Chapter 8.2 Man-made vitreous fibres

General description

Physical and chemical properties

Fibres are divided into naturally occurring and man-made (synthetic) fibres. Each of these groups can be subdivided into organic and inorganic fibres. Man-made vitreous fibres (MMVF) are a large subgroup of inorganic fibres. Fibre dimensions established in the 1960s for the measurement of asbestos fibres are used to denote which fibres should be counted for occupational safety: these are fibre length (F_L) > 5 µm, fibre diameter (F_D) < 3 µm and aspect ratio (F_L/F_D) > 3.

Vitreous fibres are currently the commercially most important group of fibres, although in future crystalline fibres (e.g. fibres from aluminium oxide, silicon carbide, silicon nitride and carbon) may become increasingly important. MMVF are made from glass, natural rock or any readily fusible slag, and are all amorphous silicates. The terms “glass”, “rock”, “slag” and “ceramic” fibres refer to the starting materials. These terms are used commercially and are now also used in the scientific literature. Consequently, they erroneously create the impression that they denote a biologically relevant delimitation. This is not the case, particularly with regard to their durability in the lung or similar biological milieu. They are also unsuitable terms for the assessment of carcinogenicity, as the properties of the main types currently produced cannot be generally applied to all of the manufactured types bearing the same trade name.

To make the final product, manufacturers add a thin binder to the fibres. The composition and proportional quantity of the binder may differ considerably, both between manufacturers and according to requirements for the end product. With rock and slag wools, different types of oil are used as a lubricant, but in the case of glass fibres the finished product is usually a complex formulation containing a lubricant, a resin for binding and one or more cation-active agents for adhesion.

In 1988, WHO *(1)* classified MMVF into four categories according to their manufacturing process and dimensions.

- *Continuous-filament fibres* are made exclusively from glass and have an approximate range of mean diameters of 6–15 µm.
- *Insulation wool* includes rock wool, slag wool and glass wool. Rock and slag wools are made by allowing molten rock or slag to run through a series of small openings in a revolving spinner and then attenuating the primary filament by air or steam blowing. Glass fibres are made from either borosilicate or calcio-alumina silicate glass. Nominal fibre diameters are 2–9 µm.
- *Refractory fibres* (including refractory ceramic fibres, RCF) are a large group of different types of amorphous or crystalline synthetic mineral fibre that are highly resistant to heat. They are produced from kaolin clay, oxides of aluminium, silicon or other minerals, or less commonly from non-oxide materials such as silicon carbide or silicon nitride. Nominal fibre diameters are 1.2–3.5 µm.

- *Special purpose fibres* are made exclusively from glass and have a nominal fibre diameter of 0.1–3 µm.

For the purposes of this book, MMVF have been placed in six categories according to differences in composition:

- continuous-filament glass fibres
- glass wool fibres
- rock wool fibres
- slag wool fibres
- refractory ceramic fibres
- special purpose fibres.

An overview of some typical chemical compositions is provided in Table 1. New chemical compositions are currently being developed to produce fibres with higher solubility. The most important physical property of MMVF discussed here is that they cannot fracture longitudinally into finer fibrils, in contrast to asbestos and some other man-made fibres. Because of their vitreous nature, they are subject only to transverse fracturing. The result of this fracturing is a reduction in length, the original diameter of the fibre remaining unchanged.

Table 1. Chemical composition of MMVF in weight percent

	Glass wool	Rock wool made from basalt melted in a furnace	Rock wool made from basalt and other materials melted in a cupola	Slag wool made from slag melted in a cupola	Kaolin alumino-silicate	High purity alumino-silicate	Refractive ceramic fibres Zirconia alumino-silicate
SiO_2	55–70	45–48	41–53	38–52	49.5–53.5	48.5–54	47.5–50
Al_2O_3	0–7	12–13.5	6–14	5–15	43.5–47	45.5–50.5	35–35
B_2O_3	3–12						
K_2O	0–2.5	0.8–2	0.5–2	0.3–2	< 0.01	< 0.01	< 0.01
Na_2O	13–18	2.5–3.3	1.1–3.5	0–1	0.5	0.2	0.3
MgO	0–5	8–10	6–16	4–14	< 0.1	< 0.01	0.01
CaO	5–13	10–12	10–25	20–43	< 0.1	< 0.05	< 0.05
TiO_2	0–0.5	2.5–3	0.9–3.5	0.3–1	2	0.02	0.04
Fe_2O_3	0.1–0.5				1	< 0.2	< 0.05
FeO [b]		11–12	3–8	0–2			
Li_2O	0–0.5						
S		0–0.2	0–0.2	0–2			
SO_3	0–0.5						
F_2	0–1.5						
BaO	0–3						
P_2O_5							
ZrO_2					0.1	0.2	15–17
Cr_2O_3					< 0.03	< 0.01	< 0.01

