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Evaluation of airborne respirable particulate matter and polycyclic aromatic hydrocarbon exposure of asphalt workers

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Abstract

Introduction: Assessment of exposure to the airborne respirable particles (PM10) and polycyclic aromatic hydrocarbons (PAHs) of asphalt manufacturing and road paving workers in the Campania region (Italy).
Materials and Methods: A study was carried out during 2006 and involved 5 firms producing and employing bitumen in road paving activities. The workers studied were categorized on the basis of their job as workers in bitumen manufacturing, in road paving and in workers not exposed at bitumen fume considered like controls.
Results: In the manufacturing plants the average concentrations of airborne PM10 were 1125±445 μg/m3 in the HMA manufacturing workers' areas; 314±81 μg/m3 in the process surveyors' cabins and 92±27 μg/m3 in the controls' areas (administrative offices). Within the breathing zones of the worker, the average PAHs levels in air were as follows: 367±198 ng/m3 for HMA manufacturing workers; 348±172 ng/m3 for process surveyors; 21±2 ng/m3 for the controls. At the road paving sites the average airborne PM10 levels were 1435±325 μg/m3 for roller operators; 1610±356 μg/m3 for paver operators; 319±108 μg/m for the controls (traffic controllers). PAHs in the breathing zones were 1220±694 ng/m3 for the paver operators; 1360±575 ng/m3 for the roller operators' and 139±135 ng/m3 for the traffic controllers'. The results show that the more consistent hazard for asphalt workers' health is derived from exposure to airborne PM10 both in exposed and in non-exposed (controls) workers.

Key words: asphalt workers, exposure, respirable particulate matter, airborne polycyclic aromatic hydrocarbons

Introduction

In the USA the National Institute for Occupational Safety and Health (NIOSH) in 2000 published an update on the health effects of occupational exposure of those U.S. workers potentially exposed to asphalt and asphalt fumes during the manufacturing of asphalt products and during paving and roofing operations. Workers employed in the asphalt industry showed a large variety of irritation symptoms. In particular besides nasal and throat irritation, headache and coughing, workers with occupational exposures to asphalt fumes during paving operations, insulation of cables and during the manufacturing of fluorescent light fixture also reported skin irritations, pruritus, rashes, nausea, stomach pains, decreased appetite and fatigue. Workers involved in asphalt paving operations also experienced coughing, wheezing, shortness of breath and pulmonary function changes.

