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Alan Jones, Aracelli Sanchez Jimenez

WORLD HEALTH ORGANISATION
COLLABORATING CENTRE
FOR OCCUPATIONAL HEALTH

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This review assesses the available data on inhalation exposure to mineral fibres during installation of mineral wool insulation products. The relevant studies from the UK were undertaken in the 1970s or 1980s and subsequently there have been substantial changes in insulation products and methods of installation. Therefore, this report summarises and compares more recent measurements from published and unpublished studies from various countries including Australia, USA, Canada, France, Denmark, Sweden as well as the earlier studies from the UK. The objective was to assess whether these data provide a sufficient basis to determine likely current exposure concentrations during installation of such products in the UK.

Some clear general patterns emerge. The 8-hour time weighted exposure concentrations associated with most installation tasks are generally below 1 fibre/ml, according to the combined body of measurements. However, there were some substantial differences between measurements from different countries, which may reflect significant differences in ways of working, site conditions, or other factors. It is therefore not possible to make more refined estimates of current exposures in the UK from these data. Several studies identify the importance of updating the measurement data to reflect current practice and materials, and we suggest that this should be done in the UK.

Most of the available data relate to fibre number concentrations, but the limited body of dust mass concentrations indicates that there is merit in using gravimetric sampling to monitor the effectiveness of risk management measures.

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SUMMARY

Introduction
Mineral wool insulation products are widely used in a range of applications. The technical characteristics of these products have improved during the period since any published UK study of occupational exposures during their use, and consequently it is clear that the historical exposure data are not adequate to characterise current conditions. However, there have been more recent studies undertaken in other countries. Therefore, this report examines the internationally available data to assess how much can be inferred about likely concentrations during application of mineral wool insulation products in the UK.

This study was undertaken on behalf of MIMA (the Mineral Wool Insulation Manufacturer's Association) formerly known as Eurisol.

End uses
From the information supplied to us by MIMA, the procedures for installing most mineral wool insulation products in the UK are essentially similar for a wide range of applications. The main differences are in the tools (e.g. knife or saw) used for cutting the product to fit, the amount of cutting needed for a particular job, the orientation of the location of the mineral wool product with respect to the installer (e.g. application in the floor below, wall to the side, or ceiling above) and the extent to which the installation workplace is enclosed or open (e.g. small attic or large room). All of these circumstances are likely to be very influential on the concentrations encountered.

We have therefore produced a list of the relatively few basic tasks that, with slight variations, cover a wide range of installations within buildings.

Exposure limits and types of measurement
This report describes briefly the key features of the measurement methods and lists the occupational exposure limits in 17 countries of Europe and North America. Exposure limits in terms of fibres number concentrations (fibres/ml) are specified in all the listed countries. Limits in terms of gravimetric particulate concentrations (mg.m^{-3}) are specified in five of the countries.

Fibre number concentrations from a US database.
From summarised data from the US North American Insulation Manufacturers Association (NAIMA), it appears that the end user activities associated with typical 8-hour time-weighted average concentrations greater than 0.2 fibres/ml are:

- Blowing wool without binder, about 0.8 fibres/ml;
- Blowing wool with binder, about 0.3 fibres/ml;
- Removal of board or blanket, about 0.4 fibres/ml;
- Compressed air cleanup after removal, about 0.6 fibres/ml;
- Duct wrap, about 0.35 fibres/ml;
- Power tools, about 0.35 fibres/ml;
- Ceiling tiles, installation about 0.25 fibres/ml;
- Cavity wall fill insulation, about 0.2 fibres/ml.

(Note, the concentrations quoted above have been rounded to the nearest 0.05 fibres/ml.)

All the other tasks showed geometric mean 8-hour time-weighted concentrations that were 0.2 fibres/ml or less. In particular, this includes installing blankets or batts.

When the data for industry sectors were assessed. Marchant *et al* (2009) reported that there were data from a large number of samples giving the mean, median and 95th percentile for exposure

distributions for the glass wool and stone wool installation sectors as a whole. These are shown in the following table.

	No of samples	Exposure concentration (fibres/ml)		
		Mean	Median	95^{th} percentile
Glass wool Installation	596	0.39	0.19	1.30
Stone wool Installation	133	0.17	0.10	0.58

When the fibre exposure concentrations were examined by job designation, it was clear that the blowing of fibres without binder gave the higher exposures for glass wool products. Without blowing, the 95^{th} percentile for glass wool installation would have been below 1 fibre/ml.

The data in the NAIMA database are derived from fibre counts produced using the US NIOSH fibre counting methods. Most of the data was produced with the NIOSH 7400B method but some of the older data (about 10% of all the NAIMA data) was reportedly produced by the older NIOSH 7400A method.

Fibre counting and sampling methods.
The difference between fibre counting methods may affect the comparability of fibre concentration data as produced by the method used in the UK with data produced by other methods, such as the NIOSH method. The differences are dependent on the fibre size distribution and therefore will not be a constant factor for all fibres. However, one comparison showed a difference of about 30%, with counts by the method used in the UK being higher than those from the NIOSH 7400B method.

Review of historical data
We have reviewed the historical data from studies over the period from about 1971 to 2003. These include some measurements during installation in the UK during the 1980s by Jaffrey *et al* (1989). The most recent published European data are for simulations of insulation of an attic or a wall from Denmark (Breum et al, 2003), which showed task average concentrations, less than 0.1 fibres/ml and dust mass concentrations ranging from 0.3 to 1.8 $mg.m^{-3}$.