[a] As is standard practice, the elements are reported as oxides, even though no such individual crystals exist in the fibres.
[b] In rock and slag wool produced from materials melted in a cupola with coke as fuel, all iron oxide is reduced to FeO. During the spinning process, a surface layer may form in which the iron is oxidized to Fe_2O_3. Typically 8–15% of the iron is oxidized to Fe_2O_3. In an electric furnace melting basalt, up to 50% of the iron is in the form of Fe_2O_3 and is more evenly distributed throughout the entire fibre volume.
Source: Thermal Insulation Manufacturers' Association *(2).*

Occurrence in air

There are numerous man-made crystalline and amorphous substances that can release respirable fibres during handling *(1–4)*.

In the 1940s the concentration of man-made fibres during production was in the range of $10^6/m^3$. Concentrations of about $10^5/m^3$ have been reported for the last decade *(5)*. An overview of the concentrations measured in various plants is given in Table 2.

Table 2. Occupational exposure to MMVF (fibres/m^3 ambient air measured by personal samplers in 13 European plants: Late 1970s; fibre length > 5µm)

Type of plant	Range of mean concentration (fibres/m^3) to employees in:	
	main production and secondary production	**specialist secondary production**
Rock or slag wool (six plants)	50 000–120 000	250 000–400 000
Glass wool (four plants)	10 000–50 000	70 000–1 000 000
Continuous filament glass (two plants)	10 000	–

Source: Doll *(6)*.

The fibre concentration during use of MMVF is in the range of 10^5– 2×10^6 fibres/m^3 *(7)* and is usually higher than in the production plants. The fraction of fibres below 1µm in diameter is higher for ceramic fibres than for the other fibres *(8)*.

Little information is available on the ambient concentrations of glass fibres. Concentrations of glass fibres in the outdoor air have been identified in a few limited studies in France, Germany and the United States *(9–11)*. In these studies, glass fibre concentrations ranged from 2 fibres/m^3 in a rural area to 1700 fibres/m^3 near a city. These levels are estimated to represent a very small percentage of the total fibre and total suspended particulate concentrations in the ambient air. Switala et al. *(12)* measured respirable glass and total fibre concentrations in the ambient air around a fibreglass wool manufacturing facility and a rural area. The concentrations of respirable glass fibres were generally below the limit of detection (10 fibres/m^3) with a maximum measured concentration of 140 fibres/m^3 around the manufacturing facility and 150 fibres/m^3 in the rural area. The average concentrations of respirable glass fibres was less than 1% of the average concentration of total respirable fibres.

Indoor concentrations of MMVF have been reported by Gaudichet et al. *(13)*. Concentrations were determined at 79 indoor and 18 outdoor locations. Indoor concentrations were found to be in the range 0–6230 respirable fibres/m^3, with a median value of 3. Outdoor concentrations were lower than 15 respirable fibres/m^3, with a median value of 1. In a study published by the German Environmental Agency *(14)*, measurements were made in buildings in which mineral wool was installed in direct contact with the room air, e.g. acoustic ceilings. Measurements were made under worst-case conditions, such as during the installation of electric cables.

Results are presented in Table 3. Under these conditions the fibre concentrations were considerably higher than the values reported by Gaudichet et al. *(13)*.

