Chapter 2: A literature review of levels and determinants of exposure to potential carcinogens and other agents in the road construction industry.


Abstract

Workers in road construction industry include asphalt plant workers, ground construction workers and road paving workers. These individuals can be exposed to a wide range of potentially hazardous substances. A summary of levels of exposure to different substances measured during road construction is presented. Modern road paving workers are typically exposed to 0.1 to 2 mg/m³ of bitumen fume which includes 10 to 200 ng/m³ of benzo(a)pyrene. Sampling strategies and analytical methods employed in each reviewed survey are briefly described. The published reports provide some insight into identity of factors that influence exposure to bitumen among road construction workers: type of work performed, meteorological conditions, temperature of paved asphalt. However, there is a lack of (a) comprehensive and well-designed studies that evaluate determinants of exposure to bitumen in road construction, and (b) standard methods for bitumen sampling and analysis. Information on determinants of other exposures in road construction is either absent or limited. It is concluded that data available through published reports have limited value in assessing historical exposure levels in road construction industry.
Introduction

There is a long-standing controversy about the health effects of fumes and vapours generated during road paving with bitumen-based† materials. There is some evidence of irritant properties of such fumes (1) and it has been suggested that exposures to aliphatic amines are responsible for some of these symptoms (2). Bitumen fumes may also contribute to the development of bronchitis among highly exposed workers (3). Neurological and acute respiratory symptoms have been reported to be precipitated by bitumen exposure in road paving workers (1). However, a more recent study by Exxon Biomedical Science Inc. failed to find such an association (4). A relationship between renal disease and bitumen fume has been suggested by one report (5). Studies conducted in Turkey provide some evidence of cytogenic damage and adverse effect on immune system due to bitumen fume exposure (6)(7). However, in a Swedish study of tar-free paving it was observed that bitumen-originating polycyclic aromatic hydrocarbons did not produce genotoxic effects (8).

International Agency for Research on Cancer (IARC) has evaluated the carcinogenicity of bitumens in 1985 and 1987 (9,10). It has classified steam-refined and air-refined bitumens as possible human carcinogens (IARC Group 2B). However, evidence for the carcinogenicity of undiluted bitumens was inadequate (IARC Group 3). Animal studies with dermal application of the condensate of oxidized (roofing) bitumen demonstrated that the condensate has carcinogenic potential (11). The degree of similarity between laboratory generated fumes and those produced in laboratories remains a subject of debate. Asphalt workers have also been listed among occupations with a possible excess of cancer (12).

The following paper summarizes information available to us through reports published through the end of 1999 on levels of exposure and determinants of exposure in road construction industry. It serves as departure point for further discussions of risk evaluation and exposure assessment among asphalt workers in a multicentric IARC study of European asphalt industry (13).

Road construction industry

We have divided all road construction workers into three job classes: asphalt mixing, ground construction and road paving. The definition of job class is consistent with that adopted for the IARC study of the asphalt industry (13). We excluded from the discussion those employees in the road construction industry whose exposure to substances emitted in the course of actual road construction is either unlikely or episodic: office staff, laboratory technicians and management.

Asphalt mixing

Asphalt mixing is a process whereby bitumen is combined with mineral aggregate to produce asphalt. This takes place at asphalt mixing plants, which fall into two general categories: drum plants and batch plants. In all asphalt plants mineral aggregates are heated and dried before being mixed with bitumen in a mixing unit. The resultant asphalt mix is either transferred directly to a transport truck, which takes it to a paving site, or stored in silos prior to transport.

† In this article we follow the European nomenclature of bitumen for petroleum binder, which, when mixed with inorganic materials, yields asphalt. In North American nomenclature bitumen is synonymous with asphalt.
In a generic batch plant, mineral aggregates are heated in a rotary drum dryer to a temperature between 135°C and 180°C. Heated and dried mineral aggregate is placed into a pug mill mixer, where it is coated with bitumen and mineral filler. Bitumen is pumped into a pug mill mixer in discrete portions from bitumen storage tanks. Drum plants differ from batch plants in that the heating and drying of the mineral aggregate as well as the addition of bitumen and filler take place in the drum mixer in a continuous mode. A deviation from this rule is a so-called twin drum plant in which two separate drums are used: one for drying and heating of mineral aggregates and the other for mixing in bitumen and filler. The drum mixer is, in essence, a modified rotary drum dryer (employed in batch plants). It is a revolving cylindrical drum with a hot gas burner, which heats mineral aggregates delivered by hoppers and an injection system for bitumen and filler.

Most asphalt plants are stationary, but a small number of them are mobile. There is also a limited number of driving asphalt plants that can mix and lay asphalt in a continuous process at the paving site.

Ground construction

Ground construction, in the context of the road paving industry, is a set of activities that are required to prepare a road surface for paving. To prepare the road surface for application of asphalt, soil removal and shaping tasks are performed. Next, the road surface may require 'stabilization' via application of lime or cement. The application of lime or cement onto the road surface is often followed by mechanical sweeping.

Paving

This broad job class encompasses work involved in different types of road paving, surface dressing as well as indoor paving. In this section, we present a generic description of these activities and most common terminology used to describe them.

Small crews of workers (5-9 individuals) perform road paving. They can usually be separated into the following job titles: paver operator, screedman, rakerman, roller driver, transport truck driver and supervisor. Transport truck drivers deliver hot application mix from an asphalt plant to the paving site. Application mixtures are transported at temperatures that range from 140 to 200°C (14). The application mixture is transferred into a paving machine which applies it to the road surface. The paver operator is seated on top of the paving machine, between the hopper that receives hot mix from the transport truck and the screed that discharges the hot mix onto the surface being paved. The screedman controls the discharge of hot mix from the screed, and is normally located immediately above the freshly spread mix. The raker (rakerman) helps to spread the hot mixture discharged from the screed by using a hand rake or a shovel. Rollers are used to compress the application mixture once it has been applied to the paved surface. Roller drivers, who, in modern operations in Europe, are typically seated in the cabin, operate them. However, older rollers that may still be used were commonly not equipped with cabins.

