# Canadian Environmental Protection Act

Supporting Documentation for Environmental Component of Priority Substances List Assessment Report

# MAN-MADE VITREOUS FIBRES

prepared by: Commercial Chemicals Branch Department of the Environment 18 June, 1993

FIBRE.SD

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#### 1.0 Introduction

This document includes only technical information prepared by Environment Canada for consideration in the assessment of whether Man-Made Vitreous Fibres are "toxic" under CEPA. The published Assessment Report for Man-Made Vitreous Fibres, and additional technical information prepared by the Department of National Health and Welfare, are available upon request from:

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#### 2.0 Identity

#### 2.1 Terminology

In this report a "fibre" is understood to be an elongated particle with a length/width or aspect ratio of  $\geq 3/1$ . Although results of a recent study suggest that an aspect ratio of  $\geq 5/1$ may be more appropriate (TIMA, 1991), fibres with these dimensions are included in the former definition.

Several types of manufactured inorganic fibres are distinguished based upon their use, physical properties and chemical composition (TIMA, 1991). Because of limitations in available data, this report is focused on four types of man-made vitreous fibres - textile or continuous filament fibres, insulation "wools" (i.e. glass, rock and slag wools), glass micro- (or "special purpose") fibres and aluminosilicate refractory ceramic fibres (RCF)<sup>1</sup>. Some synonyms and trade names for these products are presented in Table 1.

Although these substances have traditionally been considered a subset of "man-made mineral fibres" (MMMF), the appropriateness of this term has recently been questioned. As TIMA (1991) has noted, a mineral is by definition a naturally occurring substance, and therefore strictly speaking there are no man-made "minerals". Furthermore a mineral must by definition have a crystalline structure, but many of the fibres normally called MMMF (including those considered in this report) have vitreous (i.e. non-crystalline) structures. For these reasons TIMA (1991)

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Crystalline (i.e. non-vitreous) ceramic fibres such as high purity aluminum and zircon oxides, and non-oxide fibres such as silicon carbide and silicon nitride were not considered in this report.

has recommended that use of the term "man-made mineral fibres" be discontinued.

#### 2.2 Physical and Chemical Properties

MMVF typically have an amorphous structure, meaning that their constituent atoms are not arranged in a regular lattice as in crystalline materials. However in some high temperature applications, rock and slag wools, and refractory ceramic fibres can partly devitrify and be converted to a polycrystalline state (Miller, 1982; TIMA, 1991). Because of their vitreous character, MMVF typically fracture across their length and become shorter, whereas natural crystalline fibres generally cleave longitudinally producing fibrils of smaller diameter (TIMA, 1991).

Data on physical and chemical properties of MMVF are presented in Table 2. Diameters of MMVF vary depending upon their method of production (see Section 3.0). Average diameters are  $3 - 25 \ \mu\text{m}$  for continuous filament fibres,  $3 - 10 \ \mu\text{m}$  for glass wool,  $2 - 6 \ \mu\text{m}$  for rock and slag wools,  $1.2 - 3.5 \ \mu\text{m}$  for refractory ceramic fibres and  $0.2 - 4 \ \mu\text{m}$  for glass microfibres (IPCS, 1988; TIMA, 1991). In individual products the variability of fibre diameters, measured as the coefficient of variation (i.e. standard deviation  $\div$  mean x 100), can range from less than 10% for continuous filament fibres to 50% or more for insulation wools (TIMA, 1991). Although average diameters of many MMVF are normally greater than 3  $\mu$ m (the upper limit for respirable fibres) a significant proportion of fibres in some products can have diameters of < 3  $\mu$ m.

Continuous filament fibres are produced in continuous strands, which because of their length and large diameters ( $\geq 3$  $\mu$ m) are not normally respirable. TIMA (1991) estimated that the lengths of all but a very small fraction of fibres in glass wool are much greater than 250  $\mu$ m, the maximum length which can be deposited in the lung, but noted that measurement is difficult because fibres tend to break during extraction from wool products. Because of the processes used in their production, rock and slag wools, and refractory ceramic fibres can contain large quantities (20 - 60% by weight) of rounded particulate material ("shot") with diameters of 60  $\mu$ m or more (Miller, 1982; TIMA, 1991).

Softening point temperatures for refractory ceramic fibres can be as high as 1800°C, while those for other MMVF are typically in the 650 - 850°C range. Actual upper temperature limits (where fibres begin to fuse on contact) are usually 200 -300°C lower than softening points (TIMA, 1991).

Data on the chemical composition of some MMVF are presented

in Tables 2 to 4.  $SiO_2$  and  $Al_2O_3$  are the main constituents of most fibre types. Lesser amounts of "intermediate oxides" (or stabilizers) such as  $TiO_2$ , and  $ZrO_2$  and "modifiers" (or fluxes) such as MgO,  $Li_2O$ , BaO, CaO,  $Na_2O$  and  $K_2O$ , are also present. Compositions can vary considerably depending upon the characteristics needed in the final product (e.g. chemical or heat resistance) and the melt viscosity required in the manufacturing process.