The irritant symptoms were noted in workers involved in open-air paving operations, whose average personal exposures were generally below 1.0 mg/m3 total particulates and 0.3 mg/m3 benzene-soluble particulates, calculated as a full-shift time-weighted average (TWA). On the basis of the data from studies in animals and humans, and in vitro studies, NIOSH concluded that exposure to fumes from roofing, paving, and other uses of asphalt is correlated in workers with irritation of the eyes, nose, and throat when the concentrations of total particulates are generally below 1 mg/m3 and those of benzene-soluble or carbon disulfide-soluble particulates are below 0.3 mg/m3, calculated as a full-shift TWA. Data on chronic pulmonary effects, such as bronchitis, have been considered not sufficient to support an association with asphalt fume exposure. Data regarding the potential carcinogenicity of asphalt fume exposure in humans were also reviewed. The carcinogenic potential of asphalt is derived principally from the carcinogenic polycyclic aromatic hydrocarbon (PAH) content of the fumes, this in turn mainly depends on the heating temperature of the asphalt during the manufacture of asphalt products and when used in the field. The available data from studies in humans have not provided consistent evidence of the carcinogenic effects in exposed asphalt paving workers, but they have not precluded a carcinogenic risk from asphalt fumes generated during paving operations. The results from epidemiologic studies have indicated that roofers are at an increased risk of lung cancer, but it is uncertain whether this increase can be attributed to asphalt and/or to other exposures such as coal tar or asbestos. NIOSH concluded that, as the data considered were not sufficient for quantifying the acute and chronic health risks of exposure to asphalt, asphalt-based paint, or asphalt fumes and vapors, additional studies are needed to better characterize exposures and to evaluate the risk of chronic disease, including lung cancer. However, NIOSH recommended to minimize possible acute or chronic health effects from exposure to asphalt by adhering to the current NIOSH recommended exposure limit (REL) of 5 mg/m3 during any 15 min period and by implementing preventive practices as protection from dermal exposure, decreasing the temperature of heated asphalt; using engineering controls and good work practices at all work sites to minimize worker exposure to asphalt fumes and asphalt-based paint aerosols as well as protecting workers by appropriate respiratory safety devices [1]. Furthermore the American Conference of Governmental Industrial Hygienists (ACGIH) in 2004 [2] recommended that exposure to asphalt fumes should be limited to a benzene extractable inhalable particulate (BEIP) threshold limit value (TLV) of 0.5 mg/m3. In Europe, Boffetta et al.2003 [3] reported the results of a multi-country epidemiological study on cancer mortality conducted among European asphalt workers. The results of the analysis of a cohort of 29,820 male workers, employed in the European asphalt industry, exposed to bitumen (synonymous in Europe to asphalt) fumes in road paving, asphalt mixing, waterproofing and roofing, 32,245 ground and building construction workers and 17,757 other workers, with mortality documented from 1953-2000, did not suggest an increased risk of lung cancer following exposure to bitumen fumes. However, in an analysis restricted to road pavers based on a quantitative estimate of bitumen fume exposure, a dose-response was suggested for average levels of exposure to bitumen fumes and an increased lung cancer risk. The cumulative results of the study was not able to conclude the presence or absence of a causal link between exposure to bitumen fume and lung, oral, neck, head and pharyngeal cancer, but it was recommended that case-control studies should be conducted. The cohort studied didn't involve Italian workers. In Italy, about 3000 firms manufacturing and employing asphalt products are registered, in which it is estimated that about 25,000 workers are potentially exposed to bitumen fumes [4] Available data on total particulate matter (TPM) and PAH concentrations of bitumen fumes at worksites in Italy are limited [5-9]. The purpose of this study was to assess exposures to airborne inhalable particles (PM_{10}) and PAHs for bitumen manufacturing and road paving workers in the Campania region (Italy).

Materials and Methods

The study was conducted from April to August 2006 and involved 5 firms producing and employing bitumen in road paving activities in the Campania region. All not-smoking workers involved in bitumen production and in paving activities were invited to participate in the study. The workers considered not directly involved in bitumen fume exposure were invited to participate as controls. Participating workers were categorized on the basis of their job as workers in bitumen manufacturing and workers in road paving. The former group's activity consists in manufacturing hot mix asphalt (HMA) containing from 4% to 10% asphalt cement, typically received from a refinery, and a mixture of coarse and fine stones, gravel, sand and other mineral fillers. Aggregate of different materials and sizes is blended and dried, then coated with a thin film of asphalt cement, which is used mainly as a binder to hold the aggregate together and produce a homogeneous paving mixture. The asphalt cement is heated from about 149 to 177°C and mixed with mineral aggregate heated from 143 to 163 °C. The finished paving mixture is kept heated so that it can be easily applied and compacted, dispensed into trucks and hauled to the paving sites. Once transported to the worksite, the HMA is applied to the road surface. The temperature of application is generally between 112 and 162 °C. At HMA manufacturing plants we categorized as "exposed" the workers whose jobs consisted of a) moving and processing the materials (HMA manufacturing workers) and b) surveying the process (process surveyors) and c) as "not exposed" the administrative personnel (controls). The latter group's activity consists in transferring the HMA from the delivery trucks in a paver vehicle by directly pouring it into a hopper located on the front of the paver or conveying the mix with a material transfer vehicle or dumping the HMA onto the road, where it is picked up by a windrow conveyor and loaded into the paver hopper. At the rear of the paver there is a screed that distributes the HMA on the road to a pre-selected width and depth and grades the HMA to the appropriate slope as the paving moves forward. Typically a roller vehicle follows the paver to compact the asphalt. At paving sites workers usually work different jobs that cover all of the activities requested. We categorized the paver operators and roller operators as asphalt fume exposed workers and the traffic controllers as not-exposed workers. Thirty workers were enrolled in the study. Among the participants, all males 25-40 year aged, fifteen were HMA manufacturing plant workers, ten exposed and five controls, and fifteen road paving workers, ten exposed and five controls. The PM_{10} and PAH exposures were evaluated during 36 measuring campaignes, 19 at HMA plants and 17 at paving road sites. Each evaluation took place during a single daytime work shift (about 8 hours) and included: at worksites, the monitoring of air temperature (T °C), relative humidity (%) and wind speed (m/sec) and the measure of the air PM10 concentration; individually, the personal sampling of air to evaluate the PAH air concentrations at worker's breathing zone.