Recycling/resurfacing operations are often combined with road paving. The old layer of asphalt is stripped and mixed with new asphalt, either at the asphalt plant or at the paving site, and re-applied to the road surface. Heating the old asphalt with propane burners can facilitate resurfacing (hot re-paving). Cold re-paving is can also be performed. Re-paving performed at the road construction site in conjunction with paving of a new road surface is known as in situ re-paving.
In surface dressing, the binding agent is applied to the road surface in order to ensure uniform application of chipping. Binding agents are kept at a temperature of at least 90°C. They include bitumen cutbacks (mixture of bitumen and solvents, such as kerosene) and bitumen emulsions (aqueous bitumen dispersions). During surface dressing, spray bar operators (sprinklers or fantail operators) control discharge of the surface dressing material onto the existing road surface. The spray bar operator stands at the back of the truck containing the application mixture and regulates the density and width of spray via a control panel. If necessary, spraying is done manually via hoses. Chipping is spread on top of the sprayed material from a separate truck, which follows the truck from which binder is sprayed. A chipping sprayer controls this process. The chipping truck is followed by rakermen who further flatten the chipping with rakes. Rollers finish the process by pressing the chipping into the layer of binder.

Mastic laying or application of mastic asphalt may be performed either indoors or outdoors. A kettle is used to heat a mixture of very fine mineral aggregate and paving/hard bitumen to about 200°C. The kettlemen are operate and control the kettles. Mastic asphalt is poured into buckets and carried by pourers to the application site. After it is poured in a desired location, troweller/mastic layer spreads mastic asphalt. Some advances towards mechanization of mastic laying have been made.

Exposure types and levels in road construction industry

The individuals employed in the road construction industry have the potential to be exposed to a vast number of hazardous substances. For each category of exposure we will present (a) the reported exposure levels and (b) briefly characterize the analytical method used to measure or ‘define’ the exposure.

Bitumen fumes and vapours: Bitumen-attributable organic matter and benzo(a)pyrene

Vapours and fumes originating from bitumen mixtures are primarily products of the evaporation of bitumen binder from the application mixture. Therefore, they can be expected to be chemically similar to bitumen (15), but they occur simultaneously with aggregate dust, solvents, additives, diesel and other automotive exhaust. Bitumen is the residue of a fractional distillation of crude oil. It is a complex mixture containing a high proportion paraffinic and naphthenic hydrocarbons (molecular weight: 300 to 100,000). Bitumen also contains compounds with nitrogen, oxygen and sulfur functional groups. Some of these compounds fall into the category of polycyclic aromatic compounds, which include polycyclic aromatic hydrocarbons (PAH). The exact composition of bitumen depends on the source of the crude oil and the refining process (11). Literature on the composition of commercially available bitumen is ‘limited and fragmented’ (16), however some information on bitumen and its derivatives used in paving is available (17).

A variety of analytical procedures have been employed to separate bitumen-derived organic matter from the inorganic materials. Some of the principal approaches to the extraction of bitumen-derived chemicals from dust- and gas-phase samples are: benzene soluble matter, cyclohexane soluble matter, carbon disulfide soluble matter, carbon tetrachloride soluble matter, chloroform soluble matter (corrected for boiling point distribution of bitumen-attributable organic matter), dichloromethane soluble matter. Bitumen-attributed emissions were quantified either gravimetrically, or by use of gas chromatography, liquid chromatography or infrared spectroscopy. Different PAH series have been assayed as
indicators of bitumen exposure. When investigators sought to identify individual components of asphalt emissions, they employed chromatography, sometimes coupled with mass spectroscopy. Extensive reviews of sampling methodologies employed to measure PAH/bitumen emissions and an in-depth discussions of their limitations have been published (18)(19).

Inhalation exposure

It is apparent from the literature that bitumen constituents are divided in unequal proportions into particulate (fume) and gaseous (vapour) phases of bituminous emissions (16,18,20-22). Melting point appears to determine whether a substance appears in the vapour or particulate phase of asphalt emissions at a given temperature (21). The apportion of PAH into bitumen fume and vapour at typical paving temperatures can also be predicted on the basis of molecular weight: gaseous phase of asphalt emissions consisted mostly of PAH with molecular weight less than 228, while the particulate phase consisted mainly of heavier PAH (16,20) Most frequently, particulate matter from asphalt emissions (fume) was collected in personal exposure monitoring by means of total dust samplers. In recognition of the importance of the gas phase of asphalt emissions (vapour)(19), some investigators also collected samples of asphalt vapour, employing sorbent tubes to this purpose. Particulate and gas samples were often collected in series.

It has been reported that not all solvents used to extract organic matter from environmental samples of bitumen emissions have equal efficiency (19). For example, cyclohexane was reported to have lower ‘dissolving capacity’ than benzene (23). Therefore, in order to simplify comparison of the results of various studies, we will organize the discussion on the basis of the analytical methods used to extract asphalt emissions from sampling media. For each extraction method we will present, whenever possible, summaries of the levels of exposure to bitumen-attributable organic matter, and benzo(a)pyrene (most commonly assayed PAH). Since each study used different PAH series to define “total PAH” we will not consider this exposure measure. This decision is analogous to the one made in another review of exposure in the asphalt industry (11). The measurement of PAH alone can not be considered a valid measure of bitumen exposure, since (a) only trace amounts of PAH are present in bitumen and (b) the toxicity of bitumen emissions can not be entirely attributed to their PAH content (24). Thus at present, a bitumen-specific exposure marker is lacking. This is reflected in that there are no standard analytical methods for measuring bitumen emissions.

