ARISM GROUP

the asphalt roofing industry science & medical group
a health and safety information coalition

The Health Effects of Occupational Exposure to Asphalt Fumes

A Review of the available Scientific Data and On-Going Industry and Government Research

Introduction

Asphalt, a familiar and commercially important commodity, is a solid or semisolid thermoplastic material defined by the American Society of Testing Materials as a dark brown to black cementitious substance, consisting predominantly of bitumens, which occurs in nature or, more commonly, is produced by the refining of petroleum crude oils.(1) Because of its valuable properties, including adhesive characteristics, flexibility, durability, water resistance, high dielectric strength, and ability to form strong cohesive mixtures with mineral aggregates,(1)asphalt has been used extensively for over 5,000 years in pavement construction, roofing, waterproofing and other industrial applications.(2)

In the United States today, asphalt is used primarily in road paving and in the roofing industry, where it is found in such popular products as built-up roofing and modified bitumen roofing systems, asphalt shingles, and roof coatings, mastics and cements. Occupational exposure to asphalt fumes can occur in those operations in which asphalt is heated to high temperatures (well above 100°F)such as in plants manufacturing roofing asphalt products and during the installation of built-up roofing (BUR) systems. Asphalt shingles, coatings, mastics and cements (none of which are heated to high temperatures during installation), as well as other asphalt products (such as BUR) which have cooled after installation, do not release fumes.

Asphalt fumes contain trace levels of unsubstituted polynuclear aromatic hydrocarbons (PAHs), some of which have been shown to cause skin cancer in laboratory tests on experimental animals. The National Institute for Occupational Safety and Health (NIOSH) has concluded, however, that the presence of these very small concentrations of PAHs in asphalt fumes does not present a significant risk of cancer to workers.(3) As a result, existing worker health recommendations for asphalt fumes are based on the acute, reversible eye and respiratory tract irritation some exposed workers may experience.

Specifically, existing guidelines published by NIOSH(3) and the American Conference of Governmental Industrial Hygienists (ACGIH)(4) recommend that workplace exposures to asphalt fumes be kept below 5.0 mg/m^3 to protect against acute eye and respiratory irritation. Likewise, while the Occupational Safety and Health Administration (OSHA) has not set a legal standard for workplace asphalt fume exposure, a 1992 OSHA proposal to establish a 5.0 mg/m^3 limit to protect against irritation effects is pending(5).These recommendations are not identical because they are based on different methods of measuring fume exposure levels. But regardless of which method is used,

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occupational fume exposures during the manufacture and application of asphalt roofing products today are generally well below the current guidelines.[6]

In recent years, studies published in the United States and Europe have raised new questions about the possible carcinogenic properties of asphalt fumes as well as the potential for respiratory and other irritation effects at lower exposure levels.[5,7] These reports, in turn, have prompted industry, government and other organizations to launch a number of new studies to explore these questions and to identify exposure reduction controls that can be promptly implemented in the event new hazards are documented by sound scientific evidence. The purposes of this paper are to provide an up-to-date review of the available scientific evidence on the health effects of occupational exposure to asphalt fumes and to describe the ongoing government and industry research programs.

I Potential Carcinogenity

(a) Epidemiologic Studies

Because epidemiologic studies of exposed human populations provide the best scientific evidence of whether environmental agents pose health hazards, and because of the widespread use of asphalt in industry, many attempts have been made to investigate the cancer experience of workers potentially exposed to asphalt. Unfortunately, these investigations for a number of reasons have not yielded definitive results.[8,9]

The most recent authoritative review of the available epidemiological data is a 1994 paper written by the International Agency for Research on Cancer (IARC), whose carcinogenicity evaluations frequently form the basis for regulatory decisions in the U.S. and elsewhere. Based on a comprehensive and critical review of the epidemiologic literature, IARC finds no basis to conclude that exposure to asphalt fumes poses a cancer .[10] The IARC review concludes, specifically, that the published studies either fail to reveal increased rates of cancer among asphalt workers or have methodological limitations which render them unreliable as a basis for scientific evaluation. According to IARC, a frequent problem, particularly in European studies, has been what epidemiologists call “confounding” due to co-exposure to coal tar and other recognized human carcinogens.

