electricity owned and operated by the Electricity Generating Authority of Thailand (EGAT) [19]. The Mae Moh power plant associated with Mae Moh mining in Mae Moh basin (Figure 2.4), is one of the largest coal fried power plant in Thailand and Southeast Asia, with a total capacity of 2,400 megawatts. It is providing most of important electricity to the northern part and the rest to the north eastern and central part of Thailand [20].

Figure 2.4 Mae Moh mine and Mae Moh power plant

During coal combustion in power plants, the mineral matter present in coal undergoes a series of physical and chemical changes. Trace elements and polycyclic aromatic hydrocarbon (PAHs) contained many concentrate in the particles, fly ash, bottom ash as well as the combustion gases [21]. These plants operation causes both direct and indirect environmental impacts on land use, quality of life, forests and wildlife. It has also caused pollution such as forms as dust, noise, soil and water contamination [22].

Mae Moh experiences considerable air pollution problems which have been linked to increased health problems and mortality. Since the extreme air pollution was occured in Obtober 1992, thousand village people residing within seven kilometers of the plant feel ill with breathing difficaulties, nausea, dizziness and imflammation of eyes and nasal cavities cuased by inhalation of the sulfur dioside gas. Pollution problems recurred in Aril and May 1996 when six village people in the Mae Moh area died of blood poisoning. Severe air pollution in 1999 left hundreds sick and more than 600 local people suffered repiratory problems cuased by high sulfur dioside and particulates emissions. Approximately 4,033,932 tons of carbon dioxide emission was emitted annually into the atmosphere, making a biggest regional contributed to climate change. However, Mae Moh environmental impact during past of decade has been improved. After installation of high quality control system such as fule gas desulphurization (FGD) and electroprecipitation (ESP), the emission of sulfur dioxide, oxide of nitrogen and carbonmonoxide significantly were decreased and belowed the national ambient air standard [23].

At the present, particulate matter such as PM_{10} seems the most serious air polltants in the area that daily evrage PM_{10} concentration often exceed the Thai ambient air quality standard of 120 $\mu g/m^3$ espeacially in the dry season. The previous study show that the power plant is not the single sources of paticulate matter [24]. There are other sources in this area such as mining activities, vehicular emission, road dust and biomass burning that also have obvious effects on the ambient concentration of particualtes [3, 23, 24].

2.4 Particulate Matter (PM)

Particulate matter is a complex mixture of solid and liquid particles that are suspended in air. Their properties are often categorized according to aerodynamic particle diameter in micrometers. Particulate matter that is 100 microns or less in diameter is know as total suspended particulate matter (TSP). Particulate matter that is 10 microns or less in diameter is know as PM_{10} and 2.5 microns or less in diameter is know as $PM_{2.5}$ (Figure 2.5). These particles are typically consist of a mixture of inorganic and organic chemicals including carbon, sulfates, nitrates, metals, acids and semi-volatite componds.

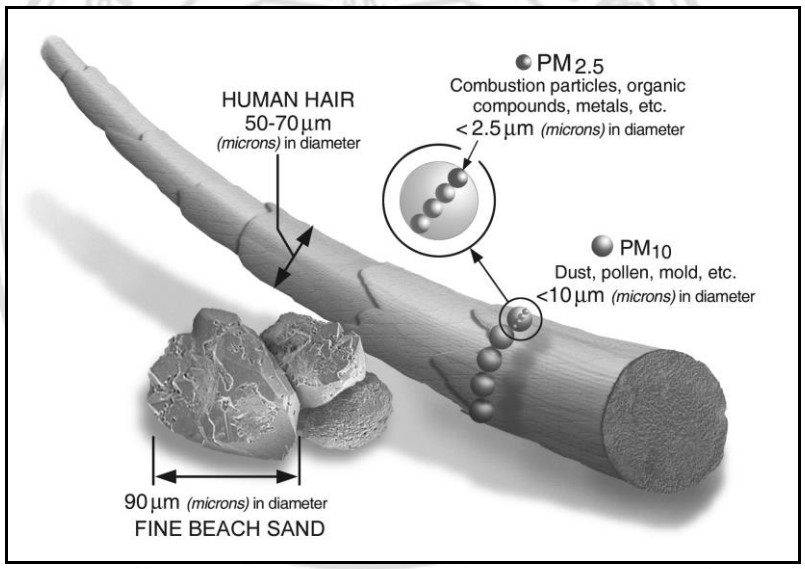


Figure 2.5 Comparison of particle size of hair and beach sand [25]