Exposure levels to bitumen fume and vapour reported in the literature are summarized in Table 2.1. Supplementary information on sampling strategy and measurement methods is also supplied in the Table. It would appear that most studies were rather small, collecting 20 to 40 measurements. They were conducted primarily in North America in the 1990’s. Exposure levels tended to be elevated during mastic paving indoors and in older studies. Exposures at asphalt plants appear to be of the same order of magnitude as those in most road paving operations. Benzo(a)pyrene levels are generally low, with older European studies being more likely to find detectable levels. In non-mastic applications, bitumen exposure levels were on the order of 0.1 to 2 mg/m³ and benzo(a)pyrene exposures ranged between 10 and 200 ng/m³. The description of sampling strategies and analytical methods was often incomplete with an exception of investigations conducted by the National Institute for Occupational Safety and Health (NIOSH) and Exxon Biomedical Science Inc.
Table 2.1: The reported levels of inhalation exposure to organic fume and vapour.

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Operation(s)</th>
<th>Total organic matter</th>
<th>Benzo(a)pyrene</th>
<th>Sampling strategy</th>
<th>Sampling media/device</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>paving of hot mix, resurfacing, application of dense road base asphalt</td>
<td>23</td>
<td>0.02-3.97</td>
<td>5</td>
<td>0.23*10^{-3} (\text{A} \quad (0.16-0.36)*10^{-3})</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>surface dressing</td>
<td>4</td>
<td>0.23 (0.1-0.5)</td>
<td>Sampling was conducted for the ‘maximum time allowable by the content and pattern of the task.’ Measurements were collected on either a single day or over several consecutive days.</td>
<td>glass fiber filter with a silver membrane filter as a backup in a closed-face 37-mm cassette</td>
<td>(14)</td>
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<tr>
<td></td>
<td>paving of hot mix and application of bitumen cutback</td>
<td>7</td>
<td>0.23 (0.1-0.3)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mastic paving (kettlemen)</td>
<td>4</td>
<td>2.9 (1.8-5.0)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mastic paving (indoor tasks)</td>
<td>8</td>
<td>6.0-13.6</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>paving</td>
<td>5</td>
<td>0.08 (0.05-0.29)</td>
<td>nd</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>single road construction project</td>
<td>7</td>
<td>0.42 (0.09-1.07)</td>
<td>3</td>
<td>0.11 to &lt;0.22</td>
<td>Measured exposure during the execution of representative tasks.</td>
</tr>
<tr>
<td></td>
<td>asphalt mixing</td>
<td>33</td>
<td>0.15 (GSD=2.8)</td>
<td>33</td>
<td>&lt;0.151</td>
<td>A cross-sectional survey of ‘asphalt’ industries. Sample industrial sites across the USA. Up to two samples per each study participant on consecutive days.</td>
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<tr>
<td></td>
<td>paving</td>
<td>37</td>
<td>0.24 (GSD=3)</td>
<td>37</td>
<td>&lt;0.151</td>
<td></td>
</tr>
<tr>
<td></td>
<td>road paving</td>
<td>?</td>
<td>0.47 (0.03-4.4)</td>
<td>Nd</td>
<td></td>
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<tr>
<td></td>
<td>Hot mix road paving</td>
<td>80</td>
<td>Fume: 0.09 (\text{G} \quad (GSD=2.57)) Volatile hydrocarbons: 0.38 (\text{G} \quad (GSD=4.75))</td>
<td>A cross-sectional survey of ‘asphalt’ industries, 2 consecutive days of sampling per person</td>
<td>Fume: modified NIOSH Method 5023; Volatile hydrocarbons: charcoal tube following particle filter</td>
<td>(4)</td>
</tr>
<tr>
<td>Solvent <em>h</em></td>
<td>Operation(s)</td>
<td>Total organic matter</td>
<td>Benzo(a)pyrene</td>
<td>Sampling strategy</td>
<td>Sampling media/device</td>
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<tr>
<td>Asphalt mixing</td>
<td>Fume: 0.06(^{G}) (GSD=1.74)</td>
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<td></td>
<td>Volatile hydrocarbons: 1.06(^{G}) (GSD=2.40)</td>
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<tr>
<td>Hot mix paving in a tunnel</td>
<td>9</td>
<td>0.3-1.26</td>
<td>nd</td>
<td>37 mm closed face sampler with Teflon filter, OSHA method 58</td>
<td></td>
<td>(38)</td>
</tr>
<tr>
<td>Hot mix paving with and without crumb-rubber modified asphalt f</td>
<td>29</td>
<td>&lt;0.007-0.61</td>
<td>Representative, up to 4 consecutive sampling days with repeats for each person</td>
<td>NIOSH method 5042, particulate phase only</td>
<td></td>
<td>(30)</td>
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<tr>
<td></td>
<td>32</td>
<td>0.01-0.88</td>
<td></td>
<td></td>
<td></td>
<td>(29)</td>
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<tr>
<td></td>
<td>3</td>
<td>&lt;0.03-0.13</td>
<td></td>
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<td></td>
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<td></td>
<td>2</td>
<td>&lt;0.1</td>
<td></td>
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<td></td>
<td>(32)</td>
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<tr>
<td></td>
<td>27</td>
<td>&lt;0.01-0.82</td>
<td></td>
<td></td>
<td></td>
<td>(33)</td>
</tr>
<tr>
<td>Cyclohexane</td>
<td>road paving</td>
<td>17</td>
<td>0.17(^{A})</td>
<td>1</td>
<td>0.61</td>
<td>nd</td>
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<tr>
<td></td>
<td>road paving</td>
<td>17</td>
<td>1(^{A}) (0.1-2.7)</td>
<td>13</td>
<td>&lt;0.05</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>application of bitumen cutback and oil gravel paving</td>
<td>6</td>
<td>0.25(^{A}) (0.1-0.5)</td>
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<td></td>
<td>road paving</td>
<td>4</td>
<td>0.01-0.02</td>
<td>nd</td>
<td>37 mm closed face sampler with glass fiber filter and Tenax GC packing as backup</td>
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<tr>
<td>Carbon disulfide</td>
<td>road paving</td>
<td>79</td>
<td>0.36(^{H}) (0.20-1.29)</td>
<td>nd</td>
<td>Particulate sampler with glass fiber filter; charcoal tube</td>
<td>(1)</td>
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<tr>
<td>Carbon tetrachloride</td>
<td>road paving</td>
<td>6</td>
<td>2.9</td>
<td>nd</td>
<td>Particulate sampler with glass fiber filter</td>
<td>(49)</td>
</tr>
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<td></td>
<td>indoor mastic flooring d</td>
<td>35</td>
<td>19.7(^{D}) (0.5-260)</td>
<td>9</td>
<td>4</td>
<td>Unspecified particulate sampler</td>
</tr>
<tr>
<td>Chloroform</td>
<td>road paving dense and</td>
<td>58</td>
<td>1.2(^{W}) (paver)</td>
<td>15</td>
<td>≤ 0.007</td>
<td>Designed to obtain exposure measurements</td>
</tr>
<tr>
<td>Solvent&lt;sup&gt;h&lt;/sup&gt;</td>
<td>Operation(s)</td>
<td>Total organic matter&lt;sup&gt;n&lt;/sup&gt;</td>
<td>Benzo(a)pyrene&lt;sup&gt;n&lt;/sup&gt;</td>
<td>Sampling strategy</td>
<td>Sampling media/device</td>
<td>Ref&lt;sup&gt;i&lt;/sup&gt;</td>
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<td>drainage asphalt; cold laying of recycled asphalt; gravel laying drivers and</td>
<td>0.3&lt;sup&gt;ae&lt;/sup&gt; (roller drivers)</td>
<td></td>
<td>during application of the most commonly used type of asphalt mixes in Sweden.</td>
<td>2 sorbent tube</td>
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<td></td>
<td>screedmen)</td>
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<td>0.4-8.9 (peak exposures 300-900 mg/m³)</td>
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<td></td>
<td>Unspecified Road work in Australia</td>
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<td></td>
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<td>(5)</td>
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</tbody>
</table>