The Hansen studies of Danish mastic asphalt workers[11,12,13] are good examples of the limitations in the available epidemiological data discussed in the IARC review. The Hansen studies, published in 1989 and 1991, raised new questions about the carcinogenicity of asphalt fumes because they found increased risks of lung and digestive tract cancers among study populations of workers in Denmark’s mastic asphalt industry. As used in Denmark, the term "*mastic asphalt*" refers to a low-volume specialty asphalt product which is applied by workers on their hands-and-knees at very high temperatures.[9,14] Neither the composition of mastic asphalt, nor the work practices used in its application, bear any resemblance to the manufacture or installation of asphalt roofing or paving materials in the U.S.

Methodological questions have been raised about various aspects of the Hansen studies, including: the absence of adequate exposure data on asphalt fumes and possible confounders; possible selection bias in the cohort definition and enumeration; indications of a reverse

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dose-response trend for lung cancer; and questionable statistical adjustments to separate-out the effects of smoking and coal tar exposures.[8,15,16] In addition, the striking differences between the morbidity and mortality patterns of Hansen's cohorts and those of U.S. asphalt workers recently studied [17, 18] suggest that non-work-related lifestyle factors may have played an etiological role in the results. Thus, the only U.S. regulatory agency to evaluate the Hansen studies to date has found them inconclusive due to such methodological concerns. [16]

Coal tar confounding also undermines the Hansen findings, as the recent IARC review concludes. In fact, IARC' finding that Dr. Hansen's study subjects were significantly exposed to coal tar is supported by a large and persuasive body of evidence, including (i) Danish highway department records; [14,19,20,21] (ii) contemporaneous formulations for mastic asphalt pavement products obtained from their Danis manufacturers;[14, 20] (iii) confirmation by Danish highway department officials based on long-term service and governmen records;[19,21] (iv) chemical analyses of randomly selected mastic asphalt pavemen samples;[20, 21] and (v) limited industrial hygiene sampling data.[21] Accordingly, Dr. Hansen has effectively acknowledged the prior use of coal tar and the need to reassess her findings.[22]

In spite of the failure of previous epidemiologic investigations to produce a definitive answer, there remains much interest in such studies as a longer-term research tool. Several years ago, the Asphalt Institute commissioned an assessment of the feasibility of conducting a retrospective epidemiologic study of workers employed in the U.S. asphalt industry in previous years. The investigators found, however, that such a study would be infeasible in large part due to the absence of adequate documentation of historical exposures and the known presence of potential confounders such as smoking.[23] IARC is in the process of evaluating the feasibility of a study of European asphalt workers,[24] and recently made available for comment a proposed study protocol which IARC projects can be completed in six years.[25] The U.S. asphalt industry has provided financial support as well as logistical assistance for this initiative.[26]

In addition, two large U.S. asphalt roofing product manufacturers are conducting mortality surveillance programs to track the health experience of their workers. Over the 25 years of experience included in these two ongoing programs, no evidence of an increased risk of cancer among asphalt roofing manufacturing workers has emerged, although more time is needed before scientifically sound conclusions can be drawn.[27,28]

(b) Toxicological Research

The primary source of the renewed scientific interest in the possible carcinogenicity of asphalt fumes arises from two NIOSH skin-painting bioassays of experimental mice.[29,30] These studies involved roofing asphalt fume condensates that were specially prepared according to a novel laboratory procedure. In the first study, laboratory fume condensates generated at 450° and 600°F (232° and 316°C) produced skin cancers in the test mice.[29,31] In the second, laboratory fume condensates generated at 600°F (316°C) were separated into five fractions (labeled A through E), which were then bioassayed alone and in various combinations. The second study found that the carcinogenic activity of the laboratory test materials was restricted to Fractions B and C, which contained significant concentrations of alkylated