Comparisons between exposure studies is not easy because of differences in types of measurements (e.g. task average concentrations compared to 8-hour time weighted concentrations, fibre counting methods, and personal and area samples). Nevertheless, from a tabulation of the data from various studies listed in chronological sequence, a trend of concentrations reducing compared to the past is fairly clear. We note that this pattern is consistent with a reported general downward trend in exposure concentrations over the same period.

Comparisons between recent international data
Published data from Canada are described in detail in Chapter 5 of this report. Chapter 6 provides a full description of the recent unpublished measurements from France, provided to us by FILMM - an organisation formed by the French industries manufacturing mineral insulation fibres. There are much fewer samples in these data sets than in the NAIMA data summarised above, but there is valuable information about the circumstances of the various samples. There details are explored to clarify the basis for comparing data sets.

A comparison of the published international data sets highlights a number of interesting features, with apparent systematic differences in levels between those reported in the recent unpublished measurements from France (from FILMM), those from Canada (Verma *et al*, 2004) and from the US (Marchant *et al* 2009). These differences indicate the difficulty in assuming data from other countries is directly relevant to the UK and the importance of having adequate data from installation of products in the UK.

The published international data indicate that a large range of concentrations within nominally the same task is to be expected. The highest concentrations appear to arise from blowing of loose fibre without binder.

The available data on dust mass concentrations during handling of mineral wool is particularly limited in the international datasets reviewed in this report. There is no mass concentration data in the US NAIMA or the Canadian databases and only limited mass concentration data from the French data supplied by FILMM.

Conclusions

The body of international mineral wool exposure data forms persuasive evidence that average 8-hour time-weighted average fibre concentrations during installation of mineral wool insulation products in the UK are likely to be below 1 fibre/ml. However, there are also substantial differences between some of the published airborne fibre concentrations measured for similar tasks, and those differences may be related to the local conditions or methods. Additional measurements in the UK would help to establish the degree to which the international data can be extrapolated to users in the UK.

There is less data on mass concentrations during installation of mineral wool products than for concentrations measured in terms of fibre number. Nevertheless the data that is available strongly suggests that controlling dust mass concentrations to below the UK workplace exposure limit of 5 $mg.m^{-3}$ would control fibre number concentrations to below 1 fibre/ml.

Recommendations

A valuable addition to the data described here would be to obtain airborne fibre number and mass concentration data in the UK for six basic tasks involved in handling mineral wool for a selection of the modern products.

Ideally the data would be obtained from a number of representative sites (e.g. at least three sites) for each task. The product types could be a mixture from slab to roll, glass wool to stone wool.

If the relevance of airborne mass concentrations is to be promoted in future, any exposure measurements should comprise simultaneous airborne fibre number and dust mass concentrations measured as Inhalable Dust.

As noted in the FILMM report, the key exposure determinants for installing rolls or slabs are expected to be the types of cutting tools, the degree of enclosure, the position of the mineral wool products being installed relative to the installer (above, below or to the vertical wall), and the ventilation conditions. This information should be recorded during any measurement surveys and the impact of these variables assessed. Measurements should be collected to a defined written protocol specifying the measurement techniques and associated contextual data to be obtained.

It seems reasonable to suggest that UK airborne fibre concentrations are likely to be of a similar order of magnitude to the body of international data reviewed here, provided work practice, building conditions, and products used are not too different. However, as described above, there are enough differences between the various available data sets that collecting UK fibre concentration data for comparison and verification is essential.

1 INTRODUCTION

IOM was commissioned to undertake a review of the published information on concentrations of insulation wool fibre during activities undertaken by users of the products. The ultimate aim of the work is to enable MIMA to support end users of products by providing information about the likely concentrations that arise during use of the products.

In reviewing the published information, our objective was to assess if (and to what extent) the data could be used to provide reliable estimates of the concentrations that arise in the course of the installation work (end-user work) that is undertaken in the UK. MIMA provided lists of the types of tasks where insulation wool fibre is used and these are summarised and discussed in Chapter 2. There is a great diversity in the ways that these products are used, e.g. in masonry cavity walls, in timber frame cavity walls, in roof spaces, underfloor, between floors, as rolls, batts (slabs), and blown fibre, and this may affect the exposures received by workers.

Two types of measurement may be used to assess the air concentrations of mineral wool fibres, giving concentrations in terms of either mass or fibre number per unit volume of air. The merits of each type of measurement are summarised and discussed in Chapter 3, to provide a basis for reviewing the published data that may include one or the other or both types of measurement.

An important source of data on airborne fibre levels is the database that has been set up in the US by NAIMA. This contains a substantial amount of recent data and therefore it was reviewed first. A critical factor in the utility of this database is the correspondence in the tasks and the descriptions of tasks with those listed by MIMAl. In addition, the NAIMA database does not include mass concentrations. Chapter 4 includes summaries of published data from the NAIMA database.

Chapter 5 describes the other published data for air concentrations associated with the use of mineral wool. An assessment of the temporal trends in the data shows that there have been substantial reductions in concentrations, and while this is important from a risk management perspective it limits the use of older data in our study.

Chapter 6 describes recent unpublished exposure data from situations where mineral fibre have been used in France, made available from France by FILMM.