A -- arithmetic mean; G -- geometric mean; nd -- not described; a -- It is not clear from the report whether the 5 samples which were analyzed for specific PAH were representative of all the samples collected in the investigation; b -- The benzene soluble matter levels could be positively biases due to migration of the components of PTFE particulate filters used in the study, into benzene solvent employed in extraction of the organic matter. This suggestion is motivated by the observation that in 22 samples, the mass of benzene soluble matter extracted from "total" dust exceeded that detected by weighing prior to extraction. c -- No information was supplied in the original report about the type of asphalt handled by the study participants, but given the low levels of benzo(a)pyrene observed, it is not likely that coal tar was present in the application mixtures during exposure monitoring. d -- Hansen argued that the measured exposures are primarily due to bitumen exposure and not coal tar, since mastic asphalt does not contain coal tar. However, industry representatives have contradicted this statement (50). e -- corrected for boiling point distribution of bitumen-attributable organic matter; f -- three worker were monitored on each sampling occasion: paver operator, screedman and roller driver; g -- personal breathing zone samples only; h -- solvent used extract organic matter; i-- reference.

**Dermal exposure**

Bitumen condensate is a product of condensation of bitumen fume and vapour. It can be expected to precipitate both on equipment handled by road construction workers and the skin/clothes of these workers.

A US study (25) reported low PAH content in dermal wipe samples of hot mix asphalt plant workers and members of road paving crews. Skin wipe samples were analyzed for 17 PAH, though only 6 PAH were detectable in all of the analyses. Only one sample out of 25 collected at the asphalt plant had detectable PAH (3 out of possible 17 PAH). The number of dermal wipe samples with detectable PAH in road paving was not reported. However, a close examination of the reported data revealed that it is not likely that more than 5 or 6 out of 30 dermal wipe samples contained any detectable PAH.
The Chevron Research and Technology Company has conducted a laboratory study of chemical composition of bitumen asphalt (26). Benzo(a)pyrene levels in asphalt fume condensate ranged from 0.04 to 2.8 ppm. Bitumen fume condensate generated in paving asphalt mixes had a total 3- to 7-ring PAH content ranging from 4 to 16 ppm (n=18).

Coal tar and coal tar pitch

Vapours and fumes originating from coal tar- and coal tar pitch-containing mixtures are the products of the evaporation of coal tar/pitch and bitumen binders. We have already presented the types and levels of the substances that can be emitted due to the evaporation of bitumen. The present discussion focuses on airborne substances of coal tar and coal tar pitch origin. Coal tar and coal tar pitch are coal distillation products, composed mainly of highly condensed aromatic hydrocarbons, including PAH. The content of PAH in coal tar/pitch has been reported to be about 100 to 1000 times higher than that of bitumen (14,26-28).

In a Dutch study, exposures at four surface dressing sites were studied (23). A mixture of bitumen and coal tar was applied to the road surface at an application temperature of 140 to 180°C. Dust samples were collected onto 37-mm cassettes with glass fiber filters. Twenty-eight full-shift personal dust samples were collected, and their cyclohexane soluble matter content was reported to have a geometric mean of 0.2 mg/m³. Unfortunately, no estimates of the variability in this calculation were provided. The reported exposure levels were not representative of the pattern of exposure in surface dressing, since workers actually involved in the spraying of binder and tank truck drivers were excluded from the study for logistical reasons. The study also investigated dermal exposure to asphalt emissions. Dermal deposition of pyrene was determined via skin pads (with polypropylene as absorbing material) attached to different sites on the bodies of workers. There was no significant correlation between airborne levels of cyclohexane soluble matter and dermal PAH exposure. The distribution of the relative amounts of individual PAH was different in airborne and dermal samples, indicating that fume available for inhalation and fume precipitating onto skin of workers during surface dressing with coal tar-containing mixes have different compositions.

A review article by Lindstedt and Sollenberg (1982) indicated that during asphalt paving of highways with asphalt-tar mixture, benzo(a)pyrene exposures of 50 to 350 µg/m³ were observed. These levels are considerably higher than those observed when coal tar was not used. The same study apparently reported that there was a ‘considerable skin exposure from the contaminated clothes.’