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3- to 7-ring polynuclear aromatic compounds (PACs), including aromatic hydrocarbons as well as sulfur and oxygen heterocycles. NIOSH and industry scientists have theorized that these large and diverse families of chemicals may well contain the subset of compounds responsible for the dermal carcinogenicity NIOSH found in the test mice.[30] Although Fractions B and C represent a small portion of the total laboratory fume condensate (about 13%), they contain many individual compounds that have not yet been specifically identified. Thus, as NIOSH has acknowledged, the source of the dermal carcinogenicity seen in the NIOSH mouse studies continues to elude us.[30]

Nevertheless, the NIOSH laboratory fume mouse studies have raised questions about whether there is a possible cancer risk to workers exposed to the asphalt fumes created in real-world manufacturing and application operations. In response, the U.S. asphalt industry, including organizations representing asphalt manufacturers as well as paving and roofing companies, formed in 1989 a coalition known as the Asphalt Industry Environmental Oversight Committee (AIEOC) to sponsor and conduct additional scientific research to find the answers left open by the NIOSH mouse studies.

The early phases of the AIEOC research program have focused on the question of the representativeness of NIOSH's laboratory test sample. In investigating this subject, industry scientists have relied heavily on standard chemical characterization techniques and short-term biological tests, particularly the Modified Ames bacterial mutagenicity assay, which has been shown to have a very high correlation with the dermal carcinogenicity of some complex petroleum-derived materials in mouse skin-painting studies.[32, 33] Early on, the program revealed a positive, although imperfect, correlation between mutagenicity as measured by the Modified Ames assay and the carcinogenicity of the five laboratory fume condensate fractions bioassayed in the second NIOSH study.[34]

Subsequent phases of the industry research on the representativeness of fume samples reveal that the laboratory-generated fume condensates used in the NIOSH mouse studies are markedly different, both chemically and toxicologically, from the asphalt fumes that are created under actual operating conditions in the field. These differences appear to arise from several specific elements of the NIOSH laboratory fume generation procedure, including: (i) vigorous stirring of a small (8 to 10 liter) sample of asphalt at 200-300 revolutions per minute; (ii) use of a vacuum pump to pull a pre-heated (100°C) air stream across the sample at a rate of 10 liters per minute; and (iii) continuous heating of the same sample under these stirring and vacuum conditions for extended periods ranging from 4 to 14 hours.[29,30,31]

None of these conditions in the NIOSH laboratory procedure exists during fume generation in actual asphalt industry operations. In real production and application operations, asphalt is not heated for extended periods, vigorously agitated, or used in conditions of significant vacuum. Basic principles of physical chemistry hold that severe laboratory processing conditions like those used in the NIOSH studies would have the effect of causing larger, more complex and much less volatile compounds, including alkylated and heterocyclic 3- to 7-ring PACs, to evolve from the parent asphalt into the laboratory fume test sample.[35] In fact, industry-sponsored compositional testing has empirically confirmed that both vigorous mechanical agitation, and the use of vacuum, substantially alter fume chemistry in precisely the fashion predicted by theoretical principles.[36]

More importantly, two independent studies of a variety of field fume samples, derived from materials, temperatures and operations typical of asphalt paving and roofing work in the U.S., have recently been reported. [36,37,38] In each case, the composition of the field fume sample was compared to a companion laboratory sample generated by applying the NIOSH laboratory protocol to the same parent asphalt, and at the same temperature, used in the field sample.

In all cases, the laboratory-generated samples contained heavy concentrations of higher molecular weight chemical species, including 3- to 7-ring PACs, while the counterpart field samples contained little or no detectable levels of such compounds.[36,37,38] In one of the two studies, the fume samples were subjected to Modified Ames mutagenicity assays; the laboratory samples tested positive, while the field samples tested negative.[38] These results are consistent with other studies finding mutagenic activity in laboratory-generated paving and roofing asphalt fume condensates, but not in field fumes generated from the same parent asphalts at standard manufacturing and application temperatures.[34,39]