Chapter 7 presents brief comments, discussion and recommendations.

2 TECHNICAL INFORMATION ON INSTALLATION OF MODERN MINERAL WOOL PRODUCTS

2.1 TASKS WITHIN THE UK USER INDUSTRY

2.1.1 Purpose

In order to be able to assess the potential relevance of international sources of data to the installation of mineral wool products I the UK, the first step was to define the range of activities that are undertaken by end users of mineral wool insulation products in the UK.

2.1.2 Applications defined by MIMA

MIMA provided descriptions of the procedures involved in installing mineral wool products for a range of applications. The processes are relatively similar for many of the applications, as shown by Table 2.1. Generally, a wrapped product is taken to the place of application, the wrapping removed, the product cut to size with a knife or hand saw, and then fixed in place commonly by friction fitting (e.g. in wall frames etc), by mechanical fixings (e.g. on ducts), or by gluing the material in place (e.g. slabs on exterior walls). Only for installation of blown loose fibres is the process markedly different, with the product being fed into a processing machine on the back of a vehicle, and then delivered into a cavity wall or loft space. None of the descriptions provided by MIMA involved the use of a power saw.

MIMA provided lists of the applications for glass wool products and separate lists for stone wool products. We have combined and simplified the lists to give the summary of the types of materials in use for various purposes in Table 2.2. There are three parts to the table:

- Part 1: in buildings generally;
- Part 2: in industry (including some industrial building applications);
- Part 3: in transportation (mobile homes) and in domestic appliances.

Within each part of the Table, the first column categorises the type of use, i.e. thermal insulation, acoustic, fire protection etc.

The columns to the right indicate the types of products, starting with six glass wool products and then five stone wool products. The definition of the type of product includes some information about the way that it is used, e.g. it includes ‘*blown glass wool with binder*’ and ‘*blown glass wool without binder*’. As stated in the header to the Table, the uses of products are indicated as being either for New (N) or Retrofit (R) installations.

The first part of Table 2.2 covers the general building applications for thermal and acoustic insulation purposes. These are the types of application which we anticipate would be undertaken by DIY users of these products. We also anticipate that the majority of DIY users would be undertaking retrofit rather than fitting to new builds or new products.

2.1.3 Practical aspects

The information from MIMA also showed that the types of installation could vary quite widely. For example, installation to roofs could be on the top of flat roofs (i.e. under the waterproof covering) or on the underside of pitched roofs (i.e. in the attic). Application to floors may involve either fitting to the underside of floors (i.e. in the floor cavity), or it can involve laying the insulation under a concrete scree floor. The different circumstances could lead to very different ventilation and dilution conditions (i.e. outdoor compared to indoor) that would affect the concentrations arising from handling of ostensibly similar products in nominally the same task of roof insulation. Therefore, descriptions at an adequate level of detail of the application and conditions will be important in identifying typical concentrations associated with particular tasks.

2.1.4 Factors that affect concentrations

The factors that could affect the concentration of using a given product in particular circumstances include:

- outdoor/ indoor with dilution ventilation;
- amount of material being used;
- the tools used to cut and fit the product (e.g. the types of cutting tools, knife, hand saw, power saw etc);
- the pattern of activity (e.g. fitting with a lot of cutting to size as opposed to largely laying in place); and
- the relative duration of the parts of the work that gives rise to airborne dust exposure.

Table 2.1 Descriptions of methods used to install mineral wool insulation products

Example of where method is used	Method	Description
Wall applications of slabs for thermal insulation	A1	1/ The material is transported to the installation location in packaging, 2/ Operator would then carry pack to place of installation (e.g. loft) and cut open packaging using an appropriate tool. 3/ Operator would cut product to size as required using a knife or hand saw; 4/ and friction fit product **between framing**.
Fire protection in buildings	A2	1/, 2/ and 3/ *as for A1 above* 4/ and friction fit into place **or secure with mechanical fixings as appropriate.**
Smoke and fire protection, in building voids	A3	*(differs from A1 only in type of space being fitted into).*
Fixing slabs to external walls	B	1/ and 2/ *as for A above* 3/ Operator would cut product to size as required using a knife or hand saw **if appropriate**; 4/ **The slabs are then fixed to the wall using glue and mechanical fixings before being over coated with a two coat render system**
Loft installations	C1	1/, 2/ and 3/ *as for A1 above* 4/ and friction fit **between joists**. 5/ *In the case of overlaying of additional material to increase installed thickness*, a 2nd layer is laid across the top of the joists.
Floor insulations	C2	(differs from C1 only in not having step 5). Fitted from above
Ceiling / floor insulations	C3	As for C2, but fitted from below.
Blown loose fibre		
Into walls	D	1/ The material is transported to installation location in sealed compressed packs, 2/ the bag is opened by the operator using an appropriate tool and the bag emptied into a processing machine which is located in the back of a vehicle. 3/ The equipment transfers the fibres pneumatically by hose and through nozzles inserted into hole drilled in the walls of the property. 4/ Operators wear appropriate personal protective equipment. There is generally no waste arising from this operation.
Into lofts	E	1/ and 2/ *as for D above* 3/ The equipment transfers the fibres pneumatically by hose into the loft space of the property. 4/ The distribution of the fibre is controlled by operators wearing appropriate personal protective equipment. There is generally no waste arising from this operation.

Example of where method is used	Method	Description
Slabs for floors and roofs		
Solid and new build floating floor	F1	1/, 2/ and 3/ *as for A1 above* 4/ **Slabs are laid out on the floor and overlaid with concrete**.
Flat roof	F2	/, 2/ and 3/ *as for A1 above* 4/ **Slabs are laid out on the floor and overlaid with a membrane.**
Industrial:		
equipment for buildings, such as air conditioning insulation	G1	1/, 2/ and 3/ *as for A1 above* 4/ **The product, which may be foil faced, is fitted internally either within the duct or externally and then fixed in place using mechanical fixings.**
Internal insulation in equipment	G2	1/, 2/ and 3/ *as for A1 above* 4/ friction fit in the equipment and **fix mechanically if required**.

Table 2.2 Part 1. In Buildings: Summary of Types of Application of glass wool (GW) and stone wool (SW) products. The methods for installation are described in Table 2.1

Function	**Application**		**Installation**	**Purpose**	**Applied in New (N) build or Retrofit (R), for both Glass Wool (GW) and Stone Wool (SW) or for one or the other where specified**							
	Location	**Description**	**Method (see Table 2.1)**		**blown loose with binder**	**blown loose without binder**	**slab, faced**	**slab unfaced**	**roll**	**Roll faced**	**mattress**	**section**
Internal Framed Installa-tions	Steel frame walls	Vertical frame Installation	A1	**Thermal**				N & R	N & R			
	Loft	Vertical frame Installation	A1	**Thermal**	N & R (SW only)			N & R	N & R			
	Loft	Over head Framed installation in Pitched roof	A1	**Thermal**				N & R	N & R (GW only)			
	Partitions	Vertical frame Installation	A1	**Thermal and acoustic**				N & R	N & R (GW only)			
External Framed Installa-tions	External wall systems	Vertical frame Installation	A1	**Thermal**				N & R				
	Timber framed cavity walls	Vertical frame Installation	A1	**Thermal**	N (& R for SW)	N & R	N & R	N & R				
	External wall systems	Vertical frame Installation	A1	**Fire stopping of combustible insulation**				N & R	N & R (GW only)			

Function	Application		Installation	Purpose	Applied in New (N) build or Retrofit (R), for both Glass Wool (GW) and Stone Wool (SW) or for one or the other where specified							
	Location	Description	Method (see Table 2.1)		blown loose with binder	blown loose without binder	slab, faced	slab unfaced	roll	Roll faced	mattress	section
Vertical wall applica-tion	Internal walls either side of solid wall, behind plasterboard	Same as vertical internal framed installation	A1	**Acoustic**				N & R	N & R (GW only)			
	Internal wall lining	Same as vertical internal framed installation	A1	**Thermal, Fixed to wall behind plaster-board**				N & R				
	Internal Walls	Same as vertical internal framed installation	A1	**Fire protection penetra-tions pipes, cables etc,**				N & R (SW only)				N & R (SW only)
	External walls	Fixing of slabs to external walls	B	**Thermal**				N & R (SW only)				
Loft installa-tions	Loft, roof spaces	Installation of insulation between joists and over laying ceiling joists, from above	C1	**Thermal**					N & R			

Function	Application		Installation	Purpose	Applied in New (N) build or Retrofit (R), for both Glass Wool (GW) and Stone Wool (SW) or for one or the other where specified							
	Location	Description	Method (see Table 2.1)		blown loose with binder	blown loose without binder	slab, faced	slab unfaced	roll	Roll faced	mattress	section
Blowing Wool	Masonry Wall - External installation	Installation of blowing wool into cavities	D	**Thermal**	N (& R SW only)	N & R (GW only)	N	N				
	Loft	Installation of blowing wool into loft spaces	E	**Thermal**		N & R (GW only)						
Floors	Suspended timber - Internal flooring.	Fitted from above same as loft, from above	C2	**Thermal and acoustic**				N & R	N & R (GW only)			
	Suspended timber - Internal flooring.	Fitted from below, same as Loft overhead installation in pitched roof	C3	**Thermal and acoustic**				N & R	N & R (GW only)			
	Internal flooring.	Solid and new build floating floor	F1	**Thermal**				N & R		N & R		
	Floor (block timber)	Fitted from above same as loft, from above	A1	**Thermal - Upgrading existing floor**				N & R		N & R		
	Floor (solid concrete) -	stopping around slab edge	A1	**Fire protection**				N (SW only)				

Function	Application		Installation	Purpose	Applied in New (N) build or Retrofit (R), for both Glass Wool (GW) and Stone Wool (SW) or for one or the other where specified							
	Location	**Description**	**Method (see Table 2.1)**		**blown loose with binder**	**blown loose without binder**	**slab, faced**	**slab unfaced**	**roll**	**Roll faced**	**mattress**	**section**
Fire Protect-ion	Internal during building constructio n	Structural columns, beams, partitions, ceilings and floors	A2	**Fire protection**				N & R (SW only)				
	Internal - generally confined spaces	Sub dividing voids	A3	**Smoke and Fire protection**				N & R (SW only)	N & R (SW only)			
Roof	Pitched Roof			**Fire stopping**			N & R (GW only)	N & R (GW only)				
	Pitched Roof		C2	**cavity and fire barriers**			N & R	N & R			N & R (SW only)	
	Pitched roof		C2	**Thermal**			N & R (SW only)	N & R (SW only)	N & R (SW only)	N & R (SW only)		
	Flat roof	Same as solid floor overlaid with membrane	F2	**Thermal**			N & R (SW only)	N & R (SW only)				

Table 2.2 Part 2. Industrial: Summary of Types of Application of glass wool and mineral wool products.

Function	**Application**		**Installation**	**Purpose**	**Applied in New (N) build or Retrofit (R), for both Glass Wool (GW) and Stone Wool (SW) or for one or the other where specified**							
	Location	**description**	**method**		**blown loose with binder**	**blown loose without binder**	**slab, faced**	**slab unfaced**	**roll**	**Roll faced**	**mattress**	**Section**
Buildings, equipment, air conditioning thermal insulation	Internal	Insulation of ducts for use at raised temperatures	G1	**Thermal**			N & R	N & R				
	Internal	Insulation of ducts at higher temperatures	G1	**Thermal**			N & R	N & R	N & R (SW only)			
	External	Pipe insulation	G1	**Thermal**								N & R (SW only)
	Internal	equipment	G2	**Thermal**			N & R	N & R	N & R (GW only		N & R (SW only)	
	External	Twin skin metal	no description	**Thermal**					N (& R, GW only)			

Table 2.2 Part 3. Transportation and Domestic Appliances: Summary of Types of Application of glass wool and mineral wool products.

Function	Application		Installation	Purpose	Applied in New (N) build or Retrofit (R), for both Glass Wool (GW) and Stone Wool (SW) or for one or the other where specified							
	Location	Description	method		blown loose with binder	blown loose without binder	slab, faced	slab unfaced	roll	Roll faced	mattress	Section
Mobile Homes	Walls, roofs	Same as internal Framed installations	A1	**Thermal**			N & R	N & R	N & R			
Domestic appliances	Water heaters, cookers, wall heaters	Cutting to size and manual installation of insulation	G2	**Thermal**			N	N	N (SW only)			

3 MEASUREMENT OF EXPOSURE CONCENTRATIONS

3.1 INTRODUCTION

We briefly describe and comment on the different types of inhalation exposure measurement methods that are used, both in the UK and elsewhere. Concentrations of fibres in air can be measured in terms of either mass of dust per unit volume of air or number of fibres per unit volume of air. There are merits in both types of measurement. Workplace exposure limits for mineral wools, in the UK and in some other European countries, are specified in terms of both types of measurement. In other countries only the fibre number concentration measurement method is used.

3.2 REGULATORY LIMITS

3.2.1 Regulatory Limits in the UK

In the UK, occupational exposure limits for mineral wool fibres are now called “Workplace Exposure Limits” (WEL). In the official guidance document EH40 (HSE, 2005, with revisions 2007), these WEL for MMMF (Machine-made mineral fibre (except for Refractory Ceramic Fibres and Special Purpose Fibres) are specified as being 5 $mg.m^{-3}$ (*8-hour TWA of inhalable dust)* and a fibre number concentration of 2 fibres/millilitre (2 fibres/ml).

In EH40, the UK Health and Safety Executive (HSE) states that “*Machine-made (formerly 'man-made') mineral fibres are defined as man-made vitreous (silicate) fibres with random orientation with alkaline oxide and alkali earth oxide ($Na_2 0+K_2 0+CaO+MgO+BaO$) content greater than 18% by weight. Neither the gravimetric limit nor the fibres in air limits should be exceeded. Fibre concentrations of MMMFs must be measured or calculated by a method approved by HSC.*” (HSC stands for the UK Health and Safety Commission.)

The gravimetric exposure limits (WEL) for mineral wool fibres in the UK is equivalent to 50% of the gravimetric limit for dusts for which no specific WEL value is set. A WEL of 5 $mg.m^{-3}$ for mineral wool is higher than, for example, the WEL values for copper (dust or mist) at 1 $mg.m^{-3}$, or copper fume 0.1 $mg.m^{-3}$.

3.2.2 Summary of National Regulatory Limits for mineral wools

In the European Union, there are no common exposure limits set for Mineral wool fibres. However, the Scientific Committee on Occupational Exposure Limits (SCOEL) has produced recommendations for a common limit of 1 fibre/ml to be applied to “*all man made mineral fibres without indication of carcinogenicity*.”

The limits in a number of other countries are listed below in Table 3.1. The summary of national exposure limits shows that these are generally set at similar values, of either 1 or 2 fibres/ml and in some cases with a gravimetric limit specified. One country (Denmark) sets a short-term limit value (see the footnote to the Table). Three nations (Belgium, Canada, UK) set mass concentration limits in addition to fibre number concentration limits; the UK limit is specified as an Inhalable Dust limit (i.e. measured using a particle-size selective sampler) whereas the limit in Canada is specified as a “Total Dust” limit. The Inhalable dust sample is, in principle, a sub-fraction of total dust, but the difference in any measurements will vary with the size distribution of the dust and also will depend on the sampling characteristics of the so-called Total Dust sampler.

Five of the listed countries (Belgium, Canada-Quebec, Poland, The Netherlands and UK) set a fibre concentration limit of 2 fibres/ml for glass wool fibres. Three of these have the same limit for stone wool fibres, but two (Belgium and Canada-Quebec) set a lower limit of 1 fibre/ml for stone wool. Two countries (Austria and Switzerland) set a fibre number concentration limit of 0.5 fibres/ml. The remaining eight set a limit of 1 fibre/ml. Therefore, there are three levels of fibre number concentration that are relevant for compliance within these nations.

Five of the countries (Austria, Germany, Poland, Italy, USA) set respirable dust mass concentration limits; we have understood the limit in Italy to be respirable dust although our source (see foot of table) was not explicit about this. Respirable dust is, in principle, a subfraction of inhalable dust. It is a sampling convention for aerodynamically selecting the dust that could penetrate to the alveolar lung. The values of the respirable dust mass concentration limits range from 1 $mg.m^{-3}$ in Poland, 3 $mg.m^{-3}$ (in Italy and Germany) to 5 $mg.m^{-3}$in the USA. Austria sets limits for an annual average (6 $mg.m^{-3}$) and a monthly average (12 $mg.m^{-3}$).

Limits set in terms of inhalable dust concentrations or total dust concentrations also vary. Belgium and Canada-Quebec set limits of 10 $mg.m^{-3}$ for glass wool fibres, but apparently make no specification of a mass limit for stone wool fibres. Germany and the USA have inhalable dust limits (of 10 $mg.m^{-3}$) in addition to their respirable dust limits of respectively 3 and 5 $mg.m^{-3}$. Their respirable dust limits are thus either 30% or 50% of their inhalable dust limit. Poland sets the lowest Total Dust limit at 4 $mg.m^{-3}$. The UK sets an inhalable dust limit of 5 $mg.m^{-3}$.

Limits expressed as Total Dust or as Inhalable Dust will be slightly affected by the sampling method. In principle, a measurement of inhalable dust should give a lower concentration than a Total Dust sample, because the Inhalable Sampler is intended to sample according to a defined particle size selection (to be similar to the entry to human head and nose). Total Dust samplers have sampling characteristics that are less well defined; so a Total Dust sampler should in principle give a higher concentration than an Inhalable Dust sampler, but the result will actually depend on which type (or manufacture) of so called “Total Dust” sampler is used. Because Inhalable dust samplers have a defined selection characteristic, the Inhalable dust exposure limits may be regarded as a more consistent definition of a limit than the so-called total dust limits. One example of the consequence of the sampling characteristics is that the difference between the inhalable dust limit in the UK (5 $mg.m^{-3}$) and the Total Dust limit in Poland (4 $mg.m^{-3}$) will be dependent on what sampling procedures are actually used in Poland.

Table 3.1 Exposure limits for mineral wool fibres in various countries

Country	glass wool fibres		stone wool fibres, mineral wool fibres	
	Limit value - Eight hours		Limit value - Eight hours	
	Fibre number fibres/ml	Dust mass $mg.m^{-3}$	Fibre number Fibres/ml	Dust mass $mg.m^{-3}$
Austria	0.5	respirable dust 6 yearly-average 12 monthly-average	0.5	respirable dust 6 yearly-average 12 monthly-average
Belgium	2	**10**	1	
Canada - Québec	2	**total dust** **10** continuous filament	1	
	1 (microfibres)			
Denmark[1]	1		1	
France	1		1	
Finland	1		1	
Germany		Inhalable dust 10		Inhalable dust 10
		Alveolar (respirable) dust 3		Alveolar (respirable) dust 3
Hungary	1		1	
Italy	1	3	1	3
Japan				
Poland	2	respirable dust 1 Total dust 4	2	respirable dust 1 Total dust 4
Spain	1			
Sweden	1		1	
Switzerland	0.5		0.5	
The Netherlands	2			
USA	1	Respirable 5	1	Respirable 5
		Inhalable 10	I	Inhalable 10
United Kingdom	2	**inhalable dust** **5**	2	**inhalable dust** **5**

Sources: http://bgia-online.hvbg.de/LIMITVALUE/WebForm_ueliste.aspx and http://bgia-online.hvbg.de/LIMITVALUE/WebForm_ueliste.aspx
http://www.ser.nl/nl/grenswaarden/minerale%20wolvezels%20waaronder%20glaswol%20%20steenwol%20en%20superfijne%20glasvezels%20%20spf.aspx

Note [1] Denmark sets a short term limit of 2 fibres/ml, in addition to the 8 hour limit.

3.2.3 Practicality and reliability

Determination of fibre number concentrations involves counting of fibres on samples using standard techniques (e.g. MDHS 59 in the UK, or the WHO fibre counting method). The variation and bias that can that arise in fibre counting are well known. For example, in MDHS 39 dealing with measurement of airborne fibre concentrations, in a section on "Quality Assurance", it is stated that "*Because of the large differences in results within and between laboratories obtained with all manual fibre-counting methods, a good quality assurance procedure is essential. Laboratories using the method must participate in checks to assess interlaboratory variation…*".

By comparison, determinations of mass concentrations can be achieved with greater accuracy and precision. Therefore, measurements of mass concentration have practical advantages for monitoring compliance and effectiveness of control. However it is important to assess if control by mass concentration will always ensure that there is control of fibre number concentration for modern products.

3.3 FIBRE NUMBER AND MASS CONCENTRATIONS

3.3.1 Historical comparisons

Comparisons between fibre number concentrations and mass concentrations are available from a study conducted in the UK by Head and Wagg (1980). Clearly, from the date of publication of their study, their measurements were obtained for insulation products being used prior to 1980, and may be of questionable relevance to modern products. Furthermore, their data consisted partly of measurements on applications of insulation products and partly measurements on manufacturing use of insulating material. The trends in their data suggest that mass concentration limits would be exceeded before the fibre number concentrations, but as noted above this would apply to the products in use at that time, and the trends are based on small numbers of measurements which include the results from industrial activities. The trends in these data are examined further in Appendix 1.

If their results still hold, then mass concentration limits would be exceeded before the exposure limit defined as a fibre number concentration.

4 STRENGTHS AND WEAKNESSES OF THE NAIMA OCCUPATIONAL EXPOSURE DATABASE FOR SYNTHETIC VITREOUS FIBRES

4.1 NAIMA DATABASE

4.1.1 Overview

Reviewing the strengths and weakness of the NAIMA database helps identify key issues in collecting data, and shows what appears to be lacking in the NAIMA database for fulfilling MIMA's requirements.

The NAIMA database contains fibre number concentrations for a wide range of tasks, based on large amounts of data, but it does not contain mass concentration data which relates to one of the important objectives for this study.

The tasks are described only by a brief title, so it is not possible to assess how the listed (mean and range) concentrations may be affected by the circumstances of the exposures. This makes it harder to assess how the NAIMA data (for fibre number concentration) compare with the situation in the UK.

The general picture is that most tasks are associated with low 4-hour time-weighted average fibre number concentrations. However, there is not enough information to help the user to understand and interpret the significance of the range of concentrations for some tasks.

4.1.2 Background to the NAIMA data base

The background to the development of the NAIMA database - as explained by Marchant *et al* (2002) - and a summary of their view of the advantages to be gained from establishing and maintaining a database of exposure concentrations are summarised in Appendix 2.

This Chapter includes several quotes from Marchant *et al,* as they address many of the key issues relating to a database of this type. In the quotes, their references are still shown as numerical codes that refer to their reference list. **Bold font** has been **added for emphasis** of key points in their statements. Additional extracts to describe the background of the NAIMA database are contained in Appendix 2, for reference.

4.1.3 Marchant *et al*'s review (2002) of published data

Marchant *et al* (2002) briefly reviewed existing SVF exposure, before coming to the conclusion that there was a need for an updated resource of information. They commented on some of the issues of methodological differences in measurement techniques and the adequacy of information.

> *"The* ***published data, however, suffer from several important limitations****.* ***Many of the published data are relatively old, in many cases collected in the 1960s, 1970s, or 1980s, and therefore may not be representative of current industry exposure levels****. Some of the older studies also use outdated or modified sampling and fiber counting methods. In addition, the methodologies used in the various published studies are often inconsistent, limiting the ability to compare or combine data between studies. The sampling times in many of the earlier published studies are relatively short or not reported, and thus may not be representative of full-shift exposure. In several of the*

published studies, relevant information is missing from the published reports, including in some cases the number of samples collected and full specification of the sampling and analytical procedures."

The duration of sampling is a very important point and may reflect substantial differences in the objectives of the measurements and will lead to major differences in values obtained. Our literature review (e.g. in Section 5.4) describes results from studies where the objective was clearly to measure the concentration during specific tasks, but where the durations of sampling were generally not stated, so the data do not lend themselves to deriving time-weighted average concentrations for a standardised sampling period. By contrast, **the data in the NAIMA database are all for a time-weighted average concentration for 8 hour shifts based on a set sampling period of 240 minutes (i.e. 4-hours)**. This could explain why data from previous studies, apparently for the same task, can give very different values to those in the NAIMA database. For example, if a task of say installation in an attic involves some split between tasks that are the core "installation" and liable to be dusty and some tasks that are preparatory (bringing materials and equipment to the attic) that are not likely to be dusty, then the time weighted average over a 240 minute sample may represent an average over a mixture of these components. Both measurements are informative, but in different ways. Some variation in 240-minute samples may arise from the differences between sites in how long the dusty part of the task would take (e.g. insulating a very large attic area compared to insulating a modest attic area).

The comment about **differences in methodologies is also importan**t. In the literature review in the next chapter, we quote an example of comparison between NIOSH 7400A and NIOSH 7400B (Breysse *et al,* 2001) which shows an average difference of 70% between those two methods, for a particular set of samples. The same source shows a 27% difference between NIOSH 7400B and the WHO method which both report as "respirable fibres". As explained in the next chapter, the differences are dependent on the bivariate size distribution of the fibres and will therefore vary according to the characteristics of the fibres being sampled.

Marchant *et al* concluded their review of the published data by stating that:

> *"Perhaps most importantly,* ***the published exposure data do not adequately cover the full range of product types and job descriptions****. In some cases, the data are aggregated over many product types or job functions, making it difficult to predict exposure levels for specific job/product scenarios. For other products or job functions, published data are limited or nonexistent. For example, while a substantial body of exposure data has been published for manufacturing operations, the* ***available published data for many installation activities are limited.***

Marchant *et al* also noted that *The National Research Council (NRC), in a recent scientific review of SVFs, had "****recommended that additional published occupational exposure data were needed for workers handling these fibers in non-manufacturing sectors (i.e., installation job functions****))"*

4.1.4 Description of the NAIMA database and an assessment of its value to this project

From the Marchant *et al* publication of 2002, it is clear that:

- the NAIMA database comprises data collected by individual companies;
- the data includes more than 6,000 time-weighted average concentrations (for fibre number);

- one purpose was to verify that exposures are low during tasks that have traditionally been regarded as low exposures;
- another purpose was to assess exposure concentrations with new products; and
- the database was intended to provide representative concentrations to installation contractors and other industrial users for specific job functions and product type.

They considered that "***Most job functions and products are generally narrowly defined and standardized, producing relatively consistent exposure levels over time and between sites for the same product type and job function.***"

The NAIMA database was described as enhancing health and safety while at the same time reducing compliance burdens for small contractors.

The NAIMA database is geared towards assessing average exposure for contractors, i.e. it helps assess the "typical" average 8 hour time weighted average exposure for professional installers. Consequently, one of the limitations of the database in our view is that it does not contain the information that would be needed to help a user to assess when concentrations near the upper end of the range may occur for nominally the same task.

The other limitations are that it does not contain mass concentrations, and it does not let the user make allowance for differences in circumstances for specific sites.

4.2 DATA AVAILABLE FROM THE NAIMA WEBSITE

We were provided with an example of a data sheet that originated from the NAIMA website, "*INSULATION FACTS 59: Exposure Data For Fiber Glass, Rock Wool & Slag Wool Under The Health and Safety Partnership Program*". We downloaded a more recent version from the NAIMA website, "*INSULATION FACTS 78 Exposure Data For Fiber Glass, Rock Wool & Slag Wool*" (PUBLICATION. NO. NO62 8/07).

The more recent version contains similar information but with some values revised, presumably as the database has been updated. We note that there was not an obvious guide to draw a reader's attention to changes that had occurred from the previous version (or versions). That may have been because that although some changes were large in percentage terms (e.g. a doubling), the revised figure was still well below the US voluntary *"permissible exposure limit (PEL)*" of 1 fibre/ml.

The values for mean concentrations, from the more recent NAIMA sheet 78, are listed below in Table 4.1. These can be seen to be substantially lower than some of the values in the historical literature (e.g. Head and Wagg, 1980).

Table 4.1 Mean Concentrations from the NAIMA fact sheet 78. Time weighted average concentrations for samples taken for durations of 240 minutes or longer, for FIBRE GLASS and then for ROCK and SLAG WOOL. The highlighted rows pick out the small proportion of cases for which concentrations exceed 0.2 fibres/ml, and only two values relating to end users (underlined) exceed 0.5 fibres/ml.

Product Description	Time-Weighted Average (TWA)* Exposure Levels (f/ml)** Mean (Average)
Fiber Glass	
Acoustical Panel[4]	
Cutting/Sawing with Power Tools	0.06
Handling	0.02
Aircraft Insulation[4]	
Cutting/Sawing with Power Tools	0.11
Fabrication/Assembly	0.14
Appliance Insulation[4]	
Fabrication	0.12
Installation	0.07
Automotive Insulation[4]	
Fabrication/Assembly	0.03
Installation	0.01
Batts/Blankets[1,4]	
Lamination	0.04
Installation	0.13
Cutting/Sawing	0.17
Blowing Wool With Binder [1,4,6]	
Installation	0.26
Blowing Wool - Without Binder [1,4,5,6]	
<u>Installation</u>	<u>0.83</u>
Cavity Fill Insulation[4]	
Installation	0.21
Flex Duct[4]	
Installation/Assembly	0.01
Fiber Glass Mat[4]	
Forming	0.01
Fiber Glass Residential[3,4]	
Removal	0.4
<u>Compressed Air Cleanup</u>	<u>0.56</u>
Filtration Products[4]	
Fabrication	0.52
Duct Board[1,3,4]	
Fabrication	0.1
Installation	0.02
Handling	0.01
Cutting/Sawing with Power Tools	0.06
Duct Liner[1,4]	
Fabrication	0.06
Installation	0.09

Product Description	Time-Weighted Average (TWA)* Exposure Levels (f/ml)** Mean (Average)
Duct Wrap[1]	
Installation	0.35
Industrial Board/Blanket[3,4]	
Fabrication/Installation	0.05
Removal	0.44
Cutting/Sawing with Power Tools	0.07
Pipe Insulation[3,4]	
Installation	0.04
Removal	0.04
Metal Building Insulation	
Installation	0.1
Miscellaneous[1,4]	
Fabrication with Hand-Held Power Cutting Tools	0.32
Manufacturing	0.05
Rock and Slag Wool Batts/Blankets[1,2]	
Installation	0.09
High Density Batts[2]	
Installation	0.09
Blowing Wool With Binder [1,3]	
Installation	0.34
Cavity Fill Insulation [1,4]	
Installation	0.11
Ceiling Tiles[1,2]	
Installation	0.23
Industrial Board/Blanket[1,4]	
Removal 0.07	0.07
Mobile Home Insulation[4]	
Installation	0.13
Cutting/Sawing	0.12
Lamination	0.03
Pipe Insulation[2,3]	
Installation	0.02
Safing[2]	
Installation	0.1
Spray-On Fire Proofing[2]	
Installation	0.09
Feeding	0.05
Manufacturing[4]	
Bulk	0.07
Commercial & Industrial	0.07
Ceiling Panels & Tiles	0.2
Filtration	0