



Bitumens and bitumen emissions, and some heterocyclic polycyclic aromatic hydrocarbons



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In October, 2011, 16 experts from nine countries met at the International Agency for Research on Cancer (IARC) in Lyon, France, to reassess the carcinogenicity of bitumens and their emissions, and of some N-heterocyclic and S-heterocyclic polycyclic aromatic hydrocarbons (PAHs). These assessments will be published as Volume 103 of the IARC Monographs.¹

Bitumens are produced by distillation of crude oil during petroleum refining, and also occur naturally. Bitumens can be divided into six broad classes according to their physical properties and specifications required for different applications (webappendix p 1). The main use (about 80%) of bitumens is for road paving; other uses include roofing, waterproofing, sealing, and painting. The term bitumen should not be confused with asphalt, which refers to the mixture of bitumen (4–10% by weight), small stones, sand, and filler used for road paving.

Four major occupational exposures to bitumens and bitumen emissions have been evaluated for cancer risks in epidemiological studies: roofing, road paving, mastic asphalt work, and other occupations such as manufacturing of bitumen products and asphalt mixing.

Roofers are often exposed to relatively high levels of bitumen emissions, due to high application temperatures (webappendix p 1). A meta-analysis of seven studies published before 1994 reported an increased risk for lung cancer (relative risk 1.78 [95% CI 1.50–2.10]),² with risk estimates similar for cohort and case-control studies, the latter being adjusted for smoking. A subsequent European cohort study among workers exposed to bitumens reported an increased risk for lung cancer among roofers and waterproofing workers (standardised mortality ratio [SMR] 1.33 [95% CI 0.73–2.23]).³ However, roofers can also be exposed to other

lung carcinogens, such as coal tar from removing old roofs, and potential confounding is difficult to rule out. Four cohort studies reported increased risks for cancers of the upper aerodigestive tract, but potential confounding by tobacco smoking, alcoholic beverages, or other occupational exposures could not be excluded.

A meta-analysis of four studies of road pavers reported no increase in lung cancer risk.² The European cohort study,³ the largest study of road pavers published subsequently, reported a small increase in lung cancer mortality among road pavers compared with the general population (SMR 1.17 [95% CI 1.04–1.30]); however, the effect was attenuated when other construction workers were used as internal referents. Of the quantitative estimates of exposure to bitumen emissions modelled (cumulative, average, and duration of exposure), average exposure was significantly associated with lung cancer mortality. In a nested case-control study that excluded pavers who were likely to have been exposed to coal tar and higher levels of bitumen, there was no suggestion of an increase in lung cancer risk with various metrics of bitumen exposure.⁴ Overall, the evidence for lung cancer risk among road pavers and road maintenance workers exposed to bitumens is inconsistent. Additionally,

potential confounding by exposures to other carcinogens such as coal tar, diesel engine exhausts, or silica dust could not be ruled out.

Work with mastic asphalt involves exposure to the highest reported levels of bitumen emissions, because of its use at high temperatures (webappendix p 1). Two studies investigated cancer risks associated with exposure to bitumens during mastic asphalt work, and both showed an increased risk for lung cancer.^{3,5}

All informative studies of carcinogenicity of bitumens in experimental animals have been done in mice (apart from one inhalation study in rats⁶), with bitumen applied dermally either neat, in a solvent (benzene, acetone, toluene, mineral spirits, mineral oil), or as a condensate of emissions generated from the bitumens. One of three studies with oxidised bitumens (Class 2)⁷ and all four studies with their fume condensates⁸ showed an increased risk for skin tumours (webappendix p 2). By contrast, none of the studies with straight-run bitumens (Class 1) or their fume condensates, including the inhalation study in rats, showed an increased risk. Of the two studies that investigated cut-back bitumens (Class 3), the initiation-promotion study showed evidence of a promoting effect on skin tumours.^{9,10} Bitumens of

Agent	Evidence of carcinogenicity in experimental animals	Mechanistic evidence	Overall evaluation
Benz[a]acridine	Inadequate	Weak	3
Benz[c]acridine	Limited	Weak	3
Dibenz[a,h]acridine	Sufficient	Moderate	2B
Dibenz[a,j]acridine	Sufficient	Strong	2A*
Dibenz[c,h]acridine	Limited	Strong	2B*
Carbazole	Sufficient	Weak	2B
7H-Dibenzo[c,g]carbazole	Sufficient	Moderate	2B
Dibenzothiophene	Inadequate (no data)	Weak	3
Benzo[b]naphthol[2,1-d]thiophene	Limited	Weak	3

*Strong mechanistic evidence contributed to the overall evaluation (see text).