Table 3. Concentration of fibres of MMVF products, gypsum and other types of mineral fibre [a]

Fibre type		Concentration of fibres with length ≥ 5 µm [fibres/m³]		
		Mean ± standard deviation	Median	Maximum
MMVF	I	572 ± 818	227	5 650
	O	338 ± 466	110	2 400
Gypsum	I	1 393 ± 1 772	885	9 450
	O	2 859 ± 3 546	1300	15 000
Other	I	2 612 ± 3 668	1500	31 800
	O	1 795 ± 1 158	1600	6 300

[a] I = indoor (134 measurements); O = outdoor (39 measurements).

Source: German Environmental Agency *(14)*.

Analytical methods (in air)

Optical and electron microscopy are the most commonly used methods for measuring MMVF in air. The World Health Organization *(15)* has proposed reference methods, and a good description is given by IARC *(4)*.

Routes of exposure

Inhalation of MMVF is the dominant route of concern for chronic effects, although effects on the skin and eyes are experienced when handling MMVF.

Toxicokinetics

In general, fibres may differ from particulates in their deposition behaviour at the various surfaces of the respiratory tract. They may also have different retention times as well as different clearance pathways *(16)*.

Deposition

As for other fibres, MMVF may be deposited in the respiratory tract in four ways: impaction, sedimentation, interception and electrostatic precipitation. Impaction and sedimentation are governed by the aerodynamic diameter of the fibres, which for MMVF is close to three times the nominal diameter. Impaction generally occurs in the larger airways and sedimentation in the smaller airways. Electrostatic precipitation occurs primarily by image forces, and depends on the ratio of electrical charge to aerodynamic drag. Interception is governed by fibre length: the longer the fibre, the more likely it is that the ends will touch and stick to a surface that the centre of mass would have missed. Animal experiments have shown that increasing fibre length increases the proportion deposited in the tracheobronchial airways. Timbrell *(17)* reported that fibres longer than 100–200 µm will be "trapped" by the bronchioles and will not reach the alveoli. Deposition patterns for MMVF within the non-ciliated airways distal to the terminal bronchioles may differ substantially, but scientific data are lacking.

A comparative review of the regional deposition of particles in humans and rodents (rats and hamsters) has been published by the US Environmental Protection Agency *(18).* The relative distribution of inhaled monodisperse aerosols between the tracheobronchial and pulmonary regions of the lung in rodents and humans shows that, particularly for pulmonary deposition, the percentage deposition of particles is considerably less in rodents than in humans.

Clearance and translocation

The fate of fibres deposited within the respiratory system depends on both the site of deposition and the characteristics of the fibres. Within the first day after exposure, fibres deposited in the tracheobronchial airways are carried proximally by the mucus to the larynx, where they are swallowed and passed into the gastrointestinal tract. Fibres deposited in the non-ciliated airspaces beyond the terminal bronchioles are cleared more slowly by a variety of mechanisms and pathways, which can be classified into two broad categories: translocation and disintegration.

Translocation refers to the movement of the intact fibre along the epithelial surface to dust foci at the respiratory bronchioles, or to the ciliated epithelium at the terminal bronchioles, or into and through the epithelium with subsequent migration to interstitial storage sites or along lymphatic drainage pathways.

Disintegration refers to a number of processes, including: the subdivision of fibres into shorter segments; partial dissolution of components of the matrix, creating a more porous fibre of relatively unchanged external size; or surface etching of the fibres, creating a change in the external dimensions of the fibres. The rate of these activities depends on the size and composition of the fibre.

The elimination of durable fibres from the lung depends on fibre length, diameter and mass retained in the lungs. Alveolar macrophages can only completely phagocytose fibres up to about 10 µm in length, prior to their removal by the ciliated airways *(19,20).*

Dissolution

A number of *in vivo* experiments in rats have been performed with respect to dissolution *(21–24).* The solubility of MMVF in the lungs depends on size and composition. For example, for glass fibres there is much less dissolution of the 5-µm and 10-µm fibres than of the 20-µm fibres.

Investigations in experimental animals showed the following ranking of biopersistence of the tested samples: crocidolite > ceramic fibres > rock wool > glass wool > slag wool *(24).* This ranking may be different for other fibre preparations.