Also significant is the repeated finding in these studies that the chemical composition of the field samples bears a strong resemblance to that of Fraction A in the second NIOSH mouse skin-painting study. If anything, actual field fumes appear to be more volatile, and contain even lower concentrations of 3- to 7-ring PACs, than NIOSH Fraction A.[36,37,38] This finding is further ground for cautious optimism that field fumes will not be shown to possess the carcinogenic properties of Fractions B and C of NIOSH's laboratory fume condensate sample. Thus, despite the presence of low concentrations of 3-to 7-ring PACs and sulfur heterocycles, Fraction A showed no evidence of carcinogenicity when bioassayed alone, and showed no evidence of carcinogenic, synergistic, co-carcinogenic or tumor promotion effects in a dozen other mouse skin-painting bioassays conducted in the second NIOSH study, in which Fraction A was applied in combination with one or more of the other fractions or benzo[a]pyrene (B[a]P).[30]

Presently, research in the chemistry and toxicology areas is designed to shed light on the scientific questions that cannot be answered definitively by the available data: First, what compounds or families of compounds in Fractions B and C of the NIOSH laboratory-generated fume condensate are likely responsible for the mouse skin cancers? Second, considering the great compositional variability of asphalts and asphalt fumes, are such compounds present in any, some, or most field fumes? And third, if so, are they present in sufficient quantities to warrant concern about a cancer risk to exposed workers? Parallel studies being conducted by industry and NIOSH, in consultation with Organized Labor, are underway to get prompt answers to these questions. [40,41] In the absence of adequate epidemiologic studies or experimental rodent bioassays, the ongoing work utilizes chemical characterization and short-term biological tests, including the Modified Ames assay, which can quickly generate relevant scientific data.

The basic approach in these research programs is to subdivide Fractions B and C into ever smaller subfractions in an effort to isolate the source of the activity reported by NIOSH in laboratory-generated fumes. Once a smaller group of suspect compounds has been isolated by applying compositional and short-term biological tests to the subfractions, it will be possible to look for these compounds in field fumes and test them for the presence of biological activity. Industry and NIOSH scientists are meeting on a regular basis to share and discuss the results of their research as well as future experimental protocols.

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In a separate initiative designed to overcome the serious questions that remain about the representativeness of the NIOSH laboratory fume generation technique, industry researchers have developed an alternative laboratory fume generation procedure that better simulates field exposures. Such a procedure might be used, for example, for chemical or biological tests requiring greater quantities of fumes than can practicably be collected in actual field operations. The equipment and protocol for this new procedure has been provided to IARC, which will use them in connection with its ongoing study in Europe.[26]

II Research on Exposure Measurement and Control Techniques

Ongoing research on the health effects of asphalt fumes is not limited to possible carcinogenic effects. Also being examined are the potential pulmonary and other irritation effects, which, as noted above, form the basis of the 5.0 mg/m^3 asphalt fume exposure limits currently recommended by NIOSH[3] and ACGIH[4] and recently proposed by OSHA.[5] These effects have recently become the subject of renewed scientific attention as a result of the Norseth study of Norwegian asphalt paving workers.[42]

The Norseth study finds statistical correlations between asphalt fume concentrations and subjective employee reports of symptoms such as fatigue and eye and throat irritation, and recommends, among other things, that workplace fume exposures be kept below 0.4 mg/m^3, measured as the benzene soluble fraction of total particulate. A U.S. asphalt industry scientific review and investigation of the Norseth study has concluded that additional research and data analysis are needed in order to better understand the potential for acute pulmonary and other irritation effects among U.S. asphalt workers, and to adequately investigate other possible environmental and industrial causes of any such effects.[43,44]

Several different initiatives are underway to explore the ramifications of Norseth's findings. First, U.S. asphalt industry scientists have proposed a collaboration with Dr. Norseth and his colleagues in Norway to reevaluate the exposure-response correlations in the Norseth data, using more sophisticated statistical tools and including a large pool of data that was excluded in the report of the Norseth study that was published in 1991.

