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Human Exposure to Polynuclear Aromatic Hydrocarbons

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INTRODUCTION

Polynuclear aromatic hydrocarbons (PAH) are formed in combustion processes involving fossil fuels, or more broadly, from compounds containing carbon and hydrogen. The emissions of PAH from motor vehicles have been well documented. Benzo[a]pyrene (BaP) constitutes about 3 to 5% of the emitted, identified PAH from motor vehicles. The area-wide contribution of PAH from motor vehicles is thought, however, to be a small percentage (about 1%) of the total ambient loading. Localized exposures to motor vehicle exhaust may, however, increase this component. Principal sources of ambient PAH are heat and power generation, refuse burning, and coke production. It should be stressed that present crude emissions inventories for PAH may contain significant errors.

In addition to polynuclear compounds in ambient air, exposure also occurs from sources of PAH in the indoor environment including industrial contamination and cigarette smoking. Cigarettes, in general, represent the most important overall source of exposure among smokers. Sidestream cigarette smoke may, however, result in high exposures for nonsmokers in the indoor environment.

This paper examines the localized concentrations of PAH and estimates exposure levels which people encounter from various sources. These estimates are then compared to levels of exposure experienced by cigarette smokers, using BaP as an index compound. In this regard, it is recognized that to the extent that polynuclear aromatic compounds besides BaP are also present, BaP represents a poor surrogate for this purpose. Unfortunately, better data are generally not available.

MOTOR VEHICLE EMISSIONS OF PAH

The emissions of PAH from light duty motor vehicles were examined by Gross in 1972 and 1973 (1,2). Over 40 PAH species were identified in automobile exhaust, several of which are considered to be carcinogenic. Emis-

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TABLE 1. PNA Tailpipe emission factors[a]

Vehicle model year group	PNA emission factor
pre-68	100
68–69	41
70–71	30
72–74	31
75 U.S.	4.4
75 Calif.	2.6
Statutory standards	1

[a] Moran, J. B., "Lead in Gasoline: Impact of Removal on Current and Future Automotive Emissions," paper presented at the Air Pollution Control Association Annual Meeting, June 1974.

sions of PAH are greatest from uncontrolled (pre-1968) motor vehicles, much reduced in 1974 vehicles, and will be further reduced when the statutory standards for CO and hydrocarbons are implemented. This is because PAH emissions are related to CO emissions. Reductions in CO emissions result as a by-product in reduced PAH. Table 1 shows the relative PAH emissions from motor vehicles as a function of model year.

TABLE 2. Estimated highway exposures to exhaust PNA (as BaP) at the end of the 1976 model year

Peak hourly exposure to auto passenger:	
typical meteorology:	0.0009 $\mu g/m^3$
adverse meteorology:	0.016 $\mu g/m^3$
24-hr exposure (person living near expressway):	
adverse meteorology:	0.0011 $\mu g/m^3$

The resultant PAH emissions from the motor vehicle population of the United States were examined in detail by Moran et al. (3) of the Environmental Protection Agency in 1974. The impact of various emissions standard options was also examined in that paper. The methods developed therein are used in this chapter to estimate PAH emissions from the motor vehicle population and to estimate actual exposures, including peak hourly, and average daily *commuter* exposures to PAH, using the carboxyhemoglobin surrogate model for mobile source pollutants. Table 2 shows exposure estimates as projected by the end of the 1976 vehicle model year using this technique. Peak hourly exposures to BaP for automobile passengers during adverse meteorologic conditions are projected to be about 0.015 $\mu g/m^3$.

OCCUPATIONAL EXPOSURES

Exposure to PAH in occupational circumstances has, unfortunately, not been well studied. Among the occupational circumstances where high ex-

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TABLE 3. Occupational exposure to BaP

Exposure category	BaP exposure (ng m³)
Sidewalk tarring	78
Coal tar pitch working area	75
Roof tarring area	14
Boston sumner tunnel	0.07

posures have been observed are tarring and coke oven operations. Exposure to PAH in the cockpit of aircraft presumably as a result of sidestream cigarette smoke, is substantial. Sawicki in 1967 (5) reported concentrations of BaP in the ambient air near various emissions sources associated with occupational activities. These data are shown in Table 3. Measurements of BaP during tarring operations ranged from 14 to 78 $\mu g/m^3$. Eight-hour average exposures to BaP for workers in coke ovens and for pilots based upon data compiled by the National Institute for Occupational Safety and Health are shown in Table 4. Eight-hour exposures to BaP for coke oven workers

TABLE 4. Occupational exposure to BaP

Exposure category	8-hr average BaP exposure ($\mu g/m^3$)
Coke ovens	
Top side exposure	18
Side and bench exposure	7
Cockpit of aircraft	
Transatlantic flights	0.093
Domestic flights	0.138

ranged from 7 to 18 $\mu g/m^3$. Pilots on transatlantic and domestic flights experienced 8-hr average BaP concentrations on the order of 0.1 $\mu g/m^3$.