E-glass, a calcium aluminosilicate containing up to 10% boron, is the predominant glass composition used to produce continuous filament fibres (Table 3). In glass wool (Table 3) and most glass microfibres (Table 4) there is less aluminum than in E-glass, and sodium replaces calcium as the predominant flux. Rock and slag wool contain little boron relative to some types of E-glass (Table 3), but contain large amounts of calcium, magnesium and in some cases iron. Refractory ceramic fibres are typically made of nearly pure mixtures of equal portions of  $Al_2O_3$ and  $SiO_2$ , but as indicated in Table 5 compositions can vary somewhat depending on their application.

Binders to hold fibres together, and an oil for dust suppression, are applied to the surface of most MMVF (IPCS, 1988). Continuous filament fibres may contain a sizing agent for lubrication. Chemicals reported to have been used in binders are listed in Table 6. According to TIMA (1991) binders currently used are based mainly on phenol formaldehyde resins. During curing at elevated temperatures they are converted to an insoluble polymer containing very little formaldehyde. The binder content of insulation wool products is normally less than 5% by weight (IARC, 1988), but can be as high as 10% (TIMA, 1991).

MMVF are relatively stable in distilled water at 20°C (Forster, 1984), but at elevated temperatures ( $\geq$  37°C) distilled water can aggressively dissolve some MMVF (Forester, 1984; Leineweber, 1984). Most MMVF are also attacked by acidic or basic solutions (e.g. 2 N HCl, 2 N NaOH), and biological fluids (Spurny et al., 1983). Because of their amorphous structure, dissolution rates for MMVF are typically 2 to 4 orders of magnitude greater than those for natural crystalline fibres such as asbestos (Scholze and Conradt, 1987; Law et al., 1990).

"Stabilizers" such as aluminum, titanium and zirconium oxides strengthen MMVF structures, whereas dissolution rates increase in the presence of fluxes such as sodium, potassium, calcium and magnesium oxides (TIMA, 1991). For example, refractory ceramic fibres that contained about 50%  $Al_2O_3$  were found by Scholze and Conradt (1987) to dissolve more slowly (based on release of SiO<sub>2</sub> in flow-through tests with modified Gamble's solution at 37°C), than rock and slag wools that

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contained 10-15%  $Al_2O_3$  and up to 3%  $TiO_2$ . Glass wool that contained only 3.5%  $Al_2O_3$  and negligible  $TiO_2$  dissolved most quickly. Scholze and Conradt (1987) estimated that the time required for most MMVF to dissolve completely in their tests was 0.4 to 2 years (Table 2). Life-times for refractory fibres, and E-glass fibres containing 14.1%  $Al_2O_3$ , were estimated to be somewhat longer (up to 5.0 and 6.5 years, respectively).

Results of Scholze and Conradt (1987)'s study are generally consistent with those of in vitro tests conducted by other investigators. For example, in a 4 week stationary experiment at 37°C Forster (1984) reported that modified Gamble's solution removed about 20 times more silicon from glass wool fibres containing about 3% Al<sub>2</sub>O<sub>3</sub> than from rock and slag wool fibres containing 9.5-11.3% Al<sub>2</sub>O<sub>3</sub>. Klingholz and Steinkopf (1984) reported very similar results in stationary tests of the durability of rock and glass wools. In flow-through experiments with modified Gamble's solution at 60°C, Leineweber (1984) found the following order of stability; "E" glass fibres  $(14.7 \text{ Al}_2O_3) >$ refractory fibres (46% Al<sub>2</sub>O<sub>3</sub>) > mineral wool (9.5% Al<sub>2</sub>O<sub>3</sub>) > other glass fibres (3.9-5.4% Al<sub>2</sub>O<sub>3</sub>). More recently Potter and Mattson (1991) reported life-times of 0.04 to 0.2 years for typical glass wool fibres in in vitro flow-through tests using modified Gamble's solution at 37°C. Stability of the fibres increased with  $Al_2O_3$  content, which ranged from <0.5 to 9.9%.

Fine fibres (e.g. special propose fibres) tend to dissolve more quickly than coarser ones of similar composition (Spurny et al., 1983; Scholze and Conradt, 1987). Morgan and Holmes (1986) noted that results of *in vivo* tests indicated that glass fibres with lengths of 30 and 60  $\mu$ m dissolved much more rapidly than shorter ones (length  $\leq$  10  $\mu$ m). According to Schloze (1988) other factors that can affect the durability of fibres include their rate of cool during formation, conditions and duration of storing, the presence of binders or other coatings.

#### 2.3 Analytical Methods

Sample Collection and Preparation

Methods of collecting and preparing MMVF vary depending on whether samples are obtained from commercial products, environmental media (e.g. ambient air) or biological tissues.

TIMA (1991) described a procedure for wool products involving use of a 25 mm diameter hole punch for sample collection, ignition to remove organic binders and crushing to give fibre lengths suitable for microscopic examination. However, because fibres are broken prior to measurement, this method gives no information on the relative number of fibres with

#### specified diameters.

Fibres can be collected from ambient air on either cellulose ester membrane or polycarbonate filters (WHO/EURO, 1985; Chatfield, 1983). Normally filters are mounted in holders located in the breathing zones of potentially exposed subjects. The volume of air passed through the filter is measured, and varies with the detection limit required. Because of their irregular surfaces, membrane filters retain particles more efficiently than polycarbonate filters during transport to the laboratory. However, polycarbonate filters are required in some high-resolution analytical methods.