Biological monitoring of PAH exposures

A Dutch study of surface dressing with tar-containing binder investigated urinary metabolite level of PAH (1-hydroxypyrene) (23). Geometric means of the excreted PAH metabolite varied among paving sites from 0.7 to 2.8 µmol/mol creatinine. End-of-shift samples tended to have higher 1-hydroxypyrene content than the pre-shift ones. There was no significant correlation between airborne levels of cyclohexane soluble matter and 1-hydroxypyrene levels. However, the amounts of pyrene collected from different sites of the workers’ bodies were correlated with urinary 1-hydroxypyrene levels (r=0.4-0.6, p<0.05).

During a study of 28 subjects in tar-free paving in Sweden(8), 1-hydroxypyrene levels in urine had geometric mean of 0.96 (range 0.04-4.0) µmol/l. Referents not employed in road paving
had lower geometric mean 1-hydroxypyrene levels in urine (0.60 μmol/l, range 0.14-2.2 μmol/l, n=30). No difference between pre- and post-shift levels was observed for road pavers, but the levels dropped by an average of 0.64 μmol/l after a weekend, suggesting that the increases level of PAH metabolites was related to occupational exposure. A correlation between pyrene in the personal breathing zone and 1-hydroxypyrene levels in urine was observed (r=0.4-0.6). Road pavers did not have elevated rates of sister chromatid exchanges and micronuclei compared to referents. All subjects were non-smokers.

A study of 21 rakerman, 7 asphalt plant employees (exposed group) and 28 university/hospital staff (controls) revealed elevated 1-hydroxypyrene levels in urine of subjects exposed to bitumen fumes (6). The mean urinary 1-hydroxypyrene excretion among exposed persons was 0.78 μmol/mol creatinine versus 0.52 μmol/mol creatinine in controls. After controlling for age, sex and smoking habits, the authors concluded that bitumen fumes were associated with elevated rates of sister chromatid exchanges, micronuclei and high frequency sister chromatid exchange cells. However, 1-hydroxypyrene levels in urine and cytogenic endpoints did not correlate.

In general, it would appear that 1-hydroxypyrene levels in urine of road paving and asphalt mixing workers tend to increase if coal tar is used. They increase towards the end of work-shift and decline upon removal of bitumen exposure. The relationship among dermal deposition of organic matter, its levels in personal breathing zone and PAH metabolites in urine is poorly understood in road construction industry.

Sulfur-substituted hydrocarbons
Sulfur-substituted hydrocarbons can be emitted during road paving of crumb-rubber modified mixes (29-35). In conventional paving benzothiazole (sulfur-substituted hydrocarbon associated with vulcanized rubber) was virtually non-detectable. Other sulfur compounds were at or barely above the limit of detection. However, when crumb-rubber modified mixes were applied, benzothiazole levels ranged from 3.3 to 233 μg/m³ and other the concentrations of sulfur compounds varied from <0.5 to 792 μg/m³ (n=44). Sulfur-substituted compounds were collected by 37 mm stationary samplers loaded with Teflon filter and followed by ORBO 42 sorbent tubes. Organic matter was extracted from filters with hexane and assayed by gas chromatography with sulfur chemiluminescence detection. Samplers were positioned in locations were the highest asphalt emission levels were expected (screeds and hoppers of pavers).

Mineral aggregates
Mineral aggregates are the second primary component of asphalt. These commonly include gravel and sand, but asbestos and lime have also been used, albeit very infrequently. Another potential source of silica/quartz exposure is the road surface itself, which is manipulated during road construction. Results of studies that have measured total or inhalable dust, respirable dust and respirable silica exposures in the road construction industry are presented in Table 2.2. Just like in the case of studies of bitumen fume and benzo(a)pyrene exposure, most published studies were rather small in scale. The highest inhalable dust levels were reported during mastic paving. Inhalable dust exposures in other paving and asphalt mixing operations appeared to be similar to each other. Little information is available about respirable dust and
<table>
<thead>
<tr>
<th>Operation(s)</th>
<th>Sampling device</th>
<th>Sampling strategy</th>
<th>Respirable Dust ( \text{mg/m}^3 )</th>
<th>Total/Inhalable Dust ( \text{mg/m}^3 )</th>
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<tr>
<td></td>
<td>8 13.3^A to 14.2^A 10.5-18.2</td>
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<td>2 samples per study participant, industry-wide survey</td>
<td>6 0.24^G 3.1 (GSD)</td>
<td>33 0.78^G 2.8 (GSD)</td>
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<td>Variability‡</td>
<td>%SiO₂</td>
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<td>n</td>
<td>Mean†</td>
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<td>0.83(^A)</td>
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† – A = arithmetic, G = geometric; ‡ – Range in mg/m\(^3\) unless otherwise indicated; GSD = geometric standard deviation; SD = standard deviation (in mg/m\(^3\)); a – based on analysis of silica in only 3 respirable dust samples; b – underestimate, since 6 out of 7 samples were below 0.18 mg/m\(^3\) limit of detection; c -- it is unclear how these short periods during which exposure was measured were selected; d – 100% sulfur; e – personal breathing zone samples only; f – area samples; g – reference.

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silica exposure during road construction, but there it would seem that these exposures could be substantial during ground construction. Respirable dust levels are similar in road paving and asphalt mixing. Just as in the case of bitumen-attributable emissions, differences in methods employed by different investigators and incomplete reporting of results raise the possibility that the observed inter-study exposure patterns are confounded.

The only lime and cement dust exposure measurements in road construction industry, reported in the scientific literature, were obtained during ‘road stabilization’ work in New Zealand (27). It is not clear how common such operations are. Cement and lime dust samples were collected by open-face sampling cassettes onto cellulose acetate filters. Cement dust levels were determined gravimetrically. Lime dust levels was assayed for calcium using atomic absorption spectroscopy (NIOSH Method). The reported lime dust exposures ranged from 0.5 to 78.5 mg/m³. Five cement dust exposure measurements ranged from 17500 mg/m³ (in bag breaking and emptying) to 0.6 mg/m³ (in rotary mixer driving).