McDonald et al. *(25)* investigated human lung tissue from deceased MMVF workers matched with non-exposed controls. MMVF fibres were detected in the lung tissue of 28 of 112 MMVF workers, but at low concentrations of less than 0.2 fibres/mg dry lung weight. Those dying of lung cancer also had less than 0.2 fibres/mg dry lung weight in their lungs.

Health effects

Effects on experimental animals

Carcinogenic inhalation effects

The inhalation route of exposure used in animal experiments is in principle the most relevant one for humans. For MMVF it is generally accepted that the fibre number concentration rather than the mass is the correct measure of dose. There are several negative inhalation studies with glass and stone fibres carried out before 1985, which were reviewed by IARC *(4).* It should be noted, however, that the majority of chronic inhalation studies with exposures of up to 1600 International Union Against Cancer (UICC) crocidolite fibres/ml did not report statistically significant increases of the tumour rate, even though crocidolite fibres are considered to be potent carcinogens in humans *(26–31).* The fibre length of the UICC crocidolite samples used was relatively short, but nevertheless typical for the workplace atmosphere *(32,33)*. The strong effect of all UICC asbestos samples described in the first inhalation study of Wagner et al. *(34)* could not be reproduced by any of the other groups.

A large series of chronic inhalation experiments by RCC (Itingen, Switzerland) with fine fibre fractions of four types of refractory ceramic fibre (RCF) and four types of common glass, stone and slag insulation wool (MMVF) have been completed *(35–39).* In summary, it was shown that the dimensions of the vitreous fibres are larger and concentrations lower compared with the positive asbestos controls. It should be noted that the median fibre length of the crocidolite sample was longer than the UICC samples, but shorter than the RCF and MMVF samples. It is of interest to examine the results of the most important recent and older studies with RCF and other vitreous fibres (MMVF) in comparison with asbestos fibres. It should be noted that in this comparison, animals with benign or malignant primary lung tumour or mesothelioma are combined, and that the exposure time in some studies is 30 hours/week for two years in rats and 35 hours/week for one year in other animal studies *(26,29–31,40–43).*

Three of the four tested RCF types, as well as chrysotile and crocidolite, resulted in statistically significantly increased tumour rates in the range of 10–20%, although the fibre concentrations of RCF were substantially lower. The much higher carcinogenic potency per ceramic fibre compared with asbestos has been explained by the greater fibre lengths, although Brown et al. *(44)* have commented that the effect could be nonspecific "overload" tumours arising from high doses of possibly inert materials.

All animal groups exposed to glass, stone or slag MMVF were negative compared with the concurrent control group. However, when the statistical power of the studies was enhanced by combining the two highest exposure groups, and when they are compared with the combined control groups of all RCC fibre studies, glass fibre type 11 and stone fibre type 21 show a statistically significantly increased relative risk of about 2.5; the trend test is also positive *(45)*. As the potential carcinogenic agent of all MMVF types is the relatively durable fibrous particle shape in the respirable size range and not the chemical composition, one approach has been to combine groups of workers in the rock and slag wool industry exposed to MMVF 10, 11, 21 and 22 for statistical evaluation *(46)*. However, slag fibre type 22 has a relatively short half-time of 81 days after intratracheal instillation in rats *(47)*, indicating a lower biodurability compared with the vitreous fibre types 11 and 21 (half-times 199 and 326 days, respectively).

There has been some discussion as to whether combining the control groups of the four experiments is correct for statistical calculations *(48,49)*. It has been noted that control groups combined in epidemiological studies are not as homogeneous as the control groups in the RCC studies; but a statistically significantly increased lung cancer risk of 2.5 in proven non-smokers with the same occupation and the same lifestyle would be evaluated as a strong indication of a causative effect. At the least, the inhalation studies with MMVF cannot be evaluated as obviously negative.

Experiments with rats have shown that, compared to humans, they are relatively insensitive to development of mesothelioma after exposure to asbestos *(31,35,50–52)*. This insensitivity has to be considered in evaluating test results with other fibres and in risk characterization for humans. The RCC studies showed hamsters to be more sensitive than rats in developing mesothelioma but less sensitive in developing lung tumours following inhalation of RCF.

