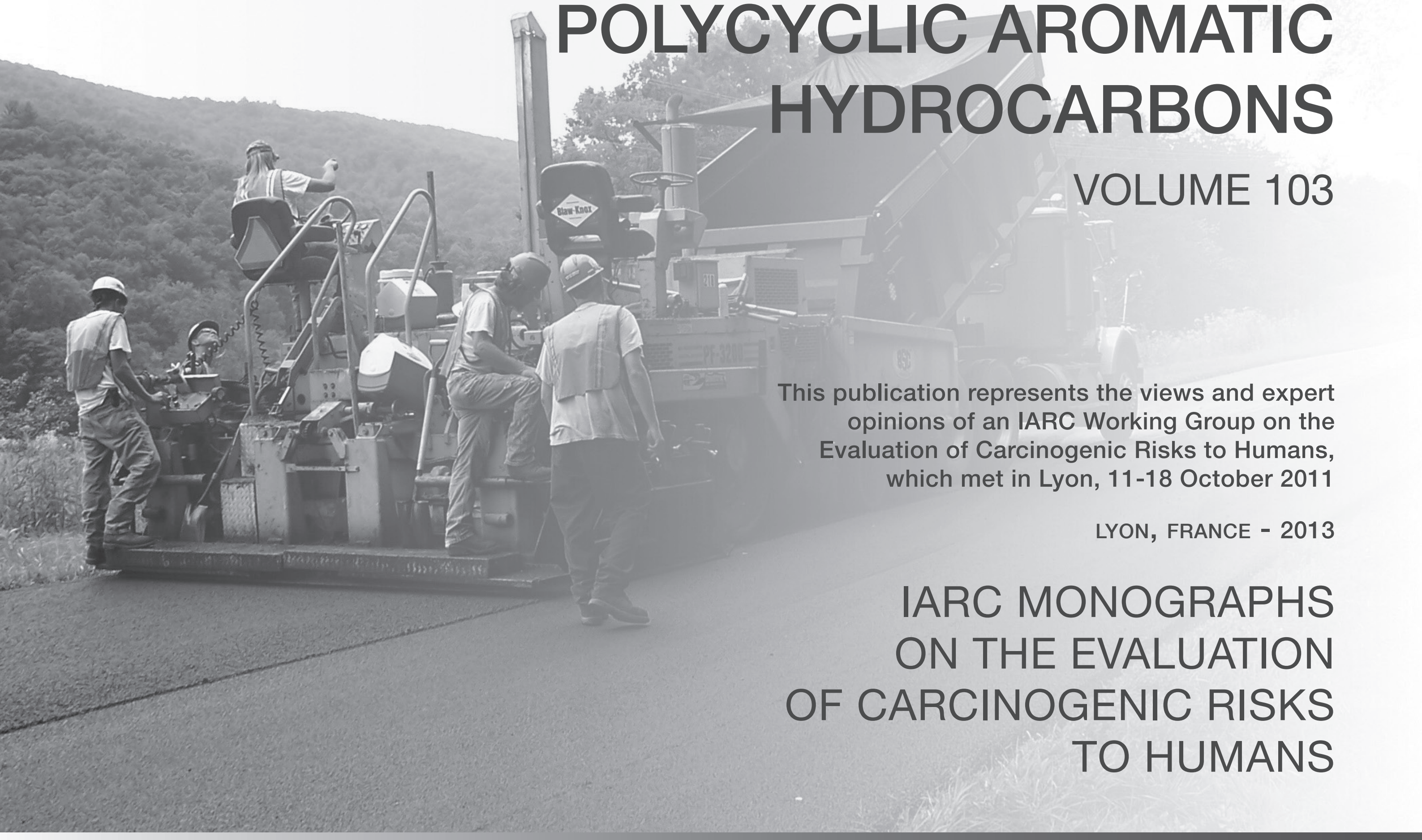
IARC MONOGRAPHS

BITUMENS AND BITUMEN EMISSIONS, AND SOME *N*- AND *S*-HETEROCYCLIC POLYCYCLIC AROMATIC HYDROCARBONS

VOLUME 103



This publication represents the views and expert opinions of an IARC Working Group on the Evaluation of Carcinogenic Risks to Humans, which met in Lyon, 11-18 October 2011