EXPOSURE TO BaP FROM CIGARETTES

BaP is one of many PAH known to be present in cigarette smoke. A report published in 1972 by the National Academy of Sciences (4) estimated that a one-pack per day smoker of unfiltered cigarettes would inhale about 0.7 μg of BaP each day. A smoker of filtered cigarettes at one-pack per day might inhale about 0.4 μg/day of BaP.

EXPOSURE TO PAH IN INDOOR AIR

The concentration of polynuclear compounds in the indoor environment is a function of a number of factors including the frequency of smoking, the

air turnover rate, the size of the room, and the presence of other sources besides cigarettes. Shown in Table 5 are the results of measurements which have been made at several indoor locations including data compiled by the National Institute for Occupational Safety and Health inside aircraft on transatlantic and domestic flights expressed as the average of concentrations in the cockpit, front, middle, and rear cabins. The aircraft data were compiled prior to the establishment of smoking and nonsmoking sections in commercial aircraft, but it is evident from these data that considerable exposure to polynuclear aromatics may occur in similar circumstances. For example, Schmeltz et al. (6) in 1975 summarized data showing indoor BaP concentrations ranging from 0.03 to 0.14 $\mu g/m^3$ in a restaurant and from

TABLE 5. Nonoccupational exposure to BaP

Location	BaP concn. ($\mu g/m^3$)
Restaurant	0.03–0.14
Kenyan hut	0.02–0.16
Inside aircraft	
Transatlantic flights	0.085 average of 0.150 cockpit, front, middle, and rear cabins
Domestic flights	

0.02 to 0.16 $\mu g/m^3$ in a Kenyan hut. These data show the high concentrations of BaP which can occur indoors as a result of smoking and cooking.

ASSESSMENT OF TOTAL EXPOSURE TO POLYNUCLEAR AROMATICS

Total exposure to polynuclear aromatic compounds, for any individual, using BaP as an index compound is a function of a number of factors including occupations, smoking habits, activity patterns, and residence. To facilitate comparison between various factors, exposures to PAH are expressed as cigarette equivalents, that is, the number of cigarettes smoked which would result in a similar BaP intake. This comparison, however, does not establish an order of hazard from these sources since toxicity depends upon a number of factors in addition to BaP. In this regard, the presence of nonaromatic hydrocarbons and nonorganic materials including trace metals has been shown to affect the carcinogenic potential of BaP using animal test systems.

Contrasts showing relative exposure to BaP are shown in Table 6. Occupational and ambient exposures assume inhalation of 10 m^3 of air during an 8-hr daily exposure period. Exposure to ambient BaP levels in urban air of 0.002 $\mu g/m^3$ is assumed in these calculations.

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TABLE 6. Influence of occupational and other factors upon BaP intake

Factor	BaP intake (μg/day)	Cigarette equivalents (packs/day)
Smoking one pack of cigarettes each day	0.4	1
Coke oven workers		
Top side exposures	180	450
Side and bench exposure	70	175
Coal tar pitch workers	750	1875
Airplane pilots		
Transatlantic flights	0.93	2.3
Domestic cross country	1.38	3.5
Employee in restaurant	0.8	2
Person living near expressway 24-hr/day (adverse meteorology)	0.02	0.05
Commuter on an expressway 2-hr/day (adverse meteorology)	0.04	0.10
Exposure to ambient BaP levels 8-hr/day	0.02	0.05

Although the above approach is admittedly simplistic, several conclusions may still be drawn. Among the most important conclusions are the following:

1. Human exposure to polynuclear aromatic hydrocarbons may occur from contamination of the indoor as well as the ambient environment.
2. The most important source of BaP exposure, in general, for smokers would be from cigarettes.
3. Workers in selected occupations have orders of magnitude greater exposures to BaP than do cigarette smokers.
4. Exposure to BaP in the indoor environment may be substantial.
5. BaP emissions from motor vehicles are relatively small compared to other sources. However, motor vehicle BaP emissions make an important contribution to total exposure for the nonsmoking vehicle using urban resident.
6. Activity model analyses, considering exposure while on and off the job may yield valuable insights as to the existence of potential high risk exposure groups.

In this regard, one final point deserves mention. At times there has not been an adequate recognition of the valuable information that may be obtained from considering both community and occupational studies in the setting of environmental exposure standards. A basic assumption in setting occupational standards has often been that exposure to a given chemical occurs exclusively while on the job and that exposure off the job is minimal or nonexistent. The activity model approach employed in this paper demonstrates that while for certain occupational categories exposed to BaP, this

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assumption is likely true, for others such as employees in restaurants and drivers of cars, this would not necessarily be the case. Clearly, one needs to consider total exposure both on and off the job in assessing the potential health effects of chemicals upon man.

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