Fibres can be separated from biological tissues by digestion in, for example, sodium hypochlorite or potassium hydroxide, or by ashing (Davies et al., 1986). However, as Johnson et al., (1984) noted, substantial losses of MMVF can occur during tissue digestion. Furthermore, Law et al. (1991) have demonstrated that MMVF can dissolve at rates of up to 1.6% per day (based on loss of SiO<sub>2</sub>) in solutions used for fixing and storing lung tissue. Thus data on MMVF in biological tissue should be interpreted with caution (IPCS, 1988).

#### Identification and Quantification

Concentrations of airborne MMVF can be measured on a total mass basis, by comparing weight of filters before and after sampling. However, MMVF are now normally identified and counted using phase contract optical microscopy (PCOM), scanning electron microscopy (SEM) or transmission electron microscopy (TEM). According to IPCS (1988), limits of visibility achievable in routine operation are 0.25  $\mu$ m for PCOM, 0.05  $\mu$ m for SEM and 0.005  $\mu$ m for TEM. However, higher limits of reliable measurement have been reported for both PCOM (up to 1.6  $\mu$ m) and SEM (0.1-0.2  $\mu$ m) (Balzer et al., 1971; Burdett et al., 1984; TIMA, 1992). Because of these differences, as well as differences in sampling strategies and fibre counting criteria, results of analysis by different methods are not always directly comparable.

Cellulose ester filters are used to collect samples of airborne fibres for PCOM (IPCS, 1998). The filter is made optically transparent with one of several clearing agents (e.g. acetone), and fibres (normally defined as particles having a length/width ratio of at least 3, and a length of at least 5  $\mu$ m) within several random areas are counted and classified visually at magnifications in the 400 - 500X range (IARC, 1988; IPCS, 1988). Application of PCOM is limited by the fact that, because of its relatively low resolution, it is unable to detect many fine (i.e. small diameter) fibres (IARC, 1988). In an attempt to standardize results from different countries the World Health Organization (WHO/EURO, 1985) proposed a reference method for monitoring airborne MMVF using PCOM. A detection limit of 0.05 fibres/cm<sup>3</sup> can normally be achieved using the WHO/EURO (1985) method (IARC, 1988). Interlaboratory comparison testing of the WHO/EURO (1985) method indicated that counting differences of up to a factor of 1.8 are possible (IPCS, 1988).

The World Health Organization has also published a reference method for measuring the size distribution of airborne MMVF using SEM (WHO/EURO, 1985). A sample of airborne particulate matter is collected on a polycarbonate (Nucleopore) filter, a subsample of which is mounted on a specimen stub and coated with a thin film of gold. It is possible to interface this apparatus with an energy dispersive X-ray analyzer (EDXA), which provides information on the chemical composition of individual fibres. Fibre lengths and diameters are measured from optically enlarged images of photomicrographs (Riediger, 1984; IPCS, 1988). Magnifications of 5000 - 10,000X are achievable using SEM (Schneider, 1979; Riediger, 1984). SEM can also be used to make in situ measurements in thinly sliced biological tissue (Spurny and Stober, 1981), thus avoiding loss of fibres that can occur during sample digestion.

TEM can be used to detect very thin fibres, and can be interfaced with both an EDXA and a selected area electron diffraction (SAED) unit. SAED permits examination of the atomic structure of individual fibres (Chatfield, 1983), thus facilitating the distinction between MMVF and natural crystalline fibres such as asbestos. Interpretation of results of TEM analysis is complicated, however, by lack of standardized sample preparation procedures, which can result in very large differences in results reported by different laboratories (Chatfield, 1983; IPCS, 1988). Generally, sample preparation methods involving either direct transfer of fibres from sample filters onto the same area of TEM specimens, or indirect transfer methods which do not affect the fibre size distribution in the original sample, are preferred (Chatfield, 1983; Toft and Meek, 1986).

#### 3.0 Production and Uses

MMVF are produced from a liquid melt of starting material (e.g. glass, rock, slag) at temperatures of 1,000 to 1,500 °C (IPCS, 1988). Slag formed during the reduction of iron ore to pig iron is the primary raw material currently used in the United States to produce slag wool (TIMA, 1991). In Canada some insulation wools are produced from slag obtained from mine tailings (Camford Information Services Inc., 1993b). Rock wool plants use basalt, as well as limestone, clay and feldspar as raw materials (TIMA, 1991). Glass wool and glass filaments can be produced from scrap glass or mixtures of raw materials (such as sand, soda ash, borax or boric acid, dolomite and limestone) similar to those used to manufacture other glass products (Ohberg, 1987; IARC, 1988). Refractory ceramic fibres are generally made by melting kaolin clay or a 50:50 mixture of  $Al_2O_3$ and SiO<sub>2</sub>, but other oxides such as  $ZrO_2$  are sometimes added to change the fibre properties. Fibres are typically produced from molten materials by rapid cooling to prevent crystallization. Methods used include mechanical drawing, blowing with hot gases, flame attenuation, and various centrifuging/blowing techniques (TIMA, 1991).