Climate parameter monitoring

At worksites the climatic parameters of temperature (T °C); relative humidity (%) and wind velocity (m/sec) were monitored daily, during every working shift, by airborne particulate matter monitoring and the air PAH sampling, using the climate monitoring system Babuc A, LSI, Milan, Italy. This instrumentation was employed in this study in indoor (HMA manufacturing plants) as well as outdoor (road paving worksites) measures. We considered the level of approximation of the outdoor climatic measures sufficient for the purpose of the study.

Airbone particulate matter (PM_{10}) monitoring

At the worksites the airborne respirable matter (PM_{10}) monitoring was carried out during every working shift by portable battery-operated laser photometers (DUSTTRAKTM Aerosol Monitor Model 8520TSI Inc., Shoreview, MN, USA) placed in positions simulating the worker's breathing exposure conditions. At HMA manufacturing plants the monitors were positioned at a height levels of about 1.5 m on a stand in the zone where workers moved and processed the materials, in the process surveyor's cabin and in the administrative office. At the road paving worksites, the PM_{10} monitors were positioned at a height of about 1.5 m on mobile carriages able to simulate the breathing exposure of the paver and roller operators and that of the traffic controller during their movements. The detection limit was 1 µg/m3.

Personal airbone PAH sampling

In order to assess the PAH inhalatory exposure of the workers, each participant was invited to collect during the working shift air samples by an active personal sampler (SP 350 SidePakTM TSI Inc. Shoreview, MN, USA). A personal sampler was clipped on the worker's clothing with the inlet positioned in the breathing zone. Air samples were collected in accordance with the NIOSH 5506 [10] method using a sampler composed of a PTFE membrane filter (37-mm, 2 m pore size, PTFE SKC Inc. Corp. Valley View Road, PA, USA, Cat.No.225-17-07) + a sorbent tube (washed XAD-2 resin, front 100 mg, back 50 mg, ORBO 43, SUPELCO Inc., Bellefonte, PA, USA, Cat. No.2-0258) connected to a battery-powered pump calibrated at a flow rate of 2.0 L/min. At the end of each sampling, samplers were properly sealed, wrapped in aluminum foil and kept in ice to minimize evaporative losses during transportation to the laboratory. The samples were refrigerated at 4°C and stored no more than 48 hours prior to extraction.

HPLC Analysys of PAHs

The PAH extraction and analyses were carried out in accordance to the NIOSH Method 5506 [10]. Filters were extracted with 5 mL of acetonitrile and each section of each tube was desorbed with the same volume of this solvent. Sixteen priority PAHs, listed by the US Environmental Protection Agency (U.S. EPA) [11] were quantified (naphthalene, acenaphthylene acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, benzo(g,h,i)perylene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, by high performance liquid chromatography (HPLC) with UV/fluorescence detection. LC analysis was carried out using a HPLC UV-VIS SHIMADZU Chromatograph model SPD-10A (SHIMADZU Scientific Instruments Inc., Kyoto, Japan) and a HPLC Fluorimeter SHIMADZU model RF-10AXL detector in series with an electronic integrator. A 250 x 4.6 mm i.d. SUPELCOSILTM LC-PAH 5 (SUPELCO Inc., Bellefonte, PA, USA) column was used. A linear gradient from 60% acetonitrile 40% deionized water to 100% acetonitrile at 1 mL/min over 20 min was applied. The fluorescence detector was set at an excitation wavelength of 340 nm and emission of 425 nm and the UV detector at 254 nm. The Σ PAHs was obtained as the sum of the concentrations of each compound detected. Analytical limits of detection (LOD), referred to a sampling period of 8 hrs with a mean air volume sampled of 0.098 m3, were in the range 0.02 - 2.00 ng/m3.

Statistical methods and analyses.