**Solvents**

One can reasonably expect that solvents used in the road construction industry are similar to those used in other industries. Organic solvents can be used directly (e.g. to clean equipment), and can form a part of application mixes. In one Dutch study (36), the use of gas oil to clean paving equipment was observed. Another study (14) reported kerosene use to clean equipment. Norseth et al. (1991) observed acute symptoms, such as ‘abnormal fatigue’ and ‘reduced appetite’, in a group of 79 road construction workers and concluded that the observed symptoms were consistent with solvent exposure. They measured mean exposures to volatile organic compounds in 77 samples to be on the order of 0.14 to 40 ppm. The authors pointed out that these solvent exposures were ‘low’ compared to those occurring in painting, dry cleaning and degreasing. This last observation seems to be corroborated by a New Zealand study (27), which reported exposures to 6 hydrocarbon solvents in road construction to be on the order of 10 to 10,000 times below the regulatory limit (unspecified). In Norway (37), the use of diesel as a solvent to clean equipment was responsible for approximately 60% (by mass) of total PAH exposure. In studies reporting solvent exposure levels, long term detection charcoal tubes were used to collect the environmental samples. Gas chromatography was employed in quantification of the hydrocarbon solvents.

**Aliphatic amines**

Aliphatic amines can be used as additives to bitumen emulsions, cutback bitumen and paving bitumen. Thus, amines can be potentially emitted during the application of such materials. The irritating potential of aliphatic amines has been recognized (2). Nevertheless, in a Norwegian study (1) of health effects among road paving workers, amine addition did not appear to produce an increase in acute symptoms. Unfortunately, the actual exposure levels were not measured. Aliphatic amine exposures of <0.02 to 0.5 mg/m³ have been measured among members of 4 crews of Swedish road paving workers involved in the application of a aliphatic amine-enriched emulsion (2). Aliphatic amines were collected simultaneously from the gas and particulate phases of emissions by using the combination of XAD2 adsorbent tube and a particulate sampler (unspecified) with glass fiber filter. Both the particulate filter and adsorbent tube were coated with 1-napthylisothiourea. The monitored workers either drove ‘the slurry machine’ or raked hot bitumen emulsion after it was applied to the road surface. The bitumen
emulsion used contained 4-6% bitumen, which in turn contained about 0.2% amine. Even though most measured exposures for individual amines were low (around the detection limit of 0.02 mg/m³) the authors speculated that the additive effect of several aliphatic amines might produce irritant effects. They also pointed out that owning to the fact the emulsion applied in their study was ‘a rather pure technical product,’ there was a possibility ‘that higher exposures will result if a wetting agent of lower purity is used.’ Thus, the aliphatic amines exposure levels reported in this Swedish study cannot be considered as representative of those arising in the application of amine-enriched bitumen emulsion.

Aldehydes

Aldehydes are not components of bitumen, but it has been suggested that they may form during the laying of asphalt. In a Swedish exposure survey (20), glass fiber filters impregnated with 2,4-dinitrophenylhydrazine was used to collect aldehydes. The filter was mounted into a sampling cassette of unspecified configuration. The samples were analyzed for formaldehyde, acetaldehyde, acrolein, propanal, benzaldehyde and tolyaldehyde using high pressure liquid chromatography. Screed operators (‘technicians’) were monitored for aldehyde exposure, yielding 16 samples. None of the assayed aldehydes occurred in detectable quantities (limit of detection: 0.007 mg/m³).

According to a review compiled by the European industry (11) concentrations of aldehydes detected during road paving by another Swedish investigation reached a level of 2.3 mg/m³. It is not clear whether conditions under which these measurements were conducted were common in the industry.

Vehicle exhaust

The majority of road-paving equipment used in Europe is powered by diesel engines. Thus, one can expect European road paving workers to be exposed to diesel exhaust. Unfortunately, there are no published reports of diesel exhaust measurements during road paving in Europe. In an evaluation conducted in the US, measurement of diesel exhaust as elemental carbon during paving in a tunnel revealed that diesel exhaust made little contribution to total organic matter exposure (n=3, 0.027-0.066 mg/m³)(38). Paving in the tunnel was conducted at night, presumably when there was little or no general traffic in the tunnel. In another US study, elemental carbon monitoring during hot mix paving in open space also indicated low diesel fume exposure (n=74, range: <0.0002 – 0.095 mg/m³) (29,31-35).

Since most of the road paving equipment is powered by diesel engines, exposure to gasoline-powered engine exhaust in road construction must originate from the background traffic. A Norwegian survey found that the levels of exhaust gases at a paving site depend on the amount of surrounding traffic (37). In a Swedish study vehicle exhaust from surrounding traffic made significant contribution to total hydrocarbon exposure during road paving (20). However, another Swedish study concluded that vehicle exhaust is not a major source of PAH exposure in road paving (8).

Nitrogen dioxide (NO₂) and carbon monoxide exposures (CO) have been associated with engine exhaust exposures. Consequently they can originate either from background traffic or road paving machinery during road paving operations. Some of the NO₂ exposures measured during Norwegian survey of exposures among road paving workers (37) were reported to
exceed ‘permissible value’. The same study indicated that the measured CO exposures were ‘low’. Unfortunately, neither measured levels, nor the occupational exposure limits used were reported. The analytical methods were not adequately described. Investigations by NIOSH reported full-shift time-weighted average CO concentrations between 8 and 40 ppm with peak values as high as 1000 ppm (30)(29,32). The CO and NO₂ in the air were not detected during night-time paving in a tunnel, presumably due to absence of general traffic (38).

**Determinants of exposure and exposure controls**

The potentially hazardous nature of road construction work raises the issue of minimizing exposure that can lead to adverse health effects. Studies of the determinants of asphalt-related exposure identified a number of factors in road construction activities that can influence exposure levels. These include job class, type of asphalt, application methods, application temperature, volatility of asphalt, meteorological conditions, tasks performed within a road paving crew, design of paving equipment, and degree of enclosure of the paving site. We will focus on summarizing the findings of those studies that relate to the identity of the determinants of exposure to bitumen fume and PAH in the industry. Data on exposure to respirable silica, asbestos, lime, vehicle exhaust, solvents, NO₂, CO, aldehydes and aliphatic amines are insufficient for the determinant of exposure analysis.