In the mechanical drawing process, which is exclusively used to manufacture continuous filament fibres, molten glass is extruded through nozzles, coated with sizing, and gathered into multi-filament strands. These are attenuated by winding onto a rotating cylinder to make fibre cakes, which are then dried, cured and converted into products such as yarns, rovings, chopped strands and milled fibres (Young, 1991; TIMA, 1991)

Blowing methods, that can be used to produce rock and slag wools (IARC, 1988) and refractory ceramic fibres (TIMA, 1991), involve attenuation of a silicate melt stream by high velocity compressed air or steam. Wools and refractory fibres can also be produced by various centrifuging/blowing methods (i.e. the rotary or TEL, wheel centrifuge and Downey processes), in which pressurized air jets act upon streams or drops of silicate liquid escaping from spinning bowls or variously shaped wheels (Ohberg, 1987; TIMA, 1991; Young, 1991). The Downey and wheel centrifuge processes generate large amounts of coarse rounded shot. Finally, some insulation wools and glass microfibres are be made by the flame attenuation process (Young, 1991), wherein glass filament is remelted and attenuated into many finer fibres with a high-temperature gas flame (TIMA, 1991). Newly formed insulation wools are typically sprayed with a binder (see Table 6), after which they are cured at elevated temperatures, cooled, cut and packaged (Ohberg, 1987).

In 1991 there were 14 Canadian plants producing insulation wools, one producing continuous filament fibres and one producing refractory ceramic fibres (Camford Information Services Inc., 1993a,b,c and d). Ten plants (including the refractory ceramic and continuous filament fibre plants) were located in Ontario, three in Quebec, two in Alberta and one in British Columbia. Total production of MMVF in Canada in 1991 was estimated to be between 250 and 300 kilotonnes (Table 10), down from a high of about 400 kilotonnes in the late 1980s (Camford Information Services Inc., 1993a,b,c and d). Glass wool accounted for about 70% of MMVF production in 1991, rock and slag wool 20%, continuous filament fibres 10%, and refractory ceramic fibres less than 1%. Since there is little stockpiling of MMVF in Canada, and cross border trade is estimated to be either small or approximately offsetting (Camford Information Services Inc., 1993a,b,c and d; TIMA, 1992), amounts of MMVF used annually in Canada are generally similar to those produced. Although glass microfibres are not known to be produced in Canada, they are likely imported in small amounts in finished products such as high efficiency filters.

It has been estimated that, in 1985, total world production of MMVF was 6,000 - 6,500 kilotonnes, of which insulation wools accounted for approximately 75-80%, and continuous filament grades for 15-20% (IPCS, 1988). Refractory ceramic fibres account for only 1-2% of worldwide MMVF production (TIMA, 1991). In the early to mid-1980s world-wide production of ceramic refractory fibres was estimated at 70 - 90 kilotonnes (IARC, 1988). According to TIMA (1992), approximately 36 kilotonnes of refractory ceramic fibres were sold in the United States in 1990.

According to Camford Information Services Inc. (1993c), most (nearly 90% of) continuous filament fibres consumed in Canada are used to produce fibreglass-reinforced plastic composites. Continuous filament fibres can also be used to reinforce cement, automotive tires and roofing materials, and can be woven into protective apparel and industrial fabrics (Roberts, 1982; TIMA, Glass, rock and slag wools are used mostly for thermal 1991). and acoustic insulation. About 15% of the rock and slag wool produced in Canada is used for acoustic ceiling tile manufacturing (Camford Information Services Inc., 1993b). Refractory ceramic fibres are used mainly for high temperature furnace and kiln insulation, but other high temperature applications include insulation for catalytic converters in automobiles, filtration, and gaskets and seals for expansion joints (IPCS, 1988; IARC, 1988; TIMA, 1991). Because of their small diameters and low bulk weight, glass microfibres are used in battery separator media, for high efficiency filtration, and as thermal and acoustical insulation in aircraft and space vehicles (TIMA, 1991).

#### 4.0 Release to the Environment

No information was found on releases of MMVF in Canada, and data elsewhere were limited to emissions in stack gases from fibre manufacturing facilities (IPCS, 1988).

According to Tiesler (1983) total fibre concentrations (measured by SEM) in emissions from insulation (glass and rock/slag) wool manufacturing plants in the Federal Republic of Germany in late 1970s ranged from 0.004 to 0.046 fibres/cm<sup>3</sup>. Only about 4% of the fibres emitted by the German production facilities were in the "respirable" range, defined by the authors as having lengths of 8 to 20  $\mu$ m and diameters of less than 1  $\mu$ m. Tiesler (1983) estimated that about 1 800 kg of MMVF were released annually to the atmosphere from insulation wool plants in Germany, of which 80 kg were "respirable". Most (> 90% of) releases were associated with fibre-forming, as opposed to curing, cooling or cutting processes. Based on a total production of about 320 000 tonnes of insulation wools in Federal Republic of Germany in 1977 (Tiesler, 1983), an average of 5.6 g of MMVF (including 0.25 g of "respirable" fibres) were released per tonne of wool produced.