Table: Evaluation of the N-heterocyclic and S-heterocyclic polycyclic aromatic hydrocarbons

the other classes were either not tested in cancer bioassays or gave inconclusive results.

Bitumens are complex mixtures that contain many organic chemical compounds. Bitumen emissions, generated upon heating, may contain two-ring to seven-ring PAHs, several of which are mutagenic and carcinogenic.¹¹ In mammalian cells, exposure to bitumen emissions or their condensates (class rarely reported) produced mutagenic intermediates and DNA adducts,^{12–14} induced DNA damage¹⁵ and micronuclei,¹⁶ and caused cellular stress and disruption of cellular defense programmes.¹⁷ Compared with control populations, blood or urine from road pavers working with bitumens showed higher levels of mutagenic urine,¹⁸ higher levels of reactive oxygen species, increased DNA damage, and cytogenetic alterations such as sister-chromatid exchange, micronuclei, and chromosomal aberrations in lymphocytes.^{19,20} In roofers, bitumen emissions induced DNA damage.

The Working Group concluded that there was “limited evidence” in humans for the carcinogenicity of occupational exposures to bitumens and bitumen emissions during roofing. In experimental animals, there was “limited evidence” of carcinogenicity for oxidised bitumens (Class 2), which are mainly used in roofing, and “sufficient evidence” of carcinogenicity for fume condensates of these oxidised bitumens. The Working Group thus classified occupational exposures to oxidised bitumens and their emissions during roofing as “probably carcinogenic to humans” (Group 2A).

Evidence in humans for the carcinogenicity of occupational exposures to bitumens and bitumen emissions during road paving was “inadequate”. Studies in experimental animals also provided “inadequate evidence” for the carcinogenicity of straight-run bitumens and fume condensates from straight-run bitumens, which are used mainly for road paving. However, the

strong evidence for mutagenic and genotoxic effects in exposed pavers led to the classification of occupational exposures to straight-run bitumens and their fume condensates during road paving as “possibly carcinogenic to humans” (Group 2B).

There was “limited evidence” in humans for the carcinogenicity of occupational exposures to bitumens and bitumen emissions during mastic asphalt work. In the absence of data in experimental animals for these types of bitumens, occupational exposures to hard bitumens and their emissions during mastic asphalt work were classified as “possibly carcinogenic to humans” (Group 2B).

Evaluations for the N-heterocyclic and S-heterocyclic PAHs, some of which have been detected in bitumen emissions, are shown in the table. No epidemiological studies of these PAHs have been reported. Studies of dibenz[a,j]acridine and dibenz[c,h]acridine in experimental systems provided strong evidence of their genotoxicity, which led to a higher overall evaluation (Group 2A and 2B, respectively) than that based solely on respective cancer bioassay data.

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We declare that we have no conflicts of interest.

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Conflicts of interest

MDM receives research support from the US National Asphalt Pavement Association. MA receives a salary from the US National Asphalt Pavement Association, and has provided testimony at regulatory hearings. WEF is an employee of Owens Corning, which manufactures and sells asphalt roofing and paving products. JFF is an employee of ExxonMobil Biomedical Sciences, a wholly owned affiliate of ExxonMobile Corp. AJK has ownership in a bitumen company, and is an employee of Heritage Research Group, a company that has received funding from industry associations for studies on bitumen and bitumen emissions. JMM is an employee of the New York State Laborers' Health and Safety Fund, which is supported by the labour union representing paving workers in that state; he is also a consultant for a similar national fund. AJR is an employee of BP, a multinational oil company that manufactures and sells bitumen and bitumen-based products, and is a representative for the industry associations Eurobitume and Concawe. All other Working Group members, specialists, representatives, and secretariat declared no conflicts of interest.