The PM_{10} and $PM_{2.5}$ are preferred for more targeted response to the problems related with inhale exposure than TSP as they are more dangerous to human health. Short term exposure to PM_{10} can irritate the lungs and resistant responses of lung construction, proceeding shortness of breath and cough. The PM_{10} can deposit in the upper respiratory tract while the $PM_{2.5}$ travel deeper into the lungs and remain for longer period of time [26].

Air quality guidelines and standards were developed in an attempt to reduce adverse impacts on human health and the environment. Ambient air quality standards for PM_{10} and $PM_{2.5}$ from United State of Environmental Protection Agency (US EPA), European Union (EU), World Health Organization (WHO) and selected countries in

Asia including Thialand were shown in Table 2.3. In Thailand, the annual PM_{10} standard is 50 μg/m^3, against the Vietnam and WHO guideline of 20 μg/m^3, and the 24 hour PM_{10} standard is 120 μg/m^3, compared to EU and WHO guideline of 50 μg/m^3. Similarly, the annual $PM_{2.5}$ standard is 25 μg/m^3 were higher than 1.6, 2.5 times as the USEPA and WHO guideline respectively. The 24 hour $PM_{2.5}$ standard, at 50 μg/m^3, is also 1.4 times higher than the USEPA, WHO, and Singapore guideline, respectively. Therefore, the PM quality standards in Thailand are usually above many times and also quite weak compared to the recommendations of the US EPA and WHO guideline [27].

Table 2.3 Summary of PM_{10} and $PM_{2.5}$ Standards (μg/m^3)

Source	PM_{10}		$PM_{2.5}$	
	24 hour	Annual	24 hour	Annual
US EPA	150	50	35	15
EU	50	40	-	35
WHO	50	20	35	10
Hongkong	180	55	-	-
India	100	60	60	40
Indonesia	150	-	-	-
Malaysia	150	50	-	-
Philippines	150	60	-	-
Republic of Korea	100	50	-	-
Singapore	150	-	35	15
Sri Lanka	100	50	-	-
Thailand	120	50	50	25
Vietnam	150	20	-	-
Japan	100	-	35	15

2.5 Implication of PM_{10}-bound PAHs

2.5.1 Formation and properties of PAHs

One of the most serious organic pollutants in particulate matter in term of health risk is polycyclic aromatic hydrocarbons (PAHs). PAHs are a group of organic compounds made up of two or more fused benzene rings in linear, angular or cluster arrangements. Different arrangements of the rings have resulted in identification of over hundred different compounds and generally occur as complex mixtures rather than single compounds. In addition, PAHs is used to include similar compounds with nitrogen, oxygen or sulfur substituents such as nitro-PAHs, hydroxy-PAHs and heterocyclic compounds. PAHs are classified by their boiling point, vapor pressure and water solubility depending on their structure. Most PAHs, especially as molecular weight increase, are soluble in non-polar organic sovalents and barely soluble in polar water. Table 2.4 shows structure and properties of some PAHs [28].

Table 2.4 Structure and properties of some PAHs

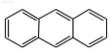
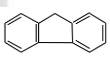
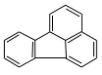
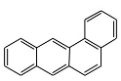
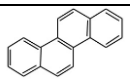
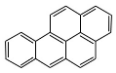
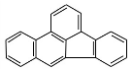
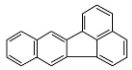
Compound	Water solubility (mg/l)	Vapor pressure (Pa)	Boiling point (°C)	Structure
Naphthalene	31	11.9	218	
Acenaphthene	3.8	0.50	279	
Anthracene	0.04	3.4×10^{-3}	340	
Phenanthrene	1.1	9.07×10^{-2}	339-340	
Fluorene	1.9	0.432	295	
Fluoranthene	0.2	1.08×10^{-3}	375-393	
Pyrene	0.13	5.67×10^{-4}	360-404	
Banz[*a*]anthracene	0.011	6.52×10^{-7}	435	