**Job class**

There is little information on the exposures at asphalt mixing plants and in ground construction, making it difficult to investigate the relationships between job class and exposures. A report from the USA (25) indicated that road paving crews can be more highly exposed to benzene soluble matter than employees of asphalt plants. However, the situation with total and respirable dust was reversed. The opposite trend was found in a Norwegian study (37). Exposure levels were found to be lower during road paving than among asphalt plant personnel. It would appear that the ground construction crews have little opportunity for asphalt fume/vapour/condensate exposure. However, their exposure to mineral aggregates can be substantial (27). Beyond this, the available reports do not allow comparison of exposures in this job class to road paving and asphalt mixing.

**Asphalt plants**

In a study of hot mix asphalt production in the USA (39), particulate samples were collected isokinetically from process effluent gas stream. Glass fiber filters were used as sample collection media. Organic matter was extracted from the filters with benzene, PAH in the organic matter were separated by chromatography and subsequently quantified by ultraviolet-visible spectrophotometry. Bitumen binder was added to the mix at 121°C. Duplicate particulate samples were simultaneously collected from gas effluents entering and exiting a water spray tower. A water spray tower was the last step in effluent de-contamination process in which emissions originating from mixer and rotary dryer were treated in a cyclone and, subsequently, a water spray tower. Benzo(a)pyrene levels in effluent prior to treatment in a water tower were on the order of 1500 µg/m³. It appeared that PAH originated from combustion gasses emitted from the rotary spray dryer (prior to addition of bitumen to the mix). This would imply that bitumen binder is only a minor source of PAH in asphalt plant emissions. The authors of the report indicated that their results could not be considered typical, since they are based on a limited number of samples. It is also difficult to extrapolate from
process effluent levels to personal exposure levels. However, the results indicate that (a) in batch asphalt plants rotary dryers can be a more important source of PAH exposure than mixers and (b) 10-to-20 fold decrease in environmental PAH emissions can be achieved by the scrubbing in a water spray tower.

In another US study (40), analysis of the available data on factors that influence environmental emissions from the drum asphalt plants was performed. The author indicated that it appears that wet scrubbers were effective in reducing the emissions. However, bag house filters, effective in reducing emissions originating from pug mill mixer plants, were ineffective in reducing emissions from drum plants. The author also reported that mix temperature, bitumen injection point in the drum mixer and coarseness of the mix appeared to influence emission levels. Elevated mix temperature was associated with higher emission rates. Increasing the distance from burner to injection point of bitumen binder appeared to lower the concentration of partially oxidized hydrocarbons in effluent. Mixing of coarser asphalt was associated with decreased particulate emission levels. It must be noted that it is not clear whether these factors affect occupational exposures of plant personnel. It is also not clear how ‘grain loading’ (exposure measure used by the author) relates to inhalable and respirable particle levels. Finally, the evaluation of the appropriateness of the author’s conclusion is hindered by incomplete description of methods and results.

Results of a survey of US asphalt industry (4) indicate that mechanics at the asphalt plants (n=2) were more highly exposed to total and respirable particulate than other asphalt plant employees. However, the highest organic matter exposures tended to occur among supervisors/clerks (n=4) and plant operators (n=3).

**Paving**

**Composition of asphalt**

The chemical composition of emissions from application mixtures depends on a variety of factors. It can be safely assumed that the chemical composition of the application mixtures has a direct effect on the determination of the composition of asphalt emissions. The composition of the application mixtures has been modified in Western Europe in recent decades due to discontinuation of the use of coal tar and pitch as components of asphalt (13). Thus, we can conclude that time period (before or after use of coal tar in road construction) can be expected to be a significant determinant of exposure to hazardous substances in the asphalt industry. This effect can be anticipated to be country-specific, since the use of coal tar was discontinued at different times depending on the country.

Addition of rubber to hot-mix asphalt, according to experiments performed by the US EPA, ‘does not have a dramatic impact on the air emissions (of particulate and PAH) generated in the paving process’ (41,42). However, extensive survey conducted by NIOSH indicates that paving with crumb-rubber modified asphalt can lead to elevated bitumen fume and benzothiazole exposures (29-35). An investigation of paving with sulfur-extended asphalt in the US revealed high total and respirable sulfur particulate exposure levels which appeared to be associated with eye and respiratory tract irritation (see Table 2.2 for exposure levels) (43). It is not clear how common paving with sulfur-extended asphalt is now or was at the time of the
investigation in 1982. Little additional data is available on exposure patterns during paving with rubber-modified and other modified asphalt mixes.

Application methods

Mastic asphalt paving has been reported to result in much higher asphalt fume exposure levels than other road construction activities (3,11,14). This conclusion can be equally based on both within- and between-study comparisons. Inhalable dust and PAH exposures during surface dressing appear to be similar to those arising in application of hot mixes. The need to reduce exposures that occur during surface dressing has been identified, even though the available exposure data is limited (11). Furthermore, inhalable dust levels and benzene soluble matter levels generated in rolling of hot asphalt appeared to be higher than those produced during cold resurfacing and application of dense base asphalt (36). Little information is available on exposures during re-paving operations, but high exposures, possibly due to tasks performed and heating of the old asphalt during re-paving, have been reported (11). Thus we can tentatively arrange road paving operations in the following order of decreasing (left to right) bitumen exposure levels:

\[
\text{mastic paving} \geq \text{re-paving} > \text{hot asphalt, surface dressing} > \text{cold applications.}
\]

Examination of Table 2.1 confirms this ranking. The highest organic matter exposure levels were reported during mastic paving (from about 2 to 260 mg/m\(^3\)). Limited data on resurfacing (re-paving) indicates that it can be associated with organic matter exposures as high as about 4 mg/m\(^3\). Exposures during hot mix paving and surface dressing were on average below 1 mg/m\(^3\) and for more recent data – below 0.5 mg/m\(^3\). Limited data on cold applications indicates that they were associated with exposure levels akin to the lower range of those observed during hot mix paving (0.1 to 0.5 mg/m\(^3\)), but given that cold applications are expected to result in lower emissions of organic matter (see section below) we felt justified in relegating them to the lowest exposure category among other road paving methods.