Recent measurements using PCOM at insulation wool manufacturing plants in the United States indicated that concentrations of "respirable" fibres (defined as having lengths > 5  $\mu$ m, diameters < 3  $\mu$ m, length/width ratio at least 5/1) in stack gases ranged from 0.00036 fibres/cm<sup>3</sup> to 0.993 fibres/cm<sup>3</sup> at 21 glass wool plants, and from 0.0024 fibres/cm<sup>3</sup> to 2.693 fibres/cm<sup>3</sup> at 19 rock and slag wool plants (TIMA/MIMA, 1990; Switala, pers. comm., 1993a and b). Average annual emissions of "respirable" fibres in stack gases of individual glass and rock/slag wool plants were estimated to be 39 and 123 kg, respectively (Switala, pers. comm., 1993b). Values were much higher (5 714 kg/year) at one microfibre (i.e. special purpose fibre) production facility. Limited data on fibre emission per unit weight produced (Switala, pers comm., 1993a) suggest that about 0.15 g of "respirable" fibres are released per tonne of glass wool produced in the United States. According to Switala (pers. comm., 1993b), these emission estimates likely represent "worst case" conditions since they are based on data for relatively old plants, and continuous operation at maximum capacity was assumed. Consistent with results of Tiesler (1983), > 90% of releases at the U.S. plants were associated with the fibre-forming stage of wool production (TIMA/MIMA, 1990).

Average concentrations of 0.116 to 2.86 fibres/ $cm^3$  (range = 0.003 to 14.13 fibres/cm<sup>3</sup>) were measured using TEM in stack gases collected in 1991 at four refractory ceramic fibres production plants and three processing facilities in the United States (TIMA, 1992). Levels were much higher (average = 63.7 fibres/cm<sup>3</sup>; maximum = 850 fibres/cm<sup>3</sup>) at a fifth production plant in New Carlisle, Indiana, however as TIMA (1992) noted, new emission controls (including a high efficiency fabric filter) have recently been installed at this facility. Although these concentrations are higher than those reported for insulation wool plants, this is partly attributable to the fact that fibres of all sizes were counted in this study, and to the high resolution of the analytical method (TEM) used. Together the five refractory ceramic fibre manufacturing plants surveyed accounted for nearly 90% of production in the United States. Annual emissions of fibres in stack gasses from individual plants ranged from 0.2 to 379 kg; average and median values were 88 and 30 kg, respectively. TIMA (1992) estimated that an average of

approximately 18 g of fibres are released per tonne of refractory ceramic fibre manufactured in the United States in 1991. Installation of new emission controls at the New Carlisle facility (which was responsible for over 80% of the releases from the five plants studied) has likely reduced this average.

Estimates of the amounts of man-made vitreous fibres released to the atmosphere from manufacturing plants in Canada in 1991 are presented in Table 8. Given that there were 9 plants producing glass wool and 5 producing rock or slag wool in Canada, and that plants in the United States are typically larger that those in Canada (Lethbridge, pers. comm., 1993), data on average annual emissions from individual insulation wool plants in the United States (Switala, pers. comm., 1993b) suggest that total release of "respirable" MMVF to the atmosphere from wool production facilities in Canada in 1991 was likely less that 1,000 kg. Furthermore, limited data on amounts of wool fibres released per unit weight produced in the United States (Switala, pers comm., 1993a) and Germany (Tiesler, 1983) suggest that total releases of "respirable" fibres from the 14 wool production plants in Canada in 1991 were about 50 kg.

Data on average annual emissions from individual refractory ceramic fibre manufacturing plants in the United States (TIMA, 1992) suggest that up to 88 kg of fibres of all sizes were emitted from the one production facility operating in Canada in 1991. However, estimates based on the amount of fibres released per unit weight produced in the United States (TIMA, 1992) suggest that emissions of refractory ceramic fibre fibres into the atmosphere in Canada in 1991 were between 2 and 36 kg. No data were identified that would permit quantification of atmospheric releases from the one continuous filament fibre manufacturing plant operating in Canada.

MMVF are also released to ambient air during product handling, use and disposal. For example releases can occur during installation of insulation wools (Marconi et al., 1987), erosion of ceiling tiles made of rock or slag wool, and repair of auto-body parts made of glass fibres (Eckert, pers. comm., 1993). However, no quantitative data on emissions from these sources are available. TIMA (1992) reported that refractory ceramic fibre concentrations (measured by TEM) in ambient air in the dumping area at an active landfill near Wyatt, Indiana, were low (< 0.0048 fibres/cm<sup>3</sup>), and concluded that releases of refractory ceramic fibres from landfills were likely very small.

No data were found on releases of MMVF in effluent from manufacturing plants. However, since process waters exposed to glass fibres are typically recycled (Lethbridge, pers. comm., 1993; Bates, pers. comm., 1993; Van Asseldonk, pers. comm., 1993; B. Eckert, pers. comm., 1993) discharges are expected to be small.

#### 5.0 Environmental Fate and Levels

#### 5.1 Fate

There is very little empirical information on the environmental fate of MMVF. However, based on their physical/chemical properties, most MMVF are expected to be relatively stable and persist in the ambient environment.

After release in stack gasses or during product handling, most MMVF are likely removed from air by gravitational settling. Finer, smaller diameter particles will remain airborne longer, and be carried further from the source. For example, during the installation of rock wool blankets Marconi et al. (1987) found that the proportion of respirable (i.e. diameters  $\leq 3 \mu$ m) relative to total airborne fibres increased from 67% in the immediate work area to 90% five metres away.

Gravitational settling and dissolution are expected to be the principal mechanisms of removal of MMVF from water (IPCS, 1988). Dissolution will be fastest in acidic water, and the finest and least chemically resistant MMVF will be most affected. Settling fibres will accumulate in bottom sediment.