Second, the asphalt industry has launched a similar study of U.S. workers, which has now entered its third phase and is expected to be completed in about a year. Results from the first two phases, although preliminary and not yet published, do not reveal adverse respiratory irritation effects at typical workplace exposure levels of approximately 1.0 mg/m^3 and below (measured as benzene soluble fraction). The data are, of course, subject to reevaluation after completion of the third phase, and workers with higher exposures are needed to reliably establish a no-observed-effect level. In addition, an ongoing NIOSH-Federal Highway Administration (FHWA) study of crumb-rubber-modified (CRM) paving asphalts is examining the potential for acute respiratory irritation effects in conventional asphalt paving operations as well as CRM jobs.[41] Industry epidemiologists and industrial hygienists have been consulting with NIOSH researchers on the design and implementation of both the AIEOC and NIOSH-FHWA studies.

Through these and other efforts, a much better understanding of the acute respiratory irritation risks to asphalt workers, as well as data that will permit scientists to isolate the specific causes of any such effects from the numerous environmental agents that could be responsible,[43,44] may be available within a year or so.

The U.S. asphalt industry, in consultation with Government and Organized Labor, has initiated several efforts to identify fume exposure reduction techniques that can be promptly implemented should the ongoing health effects studies identify a need to reduce exposures below their current levels. The first step in this area of research was an industry-sponsored cross-sectional exposure study, which was completed in 1991 This study demonstrated worker exposures in all sectors of the asphalt industry to be well-controlled, with typical exposures falling well below current recommended limits.[6]

Recently, asphalt roofing industry representatives initiated discussions with roofing kettle manufacturers to identify ways of modifying roofing kettles to lower exposures even further, and are actively participating in a study recently announced by NIOSH to identify feasible means of lowering fume exposures in roofing operations. [45] Similar efforts are underway in the paving sector.[41, 46]

U.S. asphalt industry scientists are also actively working on a program to develop an improved and standardized methodology for measuring asphalt fume concentrations in the workplace. Historically, occupational exposures to asphalt fumes have been evaluated by collecting air samples using several, somewhat different benzene soluble fraction (BSF) methods developed to measure coal tar pitch volatiles (specifically, OSHA Method 58[47] and NIOSH Method 5023[48]) or using the total particulate method (NIOSH Method 0500[49]) The BSF method, which measures the organic component of the fume, is regarded by many industrial hygienists as a more appropriate index of potential health effects because of asphalt's organic nature. The total particulate method captures airborne particulates other than asphalt fume droplets, and measures inorganic materials that are not considered likely to play a role in potential asphalt-related toxicity.

A scientific evaluation of the two BSF methods specifically addressing asphalt fume exposure assessment has recently been completed by U.S. asphalt industry scientists. The 1995 report on this study concludes that the NIOSH 5023 method, with some minor enhancements, provides the most accurate way to assess exposure to asphalt fume. This report and a proposed revision to the current method were presented to NIOSH scientists at meetings in March and May 1995, at the Petroleum Institutes Forum and at the American Industrial Hygiene Conference & Exposition, and have been submitted for publication in a peer-review industrial hygiene journal[50]. Additional method development work may well become necessary if and when the ongoing toxicology research isolates the compounds in the NIOSH laboratory fume condensates that may be responsible for the dermal carcinogenicity seen in the NIOSH mouse studies.

IV

Discussion and Conclusion

In view of the recent developments summarized above, it should be no surprise that NIOSH and ACGIH are in the process of reevaluating their current occupational health guidelines for asphalt FUMES.[51, 52] In addition, OSHA will no doubt eventually complete rulemaking on its 1992 5.0 mg/m^3 proposal, which has been stalled by an intervening court decision.[53] The question, then, is how regulators, industry, workers and others should view the emerging scientific data while the current research proceeds to a conclusion. NIOSH's existing Criteria Document for asphalt fumes, published in 1977,[3] establishes an objective and appropriate framework for that task.

