IARC MONOGRAPHS

ARSENIC, METALS, FIBRES, AND DUSTS

VOLUME 100 C
A REVIEW OF HUMAN CARCINOGENS

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, 17-24 March 2009

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IARC MONOGRAPHS ON THE EVALUATION OF CARCINOGENIC RISKS TO HUMANS

International Agency for Research on Cancer
World Health Organization

GENERAL REMARKS

Part C of Volume 100 of the *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans* contains updated assessments of arsenic, metals, fibres, and dusts that were first classified as *carcinogenic to humans (Group 1)* in Volumes 1–99.

Volume 100 – General Information

About half of the agents classified in Group 1 were last reviewed more than 20 years ago, before mechanistic studies became prominent in evaluations of carcinogenicity. In addition, more recent epidemiological studies and animal cancer bioassays have demonstrated that many cancer hazards reported in earlier studies were later observed in other organs or through different exposure scenarios. Much can be learned by updating the assessments of agents that are known to cause cancer in humans. Accordingly, IARC has selected *A Review of Human Carcinogens* to be the topic for Volume 100. It is hoped that this volume, by compiling the knowledge accumulated through several decades of cancer research, will stimulate cancer prevention activities worldwide, and will be a valued resource for future research to identify other agents suspected of causing cancer in humans.

Volume 100 was developed by six separate Working Groups:

Pharmaceuticals
Biological agents
Arsenic, metals, fibres, and dusts
Radiation
Personal habits and indoor combustions
Chemical agents and related occupations

Because the scope of Volume 100 is so broad, its *Monographs* are focused on key information. Each *Monograph* presents a description of a carcinogenic agent and how people are exposed, critical overviews of the epidemiological studies and animal cancer bioassays, and a concise review of the toxicokinetic properties of the agent, plausible mechanisms of carcinogenesis, and potentially susceptible populations, and life-stages. Details of the design and results of individual epidemiological studies and animal cancer bioassays are summarized in tables. Short tables that highlight key results appear in the printed version of Volume 100, and more extensive tables that include all studies appear on the website of the *IARC Monographs* programme (http://monographs.iarc.fr). For a few well-established associations (for example, tobacco smoke and human lung cancer), it was impractical to include all studies, even in the website tables. In those instances, the rationale for inclusion or exclusion of sets of studies is given.

Each section of Volume 100 was reviewed by a subgroup of the Working Group with appropriate subject expertise; then all sections of each *Monograph* were discussed together in a plenary session of the full Working Group. As a result, the evaluation statements and other conclusions reflect the views of the Working Group as a whole.

Volume 100 compiles information on tumour sites and mechanisms of carcinogenesis. This information will be used in two scientific publications that may be considered as annexes to this volume. One publication, *Tumour Site Concordance between Humans and Experimental Animals*, will analyse the correspondence of tumour sites among humans and different animal species. It will discuss the predictive value of different animal tumours for cancer in humans, and perhaps identify human tumour sites for which there are no good animal models. Another publication, *Mechanisms Involved in Human Carcinogenesis*, will describe mechanisms known to or likely to cause cancer in humans. Joint consideration of multiple agents that act through similar mechanisms should facilitate the development of a more comprehensive discussion of these mechanisms. Because susceptibility often has its basis in a mechanism, this could also facilitate a more confident and precise description of populations that may be susceptible to agents acting through each mechanism. This publication will also suggest biomarkers that could render future research more informative. In this way, IARC hopes that Volume 100 will serve to improve the design of future cancer studies.

Specific remarks about the review of the agents in this volume

1. Arsenic and metals

One issue for several of these agents was the designation of the agent classified as carcinogenic. Arsenic and the metals considered exist in several oxidation states and in different forms that have different chemical and physical properties: metallic/elemental forms, alloys, and multiple compounds. For arsenic and the metals, the Working Group needed to consider whether:

1) the metallic/elemental form itself is carcinogenic;
2) the metallic/elemental form and the compounds are carcinogenic; or
3) only certain compounds are carcinogenic.

The simultaneous review of arsenic and multiple metals in this volume offered the opportunity for the Working Group to address the designation of these elements and/or their compounds in a uniform fashion. There had been some lack of consistency in prior designations, in part reflecting the nature of the evidence available and precedents in terminology around specific elements. Arsenic, for example, is widely referred to as "arsenic" alone and not as "arsenic and arsenic compounds."

In the *Monograph* on nickel and nickel compounds, the Working Group phrased its evaluation of the epidemiological studies as "mixtures of nickel compounds and nickel metal." The overall evaluation, however, was constrained to cover only nickel compounds and not nickel metal, in accordance with IARC's previously announced plan that Volume 100 would evaluate agents that had been classified as *carcinogenic to humans (Group 1)* in Volumes 1–99, and only nickel compounds had been classified in Group 1 in Volume 49 (IARC, 1990). Based on the previous evaluation in Volume 49, nickel metal remains classified as *possibly carcinogenic to humans (Group 2B)*. The Working Group

recommends that there is a need for IARC to re-evaluate nickel metal in the near future in the context of the review of nickel compounds in this volume.