Abrasion during transport in air or water will result in breakage into successively shorter fragments. Because of their amorphous character, MMVF are unlikely to fracture longitudinally (TIMA, 1991).

Airborne MMVF with diameters  $\leq 3 \ \mu m$  and lengths  $< 250 \ \mu m$  can be deposited in the lung of humans and other mammals if inhaled (TIMA, 1991). Information relating to the fate (i.e. clearance, translocation and degradation) of inhaled MMVF is being prepared separately by the Department of National Health and Welfare.

#### 5.2 Levels

No data were found on MMVF concentrations in Canadian air, water, sediment or soil. A limited amount of information was found on concentrations in outdoor air in Europe and the United States. However, as Meek (1991) has noted, because of differences in sampling and analytical methodology results of different studies are often not directly comparable. For example, because of its relatively poor resolution PCOM can underestimate total fibre concentrations relative to measurements made by TEM when fibres diameters are small (i.e. < 1  $\mu$ m) (Hammad and Esmen, 1984). Balzer (1976) used a combination of PCOM and electron microscopy to measure glass fibre concentrations in 36 samples of ambient air from several locations in California (Berkeley, San Jose, Sacramento, Los Angeles and the Sierra Mountains). Concentrations of fibres averaged about 0.003 fibres/cm<sup>3</sup>; their geometric mean diameter was 2.2  $\mu$ m (range = 0.1 to 18  $\mu$ m), and geometric mean length was 16  $\mu$ m (range = 1.2 - 160  $\mu$ m). However, the significance of these results is uncertain since methods of sampling and analysis were not well described (IPCS, 1988).

In 1981-82 in the Federal Republic of Germany 2 - 4 month average total glass fibres concentrations in air measured by TEM were reported to range from 0.0004 to 0.0017 fibres/cm<sup>3</sup> in three large cities (number of samples 6 - 21; Hohr, 1985). The average concentration in 9 samples from one rural site was 0.00004 fibres/cm<sup>3</sup>. Geometric mean diameters ranged from 0.25 to 0.89  $\mu$ m, and geometric mean lengths from 2.54 to 3.64  $\mu$ m. Glass fibres comprised 1 - 5% of the inorganic fibres present, and were typically several times less abundant than asbestos fibres.

TEM was used to measure concentrations of fibres of all sizes in ambient air near the boundaries of several refractory ceramic fibre manufacturing and processing plants, and a sanitary landfill operation in the United States in 1991 (TIMA, 1992). Arithmetic mean concentrations of refractory ceramic fibres (based on 8 - 20 samples) ranged from 0.0013 to 0.0016 fibres/cm<sup>3</sup> near processing plants and the landfill, and from 0.0036 to 0.0150 fibres/cm<sup>3</sup> near manufacturing plants. The highest individual value reported was 0.0479 fibres/cm<sup>3</sup>, measured near a manufacturing plant. Diameters of measured fibres were typically  $\leq 0.5 \ \mu m$  (all were < 3  $\mu m$ ); lengths were typically about 10  $\mu m$ (maximum was 75  $\mu m$ ).

In an early study using PCOM, Balzer et al. (1971) reported a mean glass (i.e. vitreous) fibre concentration of about 0.0002 fibres/cm<sup>3</sup> (range = < 0.00005 to 0.010 fibres/cm<sup>3</sup>) in ambient air in the San Francisco Bay area. Since all fibres with diameters of more than 1.6  $\mu$ m and lengths of over 4.8  $\mu$ m were counted, some non-respirable fibres (diameters > 3  $\mu$ m) were likely included. The authors noted that when expressed on a weight basis, the glass fibre concentration was about 0.3  $\mu$ g/m<sup>3</sup>, corresponding to 0.5% of the total particulate matter present in air in the Bay area at that time.

Glass fibre levels were measured in outdoor air in Paris, France, by Gaudichet et al. (1989) using PCOM. Samples were collected from 18 locations throughout the city beginning in 1981. Five-day average concentrations ranged up to 0.000015 fibres/cm<sup>3</sup> (mean 0.000002 fibres.cm<sup>3</sup>) for "respirable" fibres (diameter  $\leq$  3  $\mu$ m), and from 0.0000003 to 0.000022 (mean 0.000004 fibres/cm<sup>3</sup>) for total fibres. Recent attempts to model "respirable" MMVF (lengths > 5  $\mu$ m, diameters < 3  $\mu$ m and length/width ratios of at least 5/1) concentrations near representative insulation wool manufacturing facilities in the United States predicted maximum concentrations of 0.000001 to 0.00708 fibres/cm<sup>3</sup> (Lethbridge, pers. comm., 1992). A monitoring program involving collection of 12-hour "Hivol" samples on seven consecutive days in June and December of 1988 at several stations within a 3 km radius of a large building insulation plant in Newark, Ohio, indicated typical concentrations of <0.00001 fibres/cm<sup>3</sup> (analysis by PCOM; Switala, pers. comm., 1993a and b). The maximum value reported in air near the plant was 0.00014 fibres/cm<sup>3</sup>.