Table 2.4 Structure and properties of some PAHs (Continued)

Compound	Water solubility (mg/l)	Vapor pressure (Pa)	Boiling point (°C)	Structure
Chrysene	0.0019	1.04×10^{-6}	441-448	
Banzo[*a*]pyrene	0.0015	6.52×10^{-7}	493-496	
Benzo[*b*]fluoranthene	0.0015	1.07×10^{-5}	168	
Benzo[*k*]fluoranthene	0.0008	1.28×10^{-8}	217	
Benzo[*ghi*]perylene	0.00014	1.33×10^{-8}	525	

2.5.2 Sources characterization

PAHs can be found in various compartments of environment include air, surface water, sediment, soil, food and in lipid tissue of both aquatic and terrestrial organisms. The major sources of PAHs emission may be divided into two classes. PAHs are formed mainly as a results of anthropogenic processes, espeacilally the incomplete combustion of organic materials during industril and other human activities, such as processing of coal and wood, combustion of natural gas, including for heating, combustion of fuel, vehicle traffic, cooking and tobacco smoking, as well as some part of natural processes such as forest fires and volcanoes. Specific PAHs has been suggested as being indiactive for certain processes that release PAHs into the environment. These PAHs are called chemaical marker for source characterizations. The concentrations of specific PAH compounds, or a group of PAHs, have been used to indicate towards the corresponding emission sources. Table 2.5 shows the sources characterization by different chemical marker [29].

Table 2.5 Sources characterization by different chemical markers

Sources	Activities	Chemical markers
Stationary sources	Steel industry	BaP and BaA
	Power plant	DBA
	Incineration	Pyr, Flu, IDP and Chr
Mobile sources	Diesel vehicle emission	Flu, Phe, Pyr, Chr, BbF and BghiPe
	Gasoline vehicle emission	Flu, Chr, IDP and BghiPe
Combustion	Combustion of incineration	Pyr, Flu and Phe
sources	Roadside soil particles	Phe, Flu and Pyr
	Pyrolysis of fuels	Flu, Pyr, Phe, BghiPe and IDP
	Industrial oil burning	Pyr, Chr, and BaP
	Wood burning	BaP
	Coal combustion	Chr, BkF

Acy, Flu, Pyr, Chr, BbF and BghiPe are markers for vehicle emissions. Phe, Flu and Pyr are associated with roadside soil particles, which appear to be absorbing volatile PAHs from vehicle emissions as well. BaP and Flu can be tracers for wood combustion or oil industrial combustion. The Chr, BkF, Phe, Flu and Pyr are usually associated with coal combustion [30].

2.5.3 Distribution patterns

Distribution patterns of PAHs could be classifried according to their number of aromatic rings as follow 2-ring including Nap, 3-ring including Acen, Ace, Fle, Phe and An, 4-ring including Flu, Pyr, Chr and BaA, 5-ring including BbF, BkF, Banzo[*a*]pyrene and DBA, 6-ring including BghiPe and IDP. They can be further classifired into low molecular weight (LMW) including 2- and 3-rings PAHs, middle molecular weight (MMW) including 4-rings PAHs and high molecular weight (HMW) including 5- and 6-rings PAHs as show in Table 2.6 [31].

Table 2.6 Ring number and their relative molecular weight of some PAHs

PAHs Compound	Abbreviation	Ring number	Relative Molecular Weight
Low molecular weight	LMW		
Naphthalene	Nap	2	128.2
Acenaphthylene	Ace	3	152.2
Acenaphthene	Acen	3	154.2
Fluorene	Fle	3	166.2
Phenanthrene	Phe	3	178.2
Anthracene	Ant	3	178.2
Middle molecular weight	MMW		
Fluoranthene	Flu	4	202.3
Pyrene	Pyr	4	202.3
Chrysene	Chr	4	228.3
Banz[*a*]anthracene	BaA	4	228.3
High molecular weight	HMW		
Benzo[*b*]fluoranthene	BbF	5	252.3
Benzo[*k*]fluoranthene	BkF	5	252.3
Banzo[*a*]pyrene	BaP	5	252.3
Dibenz[*a,h*]anthracene	DBA	5	278.4
Benzo[*ghi*]perylene	BghiPe	6	276.3
Indeno[1,2,3-*cd*]pyrene	IDP	6	276.3