The situation was similar for chromium in that the review in Volume 100 considered the carcinogenicity of chromium (VI), but not of chromium with other oxidation states. The decision to omit metallic chromium or chromium (III) compounds from present assessment should not be interpreted as implying that these compounds are not carcinogenic or that the current evidence base is unchanged from that at the time of Volume 49 (IARC, 1990). Indeed, the evidence base has expanded and the Working Group does not pre-judge what the results of a new evaluation might be.

In the *Monograph* on arsenic and arsenic compounds, the Working Group developed a single updated assessment of agents that had been evaluated in previous *Monograph*s on arsenic and arsenic compounds (Volume 23 and Supplement 7, IARC, 1980, 1987a), arsenic in drinking-water (Volume 84, IARC, 2004), and gallium arsenide (Volume 86, IARC, 2006). It should be understood that arsenic in drinking-water and gallium arsenide should continue to be regarded as *carcinogenic to humans*, covered in this volume by the evaluation of arsenic and inorganic arsenic compounds.

In interpreting the human evidence on these agents, a particular difficulty was posed by the mixed exposures sustained by the worker populations included in the cohort studies. For groups exposed simultaneously to an agent in elemental/metallic form and to its compounds, the evidence may be uninformative as to the components of the mixture that cause cancer. When the evidence comes only from mixed exposure circumstances, the Working Group considered that the evaluation should be phrased as referring to "exposure to the element and its compounds."

This phrasing should not be interpreted as meaning that:

1) separate human evidence is available for the metallic/elemental form itself and for each of its compounds or

2) the evaluation of human evidence applies separately to the metallic/elemental form and to each of its compounds.

From the human evidence, insight can be gained as to the specific carcinogenic agent if sufficient informative studies are available on multiple cohorts having exposures to differing speciations of the element. Additionally, cancer bioassay and mechanistic evidence are critical to determining which components of the exposure mixture are carcinogenic, and were given full consideration by the Working Group.

2. Fibres and Dusts

When an agent is referred to as a dust, the assumption made by the Working Group was that the major route of exposure was by inhalation.

The assessment of toxicity and carcinogenicity of poorly soluble materials in the form of particles or fibres is difficult for the following reasons:

First, chemical composition alone does not fully define the relevant biological properties of particulate materials.

Second, particulate and fibrous carcinogens may undergo more complex metabolic transformation than other chemical agents. The surface of dusts may be modified *in vivo*, for example, there may be removal or deposition of metal ions or protein adsorption. These *in vivo* modifications may alter potency of the native particles or fibres.

Third, when comparing potency of dust particles, surface area may be a more appropriate dose metric than mass. In many cases, the extent of particle-derived free radicals and release of inflammatory mediators and the subsequent biological response correlate with surface area.

Fourth, particles and fibres with low solubility including quartz and asbestos fibres induce toxicity in the particulate form and not as individual molecules or ions. Particles and fibres may be deposited and retained in a focal area for a long time and contribute to the induction of lesions at this site. Particles and fibres may also be translocated to extrapulmonary sites.

Two occupations previously classified in Group 1 are considered in this volume. Boot and shoe manufacture and repair was previously evaluated in Volume 25 and in Supplement 7 (IARC, 1981, 1987a). In this volume, the Working Group concluded that the nasal sinus tumours and leukaemias observed in the epidemiological studies could be attributed to exposure to leather dust and to benzene, respectively. In accordance with the Preamble (see part B, Section 6a), the Working Group focused its evaluation more narrowly on leather dust, after searching for other studies involving this new agent. The Working Group renamed this *Monograph* "Leather Dust." (The *Monograph* on Benzene will be updated in Part F of Volume 100.)

Furniture and cabinet making was also previously evaluated in Volume 25 and in Supplement 7 (IARC, 1981, 1987a). In this volume, the Working Group concluded that the tumours of the nasal sinus and nasopharynx observed in the epidemiological studies could be attributed to exposure to wood dust or formaldehyde. Accordingly, these studies are reviewed in this volume in the *Monograph* on Wood Dust. (The *Monograph* on Formaldehyde will also be updated in Part F of Volume 100.)

The previous *IARC Monographs* on Talc Containing Asbestiform Fibres (Volume 42 and Supplement 7, IARC, 1987a, b) concerned talc described as containing asbestiform tremolite and anthophyllite. These fibres fit the definition of asbestos and therefore a separate review of talc containing asbestiform fibres was not undertaken. The studies on talc containing asbestiform fibres were considered when developing the *Monograph* on asbestos. Talc containing asbestos as well as other mixtures containing asbestos should be regarded as *carcinogenic to humans*.

