中文摘要

本論文主要研究目的在於評估寺廟燒香環境中香客與寺廟工作人員暴露於氣懸顆粒物質 (particulate matters，PMs) 與多環芳香烴化合物 (polycyclic aromatic hydrocarbons，PAHs) 之健康風險。本研究以一整合性機率風險評估架構應用予前人發表之實驗數據中，並採用苯並[a]芘 (benzo[a]pyrene，B[a]P) 與其毒性當量濃度 ($B[a]P_{eq}$) 兩種方法去評估 PAHs 之致癌風險。然而，此架構整合流行病學與動物實驗資料、終生癌症風險模式、人體呼吸道 (human expiratory tract，HRT) 模式及以生理為基礎之藥理動力或動態學(physiologically-based pharmacokinetics/pharmacodynamics，PBPK/PD) 模式，進而推估人體肺部不同粒徑 PM 之暴露量、人體組織中 PAHs 之濃度以及三個不同程度暴露族群之癌症風險。結果顯示極度與高度暴露族群之吸入增量終生癌症風險 (incremental lifetime cancer risk，ILCR) 高於美國環境保護署 (United States Environmental Protection Agency，USEPA) 所建議之百萬分之一 (10^{-6}) 的標準，且三個暴露族群在食入與皮膚接觸途徑同樣有較高的 ILCR (10^{-6}–10^{-4})；極度暴露族群 95% 機率之總 ILCR (TILCR) 範圍為 $9.87\times10^{-4} – 1.13\times10^{-3}$，而高度與適度暴露族群則分別為 $6.44\times10^{-5} – 7.50\times10^{-5}$ 與 $5.75\times10^{-6} – 6.99\times10^{-6}$，結果指出極度暴露族群具有高潛在之健康風險。 PM 與 B[a]P 之質量中位粒徑 (mass median diameters，MMDs) 在肺泡區塊中為最小，且肺泡區塊中之細粒徑 PM 與 PAHs 平均每日劑量顯著地高於氣管、支氣管及細微支氣管區塊。 針對外部 B[a]P 與 $B[a]P_{eq}$ 暴露，分別有 50% 機率之去氧核糖核酸 (deoxyribonucleic acid，DNA) 加成產物頻率比超過 1.28 (95% confidence interval (CI): 0.55 – 2.40) 與 1.78 (95% CI: 0.84 – 2.95)，針對內部 B[a]P 與 $B[a]P_{eq}$ 暴露，分別有 10% 或以上機

率之人體肺部腫瘤發生率為 7.62×10^{-5} % (95% CI: 3.39×10^{-5} – 1.71×10^{-4} %) 與 3.87×10^{-4} % (95% CI: 1.72×10^{-4} – 8.69×10^{-4} %)。結果指出人體暴露於寺廟中之 PAHs 可能導致顯著 DNA 加成產物之形成，進而促使肺部腫瘤之發展。本研究成功提出一整合性風險評估架構評估台灣寺廟中可呼吸性 PMs 與致癌性 PAHs 之人體暴露與健康風險。本研究結果亦可提供作為未來室內空氣品質管理與擬定標準之參考。

關鍵詞：寺廟；拜香；顆粒物質；多環芳香烴化合物；苯並[a]芘；機率性；人體呼吸道；以生理為基礎之藥理動力學；風險

Abstract

The major objective of this thesis is to assess human health risks from exposure to airborne particulate matters (PMs) and polycyclic aromatic hydrocarbons (PAHs) during working in or visiting a typical Taiwanese temple. We present an integrated probabilistic risk assessment framework appraised with reported empirical data. Benzo[a]pyrene (B[a]P)- and B[a]P toxic equivalents ($B[a]P_{eq}$)-based concentrations are applied to assess PAHs. The framework integrates epidemiological and animal experimental data, lifetime cancer risk model, human respiratory tract (HRT) model, physiologically based pharmacokinetic (PBPK) models, and pharmacodynamic (PD) -based dose-response models to quantitatively estimate levels of size-dependent PM exposure in human lung regions, PAHs concentrations in human tissues, and cancer risks for three groups with different levels of exposure. The results show that the incremental lifetime cancer risks (ILCRs) are greater than the acceptable level of 10-6 for extreme and high exposed groups through inhalation route. The result also indicates that the higher ILCRs (10^{-6} – 10^{-4}) are found in ingestion and dermal contact route for three exposed groups. For personal extreme exposure to carcinogenic PAH in the temple, 95% probability total ILCR (TILCR) (9.87×10^{-4} – 1.13×10^{-3}) is much greater than the range of 10^{-6} – 10^{-4}, indicating high potential health risk; whereas for high and moderate exposed groups, 95% probability TILCRs range from 6.44×10^{-5} to 7.50×10^{-5} and 5.75×10^{-6} to 6.99×10^{-6}, respectively. The alveolar–interstitial (AI) region has the smallest median mass diameters (MMDs) of PM and B[a]P. The average daily doses of PMs and PAHs obtained from fine fraction depositing to the AI region are significantly higher than those to the bronchial (BB) and bronchiolar (bb) regions. The 50% probability of exceeding the deoxyribonucleic acid (DNA) adduct frequency ratios are estimated to be 1.28 (95% confidence interval (CI): 0.55 – 2.40)

and 1.78 (95% CI: 0.84 – 2.95) for external exposure of B[a]P and $B[a]P_{eq}$, respectively. The probability of 10% or more of human affected by lung tumor is approximately 7.62×10^{-5} % (95% CI: 3.39×10^{-5} – 1.71×10^{-4} %) and 3.87×10^{-4} % (95% CI: 1.72×10^{-4} – 8.69×10^{-4} %) based on the internal exposure profiles of B[a]P and $B[a]P_{eq}$, respectively. Here we show that human exposure to B[a]P in temples may induce significant levels of DNA adducts and that promote lung tumor development. This study successfully provides a framework for refinements in exposure and health risk assessment of respirable PMs and carcinogenic PAHs in Taiwanese temples. Our results can provide as a reference index in the future for better indoor air quality management.

Keywords**:** Temple; Incense burning; Particulate matters; Polycyclic aromatic hydrocarbons; Benzo[a]pyrene; Probabilistic; Human respiratory tract; PBPK; Risk