Carcinogenic effects after intratracheal instillation

There are few positive intratracheal studies with man-made fibres in rats and hamsters. Only fibres with relatively short lengths and small diameters such as asbestos fibres can be instilled repeatedly at the high doses that may be required to induce tumours. Thicker and longer fibres tend to agglomerate and can block the airways. Experiments with silicon carbide and glass microfibres have reported lung tumours *(53–55)*, although other studies were negative *(27,56)*.

Carcinogenic effects after intrapleural or intraperitoneal administration

Intrapleural and intraperitoneal implantation techniques have been used to induce tumours *(57,58)*. Intraperitoneal studies designed to investigate the relative potency of a range of MMVF to induce tumours in rats demonstrated that soluble fibres such as glass B-01 have a lower potency than durable fibres such as crocidolite and ceramic fibres *(47,59,60)*. Fibrosis has also been investigated using these implantation techniques *(61–63)*.

Conclusions from the carcinogenicity studies

The maximum tolerated dose or exposure concentration of typical relatively thick (median 1 µm) and long (median 15 µm) MMVF seems to be limited in inhalation experiments to about 200–250 WHO fibres/ml, in contrast to 1500–10 000 WHO fibres/ml for asbestos. Thus the tumour-producing effect of these MMVF can be detected with this test model only if their carcinogenic potency is much higher than that of asbestos.

The relevance of results from the intrapleural and intraperitoneal implantation studies has been discussed at length *(64,65)*. At present, a final evaluation cannot be given. However, the numerous negative results with high doses of non-fibrous particles, and the great quantity of consistent new data on dose–response relationships of many fibre samples, justifies the intraperitoneal test at least for mechanistic studies. Observations indicate that all kinds of elongated dusts have the potential to cause tumours if they are sufficiently long, thin and durable *in vivo*.

There is no doubt that longer fibres have higher carcinogenic potency than shorter ones of the same material, but because of the wide distribution of fibre lengths in the tested samples the carcinogenic potency of a given fibre length cannot be estimated. The significance of diameter and aspect ratio and persistence in the body for carcinogenic potency is not well understood.

There is a lack of understanding of the processes of carcinogenesis from fibres in the lung and in the serosa. Nevertheless, considering the many examples of fibre types that induce tumours of both tissues, it may be prudent to assume in principle that fibre types that induce tumours in one of the tissues are carcinogenic in the other. These factors make it difficult to extrapolate the ranking order found in the intraperitoneal test to humans.

Effects on humans

Non-carcinogenic effects

Effects on the skin and superficial mucous membranes
Skin irritation is the most common health problem associated with handling of MMVF. Irritation is almost always due to coarse fibres (4–5 µm), with more severe irritation being caused by coarser fibres. Irritation disappears with continued exposure, but recurs if exposure is interrupted for a few days *(66).*

Contact with uncured resins, hardeners and accelerators during the production of MMVF may give rise to sensitization. Glass fibre itself, however, is not a sensitizing agent. Cuypers et al. *(67)* investigated workers on the spinfloor (spinners) of a glass fibre production plant, by patch testing with raw materials and finishers used in the glass fibre industry and with a standard series of well known allergens. A total of 54% showed positive tests, and epoxy resin was the most prominent allergen.

Effects on the eyes
It is known that airborne fibres may accumulate at the eyes of workers handling MMVF products. Schneider & Stokholm *(68)* and Stokholm et al. *(69)* found that the number of non-respirable fibres accumulating in the eyes correlated with the total dust. No correlation was found, however, between the number of fibres in the mucous alone and the airborne fibre concentration.

Effects on the respiratory system
WHO *(1)* concluded that MMVF exposure was probably incidental rather than causal in most cases of irritation of the upper respiratory tract and more serious pulmonary diseases, since these have not been observed in most of the more recently conducted epidemiological studies. Kilburn et al. *(70)* reported reductions in indices of lung function in workers in the glass fibre manufacturing industry. Pneumoconiosis was observed in 15.1% of the workers.