Total suspended particulates (TSP) were measured in 24-hour "Hivol" samples of ambient air collected from June 30 to October 25, 1989, at two sites near a continuous filament fibre manufacturing plant in Guelph, Ontario (Dobroff, unpublished data, 1993). The geometric mean values for samples taken on the roof of the plant and 200m away were,  $35 \ \mu g/m^3$  (range = 2 - 82  $\mu g/m^3$ ) and 29  $\mu g/m^3$  (range = 3 - 90  $\mu g/m^3$ ), respectively. These concentrations are below those that would be expected in a typical urban area (i.e about 50  $\mu g/m^3$ ; Dobroff, 1993) suggesting that if fibres were present, they contributed relatively little to the observed values.

Bishop et al. (1985) used a combination of PCOM and TEM to identify glass fibres in municipal sewage sludge from five large cities in the United States (Baltimore, Cincinnati, Dallas, Los Angeles and Philadelphia), however fibre concentrations were not reported.

#### 6.0 Effects on the Ecosystem

Other than results of inhalation studies on laboratory mammals being prepared separately by the Department of National Health and Welfare, no data were found on the effects of exposure to MMVF on aquatic or terrestrial organisms.

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Category	Synonym/Trade Name
Glass Wool	TEL fibreglass insulation Fiberglas <sup>R</sup> (trade name) mineral wool (in Europe and Asia)
Rock Wool	Rockwool <sup>R</sup> (trade name) basalt wool mineral wool
Slag Wool	mineral wool
Refractory Ceramic Fibres	refractory fibres ceramic fibres (some types only) Fiberfrax <sup>R</sup> bulk (trade name) Cerwool Kaowool
Special Purpose	
(or grass micro ) Fibres	Micro-Fiber (trade name) fine fibres ultrafine fibres AAAA diameter fibres AAA diameter fibres AA diameter fibres A diameter fibres B diameter fibres

Table 1. Some synonyms and trade names for man-made vitreous fibre products.

This category includes only vitreous aluminosilicate types.

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Properties	Cont- inuous Filament Fibres	Glass Wool	Rock & Slag Wool	Refrac- tory Ceramic Fibres	Special Purpose Fibres
typical diameters <sup>b</sup> (µm)	3-25	3-10	2-6	1.2-3.5°	0.2-4
length⁴ (mm)	continuous	5 (mean)	-	-	-
softening point (°C)°	680-860	650-700	-	1740- 1800	650-850
non-fibre particulate or shot (weight %)	none	traces	20-50	40-60	none
time for total fibre dissolution <sup>f</sup> (years)	-	0.4	1.2-2.0	4.9-5.0	1.0-6.5

Table 2. Physical and chemical properties of some man-made vitreous fibres<sup>\*</sup>.

- No data available

\* Data obtained from TIMA (1991), unless noted otherwise

<sup>b</sup> Average length-weighted values, except median length-weighted value for refractory ceramic fibres.

<sup>c</sup> Data from IPCS (1988)

<sup>d</sup> Values represent fibre lengths in commercial products and <u>not</u> ambient air.

 $^{\circ}$  Defined as the temperature at which viscosity of the fibres reaches  $10^{7.6}$  poise.

<sup>f</sup> Data from Scholze and Conradt (1987); measured in vitro based on loss of silicon from fibres of 1  $\mu$ m diameter in flow-through experiments using simulated extracelluar fluid (modified Gamble's solution) at a temperature of 37°C.

<b>Oxides<sup>b</sup></b>	cont	inuous f	filament	glass	rock	slag
		glass		wool	wool	wool
	"E"	"S"	"AR"	(b	asaltic	)
	glass	glass"	glass <sup>°</sup>		<u></u>	
SiO,	52-56	65	60-70	55-70	41-53	38-52
Al <sub>2</sub> O <sub>2</sub>	12-16	25	0-5	0-7	6-14	5-15
B <sub>2</sub> O <sub>2</sub>	0-10			3-12		
K <sub>2</sub> O	0-1		5-10 <sup>f</sup>	0-2.5	0.5-2	0.3-2
Na <sub>2</sub> O	0-1		5-10 <sup>f</sup>	13-18	1.1-4	0-1
MaÓ	0-5	10	1-10	0-5	6-16	4-14
CaO	16-25			5-13	10-25	20-43
TiO	0-1.5		4 C	0-0.5	0.9-4	0.3-1
Fe <sub>2</sub> O <sub>3</sub> +FeO	0-0.8		0-0.5	0.1-0.5	3-12	0-2
Zr0,			10-18			
Cr <sub>2</sub> 0,						
S					0-0.2	0-2
P <sub>2</sub> O <sub>5</sub>						0-0.5
$Li_2O$	•			0-0.5		
F <sub>2</sub>	0-1			0-1.5		
BaO				0-3		
R	Data o	otained	from TIM	IA (1991) u	inless r	oted otherwise
3	Althou	gh eleme	ents are	reported a	s oxide	es, atoms are
	arrange	ed at ra	ndom (i.	e. not as	oxide c	compounds) in
	these 1	material	.s.			
•	Used fo	or over	99% of c	continuous	filamer	nt fibre
	produc	tion (Yo	oung, 199	(1); $B_2O_3$ co	ontent f	rom Lethbridge
	(pers.	comm.,	1993).			
I	Used i	f high m	echanica	l strength	or tem	perature
	resist	ance is	required	l		
5	Used to	o reinfo	orce ceme	ent		
Ē	Assume	d Na/K r	atio 1/1	; expresse	ed as to	tal Na <sub>2</sub> O+ K <sub>2</sub> O :
	TIMA (	1991).				•

Table 3. Chemical compositions (in weight percent) of some continuous filament fibres and insulation wools\*.