In evaluating the carcinogenicity of asbestos fibres, the Working Group evaluated experimental data using the six types of asbestos fibres (Chrysotile, Amosite, Crocidolite, Tremolite, Actinolite and Anthophyllite) and erionite based on *in vitro* cellular assays and/or cancer bioassays. It should be understood that minerals containing asbestos in any form should be regarded as *carcinogenic to humans*. The Working Group agreed that the most important physicochemical properties of asbestos fibres relevant for toxicity and carcinogenicity are surface chemistry and reactivity, surface area, fibre dimensions, and biopersistence. Extrapolation of toxicity to other crystalline mineral fibres should not be done in the absence of epidemiological or experimental data based on *in vitro* and *in vivo* assays.

The toxicity of crystalline silica dusts obtained from different sources may be related to their geological history, process of particle formation, modifications during mining, processing and use, or surface contaminants even in trace amounts. Freshly ground crystalline silica exhibits a higher toxic potential than aged dusts. Crystalline silica may occur embedded in clays and other minerals or may be mixed with other materials in commercial products. It is possible that these other minerals or materials may adsorb onto the surface of crystalline silica dust and modify its reactivity. However, the extent of surface coverage and the potency of these modified dusts after residence in the lungs have not been systematically assessed.

3. Cross-cutting issues

3.1 Epidemiology

The epidemiological evidence considered in this Volume largely comes from studies of worker groups exposed to the agents under consideration. Additionally, population-based case–control studies also supply relevant evidence as do a few case series. There are several general issues related to these lines of epidemiological evidence that are covered in these comments.

The epidemiological evidence considered in this Volume largely comes from studies of worker groups exposed to the agents under consideration at levels that were high in relation to contemporary exposures, particularly in more developed countries. The cohort studies of workers have the general design of longitudinal follow-up of groups known to be exposed to the agent of interest in their workplace. Some cohort studies incorporate specific, unexposed comparison populations whereas others make a comparison to the rates of mortality in the general population, typically at the national level but sometimes on smaller geographic domains, e.g. states or counties. The measures of association used (e.g. standardized mortality ratios or SMRs) compare the rate of outcome in the exposed population to that in the unexposed population. One general concern in interpreting these measures of association is the appropriateness of the comparison population selected. National rates are often used because they are available and stable, but use of such rates may be inappropriate if there are important differences between the study population and the population at large on factors that might confound or modify the relationship between exposure and outcome. With appropriate consideration, local rates may be more suitable because factors that may confound the relationship between cancer risk and exposure, e.g. cigarette smoking, are likely to be more similar than a national population to the distributions in the worker population. Use of both national and local rates provides a sensitivity analysis as to the potential role of confounding. However, use of local rates may introduce bias if they are influenced by occupational or environmental exposures resulting from the plants under study, or if the geographical areas available for analyses do not reflect the areas from which the occupational population as drawn. Use of local rates may also result in imprecision of the epidemiological risk estimate due to instability resulting from small numbers and/or inaccuracies in small area data. The most appropriate comparison group would be other worker populations.

The informativeness of a cohort study depends on its size, i.e. the numbers of participants and outcome events. The sample sizes of the various cohort studies reflect the numbers of workers employed during the period of interest. Many of the studies had small population sizes, leading to imprecise measures of association, i.e. with wide confidence intervals. For some agents, small studies were set aside because they were uninformative. The Working Group did not attempt to combine the results of all studies, regardless of size, using quantitative meta-analysis.

3.2 Mixed exposures

In many of the cohorts studied, the workers were exposed to mixtures generated by industrial processes that contained not only the agent(s) of concern, but other potentially carcinogenic agents as well. For example, in some populations exposed to chromium, there was simultaneous exposure to arsenic. In analyses of the data from such studies, efforts were made to separate the effect of the agent of concern from the effects of other, potentially confounding agents. Such disentanglement is

possible only if the exposures are not highly correlated and the requisite data on exposures to the agents are available. There is also the assumption underlying such analyses that the effects of the various agents in the mixture are independent. In its deliberations, the Working Group recognized that exposures to many of the agents took place through exposures to mixtures containing them and took this into account in its interpretation of the evidence.

Exposures were estimated for study participants using approaches that typically were based on measurements and reconstruction of exposures based on work history and job–exposure matrices. Additionally, duration of employment was used as a surrogate for exposure. The measures of exposure were used in analyses directed at characterizing exposure–response relationships. Given the limited data available for estimating exposures, the exposure measures were subject to some degree of misclassification, likely random. One consequence of such exposure misclassification would be a blunting of estimated exposure–response relationships.

3.3 Smoking as confounder

In interpreting findings related to lung cancer and other sites for which smoking is a cause, there is the potential for confounding by smoking, particularly because many studies lacked information on smoking and direct adjustment for smoking was not possible. In assessing the potential for confounding by smoking, consideration was given to whether internal comparisons were made, which should not be as likely to be confounded as external comparisons. Additionally, some studies used available smoking information to estimate the potential for confounding by smoking. Such analyses are useful but have the underlying assumption that the effects of smoking and the agent of interest are independent.

Since the prior reviews, several data sets had undergone re-analysis by analysts who were not the original investigators. As appropriate, the Working Group considered these re-analyses to assess any insights into the original analyses.

A summary of the findings of this volume appears in The Lancet Oncology (Straif et al., 2009).

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