Carcinogenic effects
Cohort studies (see Tables 5–7) of more than 40 000 occupationally exposed workers and about 9000 deaths have shown different risks regarding lung tumours and different types of MMVF *(6,71–73).*

No increased risk was found for exposed workers in the production of textile glass fibres. After exposure of at least 20 years, a standardized mortality ratio (SMR) of 115 was reported for workers in the production of glass wool; in the production of rock and slag wool the SMR was 148.9. In factories in which only slag wool was produced the risk was 147.7 (latency period < 20 years) and 191.5 (latency period > 20 years). Exposure estimates are in line with the observed increase in cancer mortality: textile glass fibres < glass wool < rock and slag wool.

A causal relationship between fibre exposure in the production of MMVF and lung tumour induction has been questioned *(72,74)*. It is suggested that confounders such as cigarette smoking may have influenced the results. Nevertheless, both American and European studies show a decrease in lung tumour mortality in the ranking rock and slag wool > glass wool > textile glass fibres, suggesting that this is not solely due to confounders and socioeconomic differences.

The fibre concentrations of MMVF were relatively low, whereby the estimated values of the accumulated fibre dose during the early period of insulating wool production (when the concentration was higher than in later years) was in the range $1–10 \times 10^6$ fibres/m^3·years. In relation to these maximum dose values, even for chrysotile-exposed workers an SMR for lung cancer of only 101–110 would result if the dose–response-relationship of Doll & Peto *(75)* were applied *(6)*.

Boffetta et al. *(46)* investigated mortality and cancer incidence until 1990, greatly increasing the number of person-years of observation. Relationships (albeit not statistically significant) were found in the rock/slag wool cohort between lung cancer incidence and technological phases, time since first employment and duration of employment (indirect indicators of MMVF exposure). Despite the difficulty of ruling out confounding effects from tobacco smoking or occupational exposures outside the rock/slag wool industry, a carcinogenic effect of exposures occurring in the rock/slag wool working environment is a credible explanation of the findings. These results are not sufficient to conclude that the increased lung cancer risk is related specifically to exposure to MMVF: insofar as respirable fibres were a significant component of the ambient pollution of the working environment, however, they may have contributed to the increased risk.

Table 5. Mortality of employees from plants producing man-made mineral fibres: cohort studies in the United States, Canada and Europe

Country	Source	Number of plants and fibre types produced[a]	Cohort definition: number of employees and duration of employment	Follow-up		Mortality from all causes	
				Percentage	Duration	Deaths	SMR[b]
United States	Marsh et al. *(72)*	17 producers of rock, glass and slag wool, and of textile glass fibres and glass microfibres	16 661 employed for 1 year or more[c] between 1945 and 1963[d]	98	1946–1985 or [e]–1985	5806	103*
Canada	Shannon et al. *(76)*	Glass wool factory in Ontario	2557 employed for 90 days between 1955 and 1984	97	1955–1984	157	84
Europe	Simonato et al. (77)	13 producers of rock and glass wool and textile glass fibres	24 609, of which 21 967 were in production and 3642 in administration	95	1933–1961 or [e]–1981 or 1983	2719	111*

[a] Glass, rock and slag wools and textile glass fibres and special purpose glass fibres.
[b] Without the administrative employees, comparison with the national mortality statistic, or in Canada with the mortality statistic in Ontario.
[c] Six months for two plants.
[d] 1940–1963 for one plant.
[e] In each plant from the year in which production began.
* $P < 0.05$.

Source: Deutsche Forschungsgesellschaft *(71)*.

Table 6. Lung cancer mortality in the cohort studies in the United States, Canada and Europe and its dependence on the fibre type produced

Cohort [a]	Fibre type produced					
	Textile glass fibres		Glass wool		Rock and slag wool	
	Deaths [b]	SMR [b]	Deaths [b]	SMR [b]	Deaths [b]	SMR [b]
Canada	–	–	19	174*	–	–
USA	84	92	340	112	73	136
Europe	15	97	93	103	81	124
Total	99	93	452	112	154	129**

[a] For further details see Table 5.
[b] Mortality from lung tumours, and in the United States and Europe from lung tumours including carcinoma of the larynx.
* $P < 0.05$.
** $P < 0.01$.