Statistical data analysis was performed with SPSS 13.0 [12]. The significance of the differences in air mean concentrations of the respirable particulate matter (PM10) and PAHs among the two workers categories (HMA manufacturing and road paving) and within each category, were evaluated assuming a normal distribution of the data. The analysis of variance was carried out by the (ANOVA) Tukey-Kramer Multiple Comparisons Test, assuming for individual PAH that, when a result was below the detection limit (BDL), the value was one-half of the quantification limit. The level of significance was set at $P < 0.05$.

Results

HMA manufacturing plants

During all of the monitoring campaignes none of the workers involved in the study wore personal safety devices.

The PM_{10} air concentrations detected at HMA manufacturing plants, by the monitoring sites described above are shown in Table 1. The average airborne PM_{10} concentrations varied between 1125 ± 445 µg/m^3 (*HMA manufacturing workers' area*) and 314 ± 81 µg/m^3 (*process surveyors*), while in the administrative offices it was 92 ± 27 µg/m^3. A significant difference in the airborne PM_{10} exposure levels was found between *HMA manufacturing workers'* and *process surveyors'* ($p < 0.006$) and between working area and administrative offices ($p < 0.0001$). Personal mean exposures to airborne PAHs are shown, by job category, in Table 2. The average PAHs in the air at the worker's breathing level was 367 ± 198 ng/m^3 in *HMA manufacturing workers* and 348 ± 172 ng/m^3 in *process surveyors*. In the administrative personnel (*controls*) the average PAHs was 21 ± 2 ng/m^3. No significant difference in the average PAH's exposure levels was found between the two exposed worker's categories. Phenanthrene, anthracene, fluoranthene, pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, dibenz(a,h)anthracene and indeno(1,2,3-cd)pyrene were never found at quantifiable amounts. In 99% of the air samples obtained at the control's breathing levels only acenaphtylene and benzo(a)pyrene showed detectable amounts. The PAH's profiles were very similar among *HMA manufacturing workers* and

Table 1. The PM10 air concentrations µg/m3 in HMA manufacturing plants

WORKERS	PM10 Mean±S.D.
HMA manufacturing workers' area	1125±445
Process surveyors	314±81
Controls	92±27

Table 2. The personal exposure of PAH ng/m3 in HMA manufacturing plants

PAH	HMA manufacturing plants		
	HMA manufacturing workers	Process surveyors	Controls
	Mean±S.D.	Mean±S.D.	Mean±S.D.
Naphthalene	155±148	235±163	BDL
Acenaphtylene	157±144	112±45	13±6
Acenaphthene	217±58	200±71	BDL
Fluorene	30±28	36±6	BDL
Phenanthrene	BDL	BDL	BDL
Anthracene	BDL	BDL	BDL
Fluoranthene	BDL	BDL	BDL
Pyrene	BDL	BDL	BDL
Benzo(a)Anthracene	212±124	155±79	BDL
Chrysene	95±78	BDL	BDL
Benzo(b)Fluoranthene	BDL	BDL	BDL
Benzo(k)Fluoranthene	BDL	BDL	BDL
Benzo(a)Pyrene	54±24	17±11	14±5
Benzo(ghi)Perylene	BDL	BDL	BDL
Dibenzo(ah)Anthracene	BDL	BDL	BDL
Indeno(1,2,3-cd)Pyrene	BDL	BDL	BDL
Total	367±198	348±172	21±12

BDL: Below Detection Limits

process surveyors except for chrysene content, which was always below the LOD 0.07 ng/m^3 in the air personally sampled by the *process surveyors.* B(a)P, the carcinogenic PAH marker, average concentrations were: 54 ± 24 ng/m^3; 17 ± 11 ng/m^3; 14 ± 5 ng/m^3, respectively in *HMA manufacturing workers'*, *process surveyors'* and *controls'* breathing air samples. A significant difference in the B(a)P exposure levels was found between *HMA manufacturing workers'* and *process surveyors'* ($p < 0.02$) and between all the exposed versus not exposed personnel ($p < 0.004$). During the monitoring days, the average daily dry bulb temperature ranged from 19.4 to 32.6 °C, the average daily relative humidity from 51 to 58 %, and the wind velocity from 0.05 to 0.91 m/sec. A direct correlation was found between the wind speed and the airborne PM_{10} and PAH concentrations (data no shown) at HMA manufacturing areas.

Road paving sites

As at HMA manufacturing workplaces, at road paving sites during all the monitoring campaignes none of the workers involved in the study wore personal safety devices.