The type, temperature and volatility of the mixes used characterize paving methods. Consequently, differences in exposures during different road paving activities can be attributed to these properties of the application mixtures (discussed below).

Application temperatures and volatility

The quantity of bitumen fume generated appears to depend greatly on temperature of bitumen. According to the results of a laboratory study conducted by the Chevron Research and Technology Company (26), the amount of bitumen fume condensate generated at 232°C was only 2 to 12% of the condensate produced at 316°C. The degree of temperature-dependence varied with the source of the crude oil used in the manufacture of bitumen.

On the basis of a study of Norwegian asphalt workers (1), it has been recommended to keep application temperature below 150°C, which should, according to the authors, keep combined inhalable fume and vapour exposures to below 0.40 mg/m\(^3\) (carbon disulfide soluble matter). An increase in acute symptoms, supposedly reflecting a change in exposure pattern, occurred between application temperatures of 145 and 155°C. Another Norwegian study (37) reported that the temperature of the application mix was one of the most important factors in determining asphalt fume exposure. It was observed that “evaporation of asphalt fumes and
other volatile compounds’ was ‘doubled for every 15°C increase in mix temperature.’ This last finding is in agreement with a Swedish report (20).

A laboratory study of emissions from two types of asphalt commonly used in California was recently conducted (16). The percentage of PAH in gaseous phase of bitumen emissions was observed to increase with temperature. The investigators reported that pattern and amount of volatile organic matter emissions depended on the type and temperature of asphalt. The temperature range used in the tests was between 150°C and 250°C. It is not clear which properties of the asphalt were responsible for the observed ‘type of asphalt’ effect.

An analytical model of bitumen fume exposure has been developed in laboratory studies (44), indicating that the volatility and temperature of bitumen can have a significant impact on exposure levels. The model has been validated under field conditions only to a limited extent (36).

Tasks
Tasks performed by road paving workers also appear to be related to exposure levels. The operator of the paving machine is usually more highly exposed to PAH and inhalable dust than other personnel (11,20,37). High exposures among foremen where also observed (37). Screedmen were the most highly exposed (for all agents monitored) members of road paving crews according to recent investigation of US industry (4). Exposures among roller drivers were reported to be 4 times lower than for other members of a road paving crew. In surface dressing operations, it was reported that fantail operators where more highly exposed then rakermen (23). There are also some indications that the distance between the rakerman and the paver is an important factor in determining the exposure levels of these individuals: an increase in that distance appeared to reduce personal inhalable dust exposure by a half (19). The actual difference in the distance was not mentioned.

Equipment
It has been reported that the use of some paving machines can reduce exposure levels by up to 60% (37). Features of this ‘environmental paver’, presumably responsible for reduction in exposure levels, included cabins with doors and windows that can be locked, as well as partial enclosure and ventilation of the screed. The importance of closing doors and windows of cabins installed on paving machines was emphasized, since leaving them open resulted in entrapment of asphalt fumes inside the cabins. The authors of the report also recommend use of special carrying baskets (not described) which would isolate foremen from the source of exposure. NIOSH has published guidelines for design of ventilation exhaust system for screed of the paving machines (45) and subsequently evaluated performance of this control measures under laboratory and field conditions, resulting in its further refinement (46).

Enclosed paving sites, weather conditions and personal respiratory protective equipment
Enclosed paving sites, such as tunnels, were associated with some of the highest reported exposure levels (37,38). During handling of mastic asphalt indoors, exposure levels were 2 to 3 times higher than for workers at the same work-site who worked outdoors (14).
Meteorological conditions, such as air temperature (37), wind speed and direction (36,37), were listed as one of the most important factors affecting exposure levels. Asphalt and bitumen type were reported to influence exposure levels, but to a lesser extent than meteorological conditions and application temperature (37). An increase in relative humidity was reported to decrease bitumen fume exposure (20).

During one hygiene survey in the USA, it was observed that dust masks, though available to road paving workers, were not worn even when emission of asphalt fumes into workers’ face was visible (22). In another US study, the use of respiratory protection among workers exposed to asphalt fume was not observed (25).

Dermal exposure

According to the Centre for Research and Contract Standardization in Civil and Traffic Engineering (CROW) (11), ‘there is a lack of information regarding skin exposure’ to bitumen condensate. The same document speculates that ‘fumes condensed onto tools or machine surfaces may be transferred to hands and clothes.’ There are very few studies examining causes of skin exposure in road construction. The effect of protective clothing on dermal PAH exposure during handling of asphalt was difficult to evaluate in one study due to low overall levels of exposure detected by skin wipes (25). Not all workers were reported to wash hands prior to lunch breaks after handling asphalt (25). There appears to be no correlation between airborne asphalt fume and dermal deposition of asphalt condensate (23).

Conclusion

For the IARC historical cohort study of asphalt industry, data reported in published reports have limited value in assessing exposure levels. It can be used for very crude qualitative grouping of the road construction workers into groups that are likely to have similar exposure patterns. Road paving and asphalt mixing workers can be expected to have similar bitumen exposure which is higher than that of ground construction workers. In contrast, ground construction workers are probably a job class with elevated silica exposure. Workers engaged in mastic laying, those who paved hotter asphalt mixes and paved in enclosed spaces can be expected to have elevated bitumen fume exposure. Bitumen fume exposures at asphalt plants and outdoor hot mix paving and surface dressing can be expected to be similar. This comparison can be confounded by presence on organic matter of non-bitumen origin. Exposure to PAH can be anticipated to be elevated when coal tar is added to paving mixtures. There is also some evidence that the exposures have been higher in the past. However, misclassification of exposure in such grouping can be expected to be substantial and its magnitude and direction would be impossible to quantify. Assembling industrial hygiene measurements from various studies into a single database and obtaining access to unpublished data may help refine exposure assessment in road construction industry.

References