Sources: Doll *(6)*; Marsh et al. *(72).*

Table 7. Total mortality from lung cancer in cohort [a] studies in the United States and Canada for each of the fibre types produced

Fibre type	Deaths [b]	SMR [b]	
		mean value	95% confidence interval
Rock or slag wool	81	148.9*	116–183
Rock wool only	11	90.9	45–153
Glass microfibres	17	106.9	62–164
Glass wool	321	115.4*	103–128
Textile glass fibres	77	108.3	84–133
All fibre types	507	117.1*	107–128

[a] For details of the cohorts see Table 5.
[b] The lung cancer mortality data were obtained for a period after the beginning of exposure of 20 years for the American study and 15 years for the Canadian study.
* $P < 0.05$.

Source: Brown et al. *(73).*

If the observed SMRs in the MMVF industry are related only to the effects of fibres, then the following alternatives are possible:

1. glass, rock or slag wool fibres are more potent carcinogens than chrysotile fibres;

2. the carcinogenicity of chrysotile fibres has been underestimated; or
3. fibre exposure in the early phase of the production of MMVF was underestimated.

Considering the large number of other carcinogenic agents in the occupational environment in the production of rock and slag wool, the proof of a causal relationship for MMVF is difficult. Doll *(6)*, however, assumes that MMVF are at least partly responsible for the observed increased risk.

Evaluation of human health risks

Exposure evaluation
Airborne concentrations during installation of MMVF insulation are in the range 10^5–2×10^6 fibres/m^3, which is generally higher than the concentrations of about 10^5 fibres/m^3 reported for production plants. Little information is available on ambient concentrations of MMVF. A few limited studies of MMVF in outdoor air have reported concentrations ranging from 2 fibres/m^3 in a rural area to 1.7×10^3 fibres/m^3 near a city. These levels are estimated to represent a very small percentage of the total fibre and total suspended particulate concentrations in the ambient air.

Health risk evaluation
MMVF of diameters greater than 3 µm can cause transient irritation and inflammation of the skin, eyes and upper airways.

The deep lung penetration of various MMVF varies considerably, as a function of the nominal diameter of the material. For the MMVF considered here, the potential for deep lung penetration is greatest for refractory ceramic fibres and glass microfibres; both of these materials are primarily used in industrial applications.

In two large epidemiological studies, there have been excesses of lung cancer in rock/slag wool production workers, but not in glass wool, glass microfibre or continuous filament production workers. There have been no increases in the incidence of mesotheliomas in epidemiological studies of MMVF production workers *(72,77)*. Although concomitant exposure to other substances may have contributed to the observed increase in lung cancer in the rock/slag wool production sector, available data are consistent with the hypothesis that the fibres themselves are the principal determinants of risk. Increases in tumour incidence have not been observed in inhalation studies in animals exposed to rock/slag wool, glass wool or glass microfibre, though they have occurred following intracavitary administration. Available data concerning the effects of continuous filament in animals are limited.

Several types of refractory ceramic fibre have been clearly demonstrated to be carcinogenic in inhalation studies in animal species, inducing dose-related increased incidence of pulmonary tumours and mesotheliomas in rats and hamsters *(40,45,78)*. Increased tumour incidence has also been observed following intratracheal, intrapleural and intraperitoneal administration in animals.

Though uses of RCF are restricted primarily to the industrial environment, a unit cancer risk for lung tumours for RCF has been calculated as 1×10^{-6} per fibre/l (for fibre lengths > 5 µm and aspect ratio of 3:1 as determined by optical microscopy) based on inhalation studies in animals *(79)*.

Guidelines
IARC classified rock wool, slag wool, glass wool and ceramic fibres in Group 2B (possibly carcinogenic to humans) while glass filaments were not considered classifiable as to their carcinogenicity to humans (Group 3). Recent data from inhalation studies in animals strengthen the evidence for the possible carcinogenicity of RCF in humans.

Though uses of RCF are restricted primarily to the industrial environment, the unit risk for lung tumours for RCF is 1×10^{-6} per fibre/l. The corresponding concentrations of RCF producing excess lifetime risks of 1/10 000, 1/100 000 and 1/1 000 000 are 100, 10 and 1 fibre/l, respectively.

For most other MMVF, available data are considered inadequate to establish air quality guidelines.

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