Futhermore, LMW PAHs can be tracers for wood combustion or industril combustion of oil. MMW PAHs are usually associated with coal combustion and can be identified from this source [32]. HMW PAHs may be associated with vechicles emission, and can be regarde as tracers for this source [33]. When PAHs entered the atmosphere, they are found in both gaseous and particulate phases. LMW PAHs with 2- and 3-aromatic rings almost usually exist in gaseous phase while those MMW PAHs with 4-aromatic rings are semi volatile organic compounds and usually associated with in both gaseous and particulate phase. HMW PAHs with 5- or more aromatic rings are predominantly exist in particulate phase [34]. Thus, they are normally associated with particle phase, although a sinificant amount remain in the gas phase. Since the most

toxic potential of middle to high molecular weight PAHs is very well established [35]. Many studies on PAHs in ambient air are focused on PAHs bound to particulate matter [12, 29].

2.5.4 Toxicity of PAHs

Due to widespread sources and persistant characteristics, PAHs disperse through atmospheric transport and exist almost everywhere. The effects on human health depend on mainly on the length and route of exposure, the amount or concentration of PAHs one is exposed to, and of course the innate toxicity of PAHs [36].

Mixtures of PAHs are known to cause skin irritation and imflamation. Nap is direct skin irritants, while Ant and BaP are reported to be skin sensitizers as cuase of an allergic skin response in animals and humans [37]. The embryotoxic effects of PAHs have been described in experimental animals exposed to high levels of BaA during pregnancy results in birth defects and a decreased body weight in the offspring. It is not known whether these effects can occur in humans [38]. However, the Center for Children's Environmental Health reports studies demonstrate that exposure to PAH pollution during pregnancy is related to adverse birth outcomes including low birth weight, premature delivery, and heart malformations. Concerning the induction of genotoxicity in germ cell effects, Chr gave positive results in chromosome aberrations and dominant lethals in rodents [39].

The most serious PAHs such as BaP are commonly believed to contribute significantly to the development of human cancers. These compounds are metabolized enzymatically to various metabolites. Figure 2.6 shows BaP enters into the cytoplasm and binds to the aryl hydrocarbon receptor (AhR) (a). The complex enters into the nucleus, and associates to the AhR nuclear translocator (ARNT). This tertiary complex binds to specific DNA sequences on the promoter of regulated genes (b), namely genes of the CYP family, such as CYP1A. The correspondent mRNAs are transcribed (c) and migrate to the cytoplasm, where they will serve as template for the synthesis of the corresponding proteins (d). CYP enzymes are able to chemically activate BaP into an epoxide, which is the substrate for the epoxide hydrolase (e). This enzyme catalyzes the formation of dihydrodiols, which can be further activated by CYP into the highly toxic diol-epoxides. These metabolites bind to DNA, leading to mutagenic adducts formation

(f), such studies give support to the link between DNA adducts and the cancer risk in humans [39].