The first step is to examine the available epidemiologic data – the best evidence of human risk. As noted above, the most recent authoritative review has been conducted by IARC, which finds that "so far as carcinogenicity of bitumen fumes in concerned, currently available human evidence is inconclusive."[25]

The next step is to evaluate the toxicological data, particularly the two NIOSH mouse skin painting studies of laboratory-generated asphalt fume condensates. As detailed above, the available scientific data indicates that it is unlikely that the as-yet-unidentified animal carcinogens in NIOSH's laboratory fume condensates are present in field fumes in significant concentrations. The crucial question, therefore, is whether the theoretical possibility that these compounds may be present in field fumes justifies a determination that exposure to asphalt fumes presents a cancer risk to humans.

On this question, too, the 1977 NIOSH Criteria Document utilizes a sound scientific approach that should guide the evaluation of today's data. The evidence available in 1977 included data showing "low" or "truce" concentrations in asphalt fumes of B[a]P, a recognized carcinogen, and several rodent bioassays yielding low to moderate tumorigenicity for whole asphalts dissolved in solvents and for certain aromatic and saturated fractions of asphalt. NIOSH called this evidence "cause for concern," but found it insufficient to warrant a finding that asphalt fumes are carcinogenic.

Specifically, NIOSH concluded that the mere presence of "*trace*" concentrations of B[a]P could not justify a carcinogenicity finding in view of the demonstrated potential for biochemical interactions in complex hydrocarbon mixtures such as asphalt.[3] That judgment was later confirmed in the first NIOSH mouse study, which showed that the dermal carcinogenicity of laboratory fume condensates in mice is unrelated to B[a]P.[29,31] With respect to the bioassay data available in 1977 NIOSH found these studies inadequate because, among other things, they involved "exposures unlikely to be faced by U.S. workers." Acknowledging that fractionating whole asphalts, or diluting them in solvents, can enhance the tumorigenic potential of the test materials in a fashion unrepresentative of actual worker fume exposures, NIOSH called for new studies "designed to simulate the exposure potential of a normal work situation."[3]

While enormous strides have been taken since 1977 in our understanding of the chemistry and toxicology of asphalt fumes, the data available today do not satisfy the scientific criteria NIOSH established in 1977. We know that field fumes are much different, in composition and biological characteristics, from the laboratory-generated fume condensates bioassayed in the NIOSH mouse studies.[36, 37, 38] We also know that the agents in NIOSH Fractions B and C that are responsible for the mouse skin tumors, although not yet identified, are unlikely to be present in field fumes in anything more than trace concentrations – if they are present at all. The

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available evidence also reveals that field fumes bear a marked resemblance to NIOSH Fraction A, which showed no evidence of carcinogenicity in over a dozen bioassays conducted in the second NIOSH study,[30] despite the fact that it contained higher concentrations of 3- to 7-ring PACs and heterocyclics than do field fumes.[36,38] Thus, Fraction A was non-carcinogenic even though it may well have contained low levels of the unknown agent responsible for the mouse skin tumors seen in NIOSH's laboratory fume studies.

These considerations, coupled with the inconclusive human data as underscored in the recent IARC review,[10,25] demonstrate that no carcinogenicity finding for asphalt can be justified at this time. A 1944 review of the chemical and biological data by Dr. Thomas J. Slaga, a preeminent research toxicologist on the carcinogenicity of complex hydrocarbon materials, reaches the same conclusion.[54] Nor is there convincing scientific evidence that exposures to asphalt fumes at current levels in U.S. asphalt operations are associated with a significant risk of acute pulmonary or other irritation effects.[43,44]

Nevertheless, as outlined above, the U.S. asphalt industry is committed to filling the existing gaps in the available evidence and developing a sound scientific basis for identifying and preventing any and all health hazards that may result from occupational asphalt fume exposures. This objective is being vigorously pursued using a variety of scientific and technical tools, including short term chemical and biological assays, epidemiologic methods, and engineering and industrial hygiene studies. The industry research, moreover, is proceeding in tandem with parallel Government programs and in an open dialogue with scientists from both Government and Organized Labor. There is every reason to hope that these research programs will soon bear fruit in the form of a greatly improved scientific foundation for hazard and risk assessment.

Further information about the available scientific evidence on the health effects of exposure to roofing asphalt fumes and the ongoing research programs is available from any of the four U.S. asphalt roofing industry associations which have prepared this review:

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