The PM_{10} air concentrations detected at road paving sites, according to job category, are shown in Table 3. The average airborne PM_{10} concentrations varied between 1435 ± 325 µg/m^3 (*roller operators*) and 1610 ± 356 µg/m^3 (*paver operators*). At *traffic controllers*' level the average airborne PM_{10} concentration was 319 ± 108 µg/m^3. The levels of airborne PAHs are shown in Table 4. The average Σ PAHs in air at breathing worker's level ranged from 1220 ± 694 ng/m^3 (*paver operators*) to 1360 ± 575 ng/m^3 (*roller operators*). At *traffic controllers*' breathing level the PAH mean concentration was 139 ±135 ng/m^3. Fluorene, phenanthrene, chrysene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene and pyrene were never found at quantifiable amounts. Naphthalene, anthracene and fluoranthene were detected only in the *paver operators'* air samples (100%), while benzo(b)fluoranthene was detected only in the *roller operators'* breathing air samples (98%). B(a)P average concentrations were: 89 ± 80 ng/m^3; 55 ± 53 ng/m^3; 19 ± 15 ng/m^3, respectively in *paver operators'*, *roller operators'* and *traffic controllers*' breathing air samples. No significant differences were found among the average airborne PM_{10}, PAH and BaP levels of exposure between the two job categories considered. Significant differences were found comparing the average airborne PM_{10}, PAH and BaP levels of exposure between the *paver + roller operators* together and the *traffic controllers.*

During the monitoring days, the average daily dry bulb temperature ranged from 23.1 to 31.2 °C, the relative humidity from 45 to 55 %, the wind speed from 0.08 to 1.11 m/sec. A direct correlation was found between the wind speed and the airborne PM_{10} and PAH concentrations (data no shown). The average asphalt mix application temperature was 134 ± 11 °C.

Table 3. The PM10 air concentrations µg/m3 in paving road sites

WORKERS	PM10 Mean±S.D.
Paver operators	1610±356
Roller operators	1435±325
Controls	319 ± 108

Table 4. The personal exposure of PAH ng/m3 in in paving road sites

PAH	Paving road sites		
	Paver operators	Roller operators	Controls
	Mean±S.D.	Mean±S.D.	Mean±S.D.
Naphthalene	451±215	495±200	190±120
Acenaphtylene	639±523	787±627	150±149
Acenaphthene	542±425	624±245	60±37
Fluorene	BDL	BDL	BDL
Phenanthrene	BDL	BDL	BDL
Anthracene	350±141	BDL	BDL
Fluoranthene	100±50	BDL	BDL
Pyrene	BDL	BDL	BDL
Benzo(a)Anthracene	122±18	150±50	20±1
Chrysene	BDL	BDL	BDL
Benzo(b)Fluoranthene	BDL	150±62	BDL
Benzo(k)Fluoranthene	BDL	BDL	30±5
Benzo(a)Pyrene	89±80	55±53	19±15
Benzo(ghi)Perylene	100±5	72±64	17±6
Dibenzo(ah)Anthracene	BDL	BDL	BDL
Indeno(1,2,3-cd)Pyrene	BDL	BDL	BDL
Total	1220±694	1360±575	139±135

BDL: Below Detection Limits

Discussion

Studies in animals and humans, and *in vitro* studies have demonstrated that exposure to fumes from roofing, paving, and other uses of asphalt is correlated in workers with irritation of the eyes, nose, and throat when the concentrations of total particulates (TPM) are generally below 1 mg/m^3 and those of benzene-soluble or carbon disulfide-soluble particulates are below 0.3 mg/m^3, calculated as a full-shift TWA.

In the experimental conditions considered the results obtained show that workers both in HMA manufacturing plants and in road paving sites can be exposed to airborne PM_{10}, the inhalable fraction of the TPM, concentrations up to 1 mg/m^3. In the considered worksites average PM_{10} concentrations at breathing level in non exposed workers (*controls)* exceeded the Italian legal limit for PM_{10} in atmospheric air fixed at 40 $\mu g/m^3$ (D.M. n. 60/2002) [13]. These results are in agreement with previous Italian studies on TPM in bitumen fumes at worksites [5-9] .