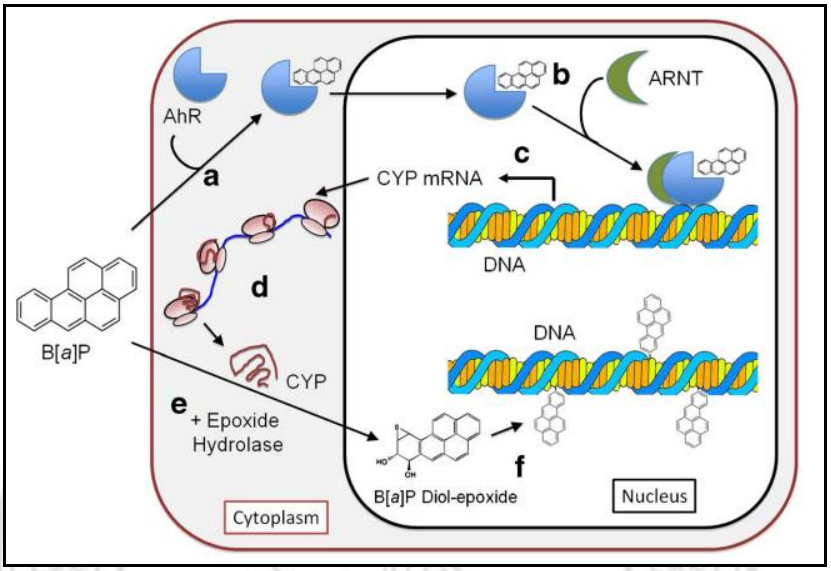


Figure 2.6 PAHs metabolism and toxicity in a vertebrate cell

Besed on the available evidence, both the International Agency for Research on Cancer (IARC) and the US EPA classified a number of PAHs as carcinogenic to nanimals and some PAHs mixtures as carcinogenic to humans. The EPA has classified the seven PAHs componds as being probable human carcinogens including BaA, BaP, BbF, BkF, Chr, DBA and IDP. Table 2.7 shows the carcinogenic classification of sixteen priority PAHs by the US EPA, campared to classifications by the IARC and the United States Department of Health and Human Services (DHHS) [35].

Table 2.7 Carcinogenic classification of 16 PAHs by specific agencies

PAHs	Abbrev	US EPA	IARC	DHHS
Naphthalene	Nap		2B	
Acenaphthylene	Ace	Not classifiable		
Acenaphthene	Acen		3	
Fluorene	Fle	Not classifiable	3	
Phenanthrene	Phe	Not classifiable	3	
Anthracene	Ant	Not classifiable	3	
Fluoranthene	Flu	Not classifiable	3	
Pyrene	Pyr	Not classifiable	3	
Chrysene	Chr	Probably carcinogen	2B	
Banz[*a*]anthracene	BaA	Probably carcinogen	2B	Animal carcinogen
Benzo[*b*]fluoranthene	BbF	Probably carcinogen	2B	Animal carcinogen
Benzo[*k*]fluoranthene	BkF	Probably carcinogen	2B	
Benzo[*a*]pyrene	BaP	Probably carcinogen	1	Animal carcinogen
Dibenz[*a,h*]anthracene	DBA	Probably carcinogen	2A	Animal carcinogen
Benzo[*ghi*]perylene	BghiPe	Not classifiable	3	
Indeno[1,2,3-*cd*]pyrene	IDP	Probably carcinogen	2B	Animal carcinogen

IARC classification: Group 1 (carcinogenic), 2A (probably carcinogenic), 2B (possible carcinogenic), 3 (not classifiable).

2.6 Literature reviews of PM_{10}-bound PAHs

Ruksasap and group were found 24 hour PM_{10} concentration nearby the power plant which natural gas as primary fuel varied from 18.0 to 79.3 $\mu g/m^3$ at site A, which is 18 km distant from stack in the direction of northwestern. The PM_{10} concentrations were found to be higher during dry season than monsoon season and not exceeded national standard at 120 $\mu g/m^3$. The total 16 PAHs concentrations varied from 0.2 to 8.0 ng/m^3. The high levels of PAHs species found in the samples were DBA, BaP, BbF and BghiPe [40].

The characteristic of 16 PAHs in PM_{10} collected form the Bangkok urban air were investigated. The results of the study revealed that high molecular weight PAHs were more abundant in airborne particle (91.7% of the total PAHs) than those of low molecular weight PAHs. BghiPe, BbF, BeP, IDP and BaP were predominant PAHs in the area folloewd by Chr, Flu, Pyr, BaA, Phe, BkF, DBA, Nap, Ace, Fluo and Ant respectively. Statistical analysis showed that total PAHs and carcinogenic PAHs are strongly correlated with the mass of PM_{10} but weakly correlated with the traffic volume of the area [41].

The spatial distribution and concentration profiles of 39 vapor and particulate PAHs have been investigated in two Japanese industrial cities. The concentrations of particulate PAHs in winter tended to be higher than those in the summer, but for vapor PAHs. Significant correlations were found between most of the PAH concentrations monitored in winter, suggesting the common emission sources. PAH profiles based on benzo[*e*]pyrene (BeP) concentration showed differential behaviors among divided areas related to potential regional emission sources such as paper-making plants, power plants, and traffic and that local distributions were dependent on the local wind direction [42].