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Oxides⁵	<b>#</b> 753	E	<b>#</b> 475	<b>#</b> 363	silica
SiO,	62-65	54-55	57-58	58-59	99.5-100
$Al_2O_3$	3-5	14-15	5-6	5	
$B_2O_3$	5-6	7-8	10-11	7-8	
K <sub>2</sub> 0	0-1	0-0.2	2-3	14-15	
Na <sub>2</sub> O	14-16	0-0.6	10-11	7-8	<0.5
MgŌ	2-3	0.3-3	0-0.5		
CaO	5-6	18-21	2-3	0-0.2	
TiO <sub>2</sub>	0-0.1	0.5-0.6	0-0.1	8	
Fe <sub>2</sub> O <sub>3</sub> FeO	0-0.1	0.2-0.4	0-0.1	0-0.1	
$2rO_2$				4	
F <sub>2</sub>	0-1	0-1		2	
BaO	0-0.2		5		
ZnO			4		

Table 4. Chemical compositions (in weight percent) of some glass microfibres<sup>a</sup>.

Data obtained from TIMA (1991) Although elements are reported as oxides, atoms are arranged at random (i.e. not as oxide compounds) in these materials.

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Oxides <sup>*</sup>	kaolin alumino- silicate <sup>b</sup>	high purity alumino- silicate <sup>b</sup>	zirconia alumino- silicate <sup>b</sup>	
sio.	50-54	49-54	48-50	
A1 <sub>2</sub> O <sub>2</sub>	44-47	46-51	35-36	
B <sub>2</sub> O <sub>2</sub>				
K <sub>2</sub> O	<0.01	<0.01	<0.01	
Na <sub>2</sub> O	0.5	0.2	<0.3	
Mao	<0.1	<0.01	0.01	•
CaO	<0.1	<0.05	<0.05	
TiO	2	0.02	0.04	
Fe <sub>2</sub> O <sub>2</sub>	1	<0.2	<0.05	
ZrO	0.1	0.2	15-17	
Cr <sub>2</sub> O <sub>3</sub>	<0.03	<0.01	<0.01	

Table 5. Chemical compositions (in weight percent) of some refractory ceramic fibres.

Although elements are reported as oxides, atoms are arranged at random (i.e. not as oxide compounds) in these vitreous fibres. Source TIMA (1991).

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Table 6. Chemicals used in binders for man-made vitreous fibres<sup>1</sup>.

phenol formaldehyde resin<sup>b</sup> urea formaldehyde resin melamine formaldehyde resin polyvinyl acetate vinsol resin urea silicones dyes ammonium sulphate ammonium hydroxide starch carbon pigment epoxy resins pseudo-epoxy resins bitumens

Source: IPCS (1988)

Principal component of most binders currently in use.

Fibre Type	Domestic Production (kilotonnes)	
Continuous Filament Fibres	20-40	
Glass Wool	180-200	
Rock and Slag Wool	50-60	
Glass Microfibres	none	
Refractory Ceramic Fibres	0.5-2.0	
Total	250-302	

Table 7. Production of man-made vitreous fibres in Canada in 1991<sup>a</sup>.

Source: Camford Information Services Inc. (1993a,b,c and d).

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Table 8. Estimates of amounts of man-made vitreous fibres released to the atmosphere from manufacturing plants in Canada in 1991<sup>a</sup>.

Plant Type		Estimates Based on Average Emissions From Individual Plants in the United States			Estimates Based on Amounts Released Per Unit Weight Produced in Other Countries		
		Number of Plants in Canada in 1991 <sup>b</sup>	Estimate of Average Annual Emissions per U.S. plant° (kg/yr)	Estimate of Maximum Total Emissions in Canada in 1991 <sup>4</sup> (kg)	Amount Produced in Canada in 1991 <sup>b</sup> (tonnes)	Estimate of Amount Released from U.S. & German plants <sup>o</sup> (kg/tonne produced)	Estimate of Total Emissions in Canada in 1991 (kg)
Insul- ation	glass wool	9	39	351	180,000- 200,000	0.0002	36-40
W001	rock/ slag wool	5	123	615	50,000- 60,000	0.0002	10-12
			TOTAL	966	TOTAL		46-52
Refractory Ceramic Fibre		1	88	88	100- 2,000	0.018	2-36
Continue filament Fibres	ous t	1	-	-	20,000- 40,000	-	-

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No data available

Emission estimates for insulation wools are based on concentrations (in stack gases) of "respirable" fibres with lengths of > 5  $\mu$ m, measured by PCOM; those for refractory ceramic fibres are based on concentrations of fibres of all sizes, measured by TEM.

Source: Camford Information Services Inc. (1993a,b,c and d) Based on recent data for insulation wool (Switala, 1993b) and refractory ceramic fibre (TIMA, 1992) production plants in the United States.

These calculated values likely represent maxima, since plants in the United States are normally larger than those in Canada. Calculated as the average of 0.00025 kg/tonne from (Tiesler, 1983) and 0.00015 kg/tonne from Switala (1993a) for insulation wools; taken directly from TIMA (1992) for refractory ceramic fibres.