The PAH mean values in HMA exposed workers are noticeably lower if compared with those referred by the SITEB study, while agree with those found in road paving workers [6].They have been both in exposed and not exposed workers about three orders of magnitude lower than 0.3 mg/m^3, suggested as a limit for benzene soluble matter by NIOSH. Nevertheless our PAH concentrations, both in paver and in roller operators, were two times higher than those found by Campo et al. [7]. Between the workers in HMA manufacturing and the operators in road paving, the exposure to respirable particulate matter (PM_{10}) didn't significantly differ; on the contrary, the exposure to PAHs was significantly higher in road paving than in HMA manufacturing workers. This finding can be probably attributed to differences in the composition of the breathing air in the two considered worksites. In the HMA manufacturing plants airborne particulates can derive mainly from the movement and the blending and drying of the mineral mixture as coarse and fine stones, gravel, sand, etc. employed which influence the quality of the air in all of the plant, as demonstrated by the quite high values of PM_{10} levels found in the breathing air samples in the administrative personnel (*controls*); in road paving the hot mixture of the minerals and the asphalt can release into the atmosphere fumes containing mainly organic compounds such as the PAHs instead of mineral particles. Above PAHs naphthalene, recently classified as being possible carcinogenic to humans [14] , was the most prevalent (100% of the analyzed samples) and the most abundant compound followed by acenaphthylene and acenaphthene. As already highlighted by other authors [5,7,8] , the prevalence of airborne low-boiling PAHs, generated in manufacturing and road paving by the moderate heating temperature of asphalt, generally not exceeding 140-160°C, was confirmed. The organic pollutant levels and the airborne distribution of individual PAH in open air can also be highly influenced, the former, mainly by the direction and speed of the wind, and, the latter, by the atmospheric temperature and the relative humidity. Unfortunately, in this study the direction of the wind was not monitored and therefore conclusion relating to this cannot be drawn.This study was carried out on small groups of workers due to the difficulties encountered in involving both firms and workers. For this reason the results obtained cannot give an overall view of the situation of the asphalt workers in Italy. However they show that, in the context studied, airborne PM_{10} exposure can represent the more consistent hazard for asphalt workers' health, in which not exposed people have also been included. To minimize possible acute or chronic health effects from exposure to asphalt fumes NIOSH has recommended exposure limit (REL) of 5 mg/m^3 during any 15 min period and to implement preventing practices as employing low-fuming asphalt or control systems of asphalt heating and emission capture; limiting the worker's exposure time and wearing personal protective equipment (PPE) as proper respiratory and clothing protections; using engineering controls and good work practices at all work sites to minimize worker exposure to asphalt fumes and asphalt-based paint aerosols [1,15]. Recently in Italy the "Istituto Superiore Prevenzione e Sicurezza sul Lavoro (ISPESL)" adopted the same safety criteria in the asphalt industry, but, underlining the PM_{10} exposure relevance in workers' health care and risk assessment, they also set out to increase air monitoring to include the control of mineral and siliceous particulates from the bitumen fumes.The employers are responsible in defining technologies and methods for preventing health hazards in worksites, introducing precautionary measures adequate to collective and individual protection.Workers have to be informed and trained in terms of protecting themselves from the risk of exposure to inhalable particles and mutagenic/carcinogenic substances [4] . As during all of the monitoring campaignes none of the workers involved in the study wore personal safety devices, more incisive actions have to be implemented at worksites.

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Table 1. The PM_{10} air concentrations µg/m³ in HMA manufacturing plants.

WORKERS	*PM10 Mean ±S.D.*
HMA manufacturing workers' area	1125 ± 445
Process surveyors	314 ± 81
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Table 2. The personal exposure of PAH ng/m³ in HMA manufacturing plants.

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Dibenzo(ah)Anthracene	BDL	BDL	BDL
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Total	367 ± 198	348 ± 172	21 ± 12

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Errata Corrige

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Table 3. The PM_{10} air concentrations μg/m³ in paving road sites.

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Roller operators	1435 ± 325
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Table 4. The personal exposure of PAH ng/m³ in in paving road sites.

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Benzo(k)Fluoranthene	BDL	BDL	30 ± 5
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Indeno(1,2,3-cd)Pyrene	BDL	BDL	BDL
Total	1220 ± 694	1360 ± 575	139 ± 135

BDL: Below Detection Limits

Errata Corrige

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