LYON, FRANCE - 2013

IARC MONOGRAPHS ON THE EVALUATION OF CARCINOGENIC RISKS TO HUMANS

International Agency for Research on Cancer

World Health Organization

GENERAL REMARKS

Background

This one-hundred-and-third volume of the *IARC Monographs* contains evaluations of the carcinogenic hazard to humans of bitumens and bitumen emissions, and of some *N*- and *S*-heterocyclic polycyclic aromatic hydrocarbons (referred to as azaarenes and thiaarenes, respectively). This volume is the fourth in a series of *IARC Monograph* volumes evaluating exposures related to air pollution. Indeed, the *IARC Monographs* Advisory Group that met in 2004 recommended that IARC develop such series, in recognition of the large contribution of air pollution to the global burden of cancer. Agents and related exposures evaluated thus far according to this recommendation include non-heterocyclic polycyclic aromatic hydrocarbons in Volume 92 (IARC, 2010a); particles and fibres in Volume 93 (IARC, 2010b) and indoor air pollution in Volumes 95 and 100E (IARC, 2010c, 2012).

This *Monograph* concerns only bitumens produced by petroleum refining and not naturally occurring bitumens. Thus the term "bitumens", as used in this volume, refers to the products derived from residues resulting from vacuum distillation of selected petroleum crude oils. These materials are called "asphalt", "petroleum asphalt" or "asphalt cement" in North America; in this volume, the term "asphalt" is used to describe mixtures of bitumen and mineral matter. Bitumens must be distinguished from coal tars, which are products of the destructive distillation of coals, and also from coal-tar pitches, which are residues from the distillation of coal tars.

A summary of the findings of this volume has appeared in *The Lancet Oncology* (Lauby-Secretan *et al.*, 2011).

Previous evaluations of the agents covered

An overview of the previous IARC evaluations for the agents covered in this volume is given in Table 1.

Categorization of bitumens into classes

The Working Group that met in February 1984 for Volume 35 categorized bitumens into eight classes representing the major types used in industry (IARC, 1985). The Working Group for the present *Monograph* reconsidered these categories and defined six classes according to current uses

Table 1 Previous IARC evaluations of the agents under review

Agent	*Monograph* volumes [a]	IARC Group	Level of evidence [b]	
			Humans	Animals
Bitumens and bitumen emissions				
Bitumens	35, Sup7	3	I	-
Steam-refined bitumen extracts [class 1]	35, Sup7	2B	-	S
Air-refined bitumen extracts [class 2]	35, Sup7	2B	-	S
Steam- and air-refined bitumen mixtures [classes 1 and 2]	35, Sup7	2B	-	S
Cracking-residue bitumens [class 8]	35, Sup7	-	-	L
Steam-refined bitumens, undiluted [class 1]	35, Sup7	-	-	L
Air-refined bitumens, undiluted [class 2]	35, Sup7	-	-	I
N-heterocyclic polycyclic aromatic hydrocarbons				
Benz[*a*]acridine	32, Sup7	3	-	I
Benz[*c*]acridine	3, 32, Sup7	3	-	L
Dibenz[*a*,*h*]acridine	3, 32, Sup7	2B	-	S
Dibenz[*a*,*j*]acridine	3, 32, Sup7	2B	-	S
Dibenz[*c*,*h*]acridine	-	-	-	-
Carbazole	32, Sup7, 71	3	-	L
7*H*-Dibenzo[*c*,*g*]carbazole	3, 32, Sup7	2B	-	S
S-heterocyclic polycyclic aromatic hydrocarbons				
Dibenzothiophene	-	-	-	-
Benzo[*b*]naphthol[2,1-*d*]thiophene	-	-	-	-

[a] Sup7, Supplement 7 of the *IARC Monographs*
[b] Level of evidence in humans and experimental animals: I, inadequate evidence; L, limited evidence; S, sufficient evidence

Table 2 Comparison of the classes of bitumen as defined by the Working Group for Volume 35 and by the Working Group for Volume 103

Volume 35		Volume 103	
Class	**Definition**	**Class**	**Definition**
Class 1	Penetration bitumens	Class 1	Straight-run bitumens
Class 4	Hard bitumens		
Class 2 [a]	Oxidized bitumens	Class 2	Oxidized bitumens
Class 3	Cutback bitumens	Class 3	Cutback bitumens
Class 5	Bitumen emulsions	Class 4	Bitumen emulsions
Class 6	Blended or fluxed bitumens	Class 5	Modified bitumens
Class 7	Modified bitumens		
Class 8	Thermal bitumens	Class 6	Thermally-cracked bitumens

[a] It is noteworthy that class 2 "oxidized bitumens" (CAS No. 64742-93-4) comprises two grades of oxidized bitumens, namely fully-oxidized (penetration index > 2) and air-rectified (semi-blown) (penetration index ≤ 2). These grades differ by their degree of oxidation during production, which leads to very different characteristics and uses. Air-rectified bitumens have applications similar to those of class 1 bitumens.

(see Table 2). Class 1 "straight-run bitumens" now encompasses the former class 1 "penetration bitumens" and class 4 "hard bitumens," while classes 6 and 7 have been merged into a single class 5 "modified bitumens," as shown in Table 2.

The influence of solvents

Bitumens are produced as a solid or highly viscous material that can be softened or solubilized in solvents for use in industrial applications and in experimental settings. The individual constituents of bitumens have variable solubility and the choice and amount of solvent used will influence the physical form of the resulting material and the composition of the liquid and solid phases. Certain solvents may selectively extract specific constituents from bitumen, and the presence of solvents is likely to alter dermal-penetration characteristics and may influence the carcinogenic outcome.

In earlier studies of carcinogenicity in experimental animals, various solvents, including benzene, toluene or cyclohexane/acetone, were used to prepare either bitumen or bitumen condensates for dermal application. Interpretation of these studies is challenging due to the use of these different solvents. Indeed, this raised some concern in relation to the possibility that the dissolved and/or suspended study material may be different from the original neat material to the extent that it should be defined as a different class of bitumen.

The influence of temperature

Bitumens are produced as a solid or highly viscous material and are heated to form a molten liquid that can be used for industrial applications such as roofing and paving. Softer grades of paving bitumen are typically heated to 140 °C, while harder paving grades and oxidized bitumens are heated to higher temperatures. The variable physicochemical properties of the individual constituents of bitumen mean that the composition and physical form of the emissions from heated bitumens are dependent on the temperature to which the bitumen is heated. This variability presents a significant challenge when assessing airborne exposure for epidemiological studies and when designing studies in experimental animals.

While in earlier studies in animals bitumen was typically applied neat or diluted in a solvent, on the skin or by subcutaneous injection (see above), studies of carcinogenicity in experimental animals conducted since the late 1980s have investigated the carcinogenic activity of bitumen-fume condensates generated at temperatures between 120 and 316 °C, in both skin and inhalation models. The condensates are liquids of lower viscosity in which the lighter constituents of lower relative molecular mass have been concentrated. Results of studies with condensates generated at > 199 °C strongly suggest that temperature plays an important role in determining the degree of exposure and also the carcinogenic potential of bitumen emissions.

Use of coal tar for road paving and roofing

Human exposure to bitumens and their emissions comes almost exclusively from occupational exposure during manufacture and use of the products. The potential for confounding by other occupational exposures is a concern in the study of the carcinogenicity of bitumens and their emissions because many workers with occupations that involve exposure to bitumens may also experience, today or in the past, exposure to coal tars, which are established human carcinogens.

In road paving, coal tars were used as such or mixed with bitumens until the early 1960s in many European countries. From the early 1960s to the mid-1970s, coal-tar use declined dramatically, but continued in some countries such as Germany and France until 1996 in specialized surface-dressing operations (Burstyn *et al.*, 2003). Coal tar was frequently used in the USA in road paving until the Second World War, and decreased drastically thereafter. Since then, coal tars have been used in some non-road applications, such as airfields, and as a pavement sealer for parking lots, driveways and bridges. Some coal-tar mixes were used in South Africa and Australia in the 1960s and 1970s in container terminals, car parks and bus terminals, which are subject to fuel spills. No information on use of coal tar for road paving in other countries was available to the Working Group.

Roofers may also be exposed to coal tar during the process of tearing off old roofing materials made with coal tar.

Studies of carcinogenicity in experimental animals

The current review of available studies on the carcinogenicity of bitumens in experimental animals indicated that of the 26 reported studies in mice, fewer than half were adequately conducted or reported to allow evaluation of carcinogenicity. In rats, of the three reported studies (one on injection, two on inhalation) there was only one adequate study (inhalation). Both reported dermal studies in rabbits were also inadequate. All the inadequate studies were published before 1980. A similar proportion of inadequate studies was also observed in the studies reviewed for the *N*- and *S*-heterocyclic polycyclic aromatic hydrocarbons. Studies were judged to be inadequate on the basis of poor study design or poor reporting, no inclusion of information about controls, limited or no histopathology or information on survival.

Although naturally occurring bitumens were not considered for this *Monograph*, it is interesting to report here a study on their carcinogenicity. Mice received lifetime dermal exposure to tar sands (containing approximately 80% sand, 10% water, and 10% hydrocarbons) or to an oily emulsion of it (created by first treating the tar sands with hot water, steam, and sodium hydroxide and then removing the solids and water). The mice treated with tar sand did not develop skin tumours (0/40), while two skin tumours developed in those treated with the oily emulsion (2/40; one papilloma and one carcinoma) (McKee *et al.*, 1986; McKee & Lewis, 1987).

Combining data on experimental carcinogenicity and epidemiological findings

In evaluating the carcinogenicity of bitumens in experimental animals, the Working Group was faced with the challenge of determining which class of bitumen was used in a study, based on the description of the study materials. The current categorization into six classes of bitumens, compared with the eight classes defined by the previous Working Group (see Table 2), and the poor description of the material used in some early studies sometimes made it difficult to attribute the study material to the proper class of bitumen.

Unlike the data for animals, the epidemiological studies were reported for four major types of occupational exposure, namely road paving, roofing, mastic-asphalt work, and several other occupations involving exposure to bitumens and bitumen emissions, including manufacturing of bitumens and asphalt products. Each of these occupational situations could involve worker exposure to several different classes of bitumens with attendant challenges for comparing or combining the data for humans and animals.

New development of products and processes

Recent research reported significant reductions in exposure levels among paving workers in Europe since 1960 (Burstyn *et al.*, 2003). The discontinuance of coal-tar use in Europe and technological advances in bitumen manufacture have contributed to reducing worker exposures. Application temperature is widely recognized as an important parameter in the generation of bitumen fume. More recently, warm-mix asphalt has been developed as a method that allows asphalt to be produced and placed on the road at significantly lower temperatures than conventional asphalt mixes. Lowering the mixing and application temperature by 10–38 °C (50–100 °F) has the potential to reduce emissions surrounding paving workers. However, these technologies may take time to introduce, particularly in low- and medium-resource countries.

References

Burstyn I, Boffetta P, Kauppinen T *et al.* (2003). Estimating exposures in the asphalt industry for an international epidemiological cohort study of cancer risk. *Am J Ind Med*, 43: 3–17. doi:10.1002/ajim.10183 PMID:12494417

IARC (1985). Polynuclear aromatic compounds, Part 4, bitumens, coal-tars and derived products, shale-oils and soots. *IARC Monogr Eval Carcinog Risk Chem Hum*, 35: 1–247. PMID:2991123

IARC (2010a). Some non-heterocyclic polycyclic aromatic hydrocarbons and some related exposures. *IARC Monogr Eval Carcinog Risks Hum*, 92: 1–853. PMID:21141735

IARC (2010b). Carbon black, titanium dioxide, and talc. *IARC Monogr Eval Carcinog Risks Hum*, 93: 1–413. PMID:21449489

IARC (2010c). Household use of solid fuels and high-temperature frying. *IARC Monogr Eval Carcinog Risks Hum*, 95: 1–430. PMID:20701241

IARC (2012). Personal habits and indoor combustions. *IARC Monogr Eval Carcinog Risks Hum*, 100E: 1–575. PMID:23193840.

Lauby-Secretan B, Baan R, Grosse Y *et al.;* WHO International Agency for Research on Cancer Monograph Working Group (2011). Bitumens and bitumen emissions, and some heterocyclic polycyclic aromatic hydrocarbons. *Lancet Oncol*, 12: 1190–1191. doi:10.1016/S1470-2045(11)70359-X PMID:22232803

McKee RH & Lewis SC (1987). Evaluation of the dermal carcinogenic potential of liquids produced from the Cold Lake heavy oil deposits of northeast Alberta. *Can J Physiol Pharmacol*, 65: 1793–1797. doi:10.1139/y87-279 PMID:3690399

McKee RH, Stubblefield WA, Lewis SC *et al.* (1986). Evaluation of the dermal carcinogenic potential of tar sands bitumen-derived liquids. *Fundam Appl Toxicol*, 7: 228–235. doi:10.1016/0272-0590(86)90152-1 PMID:3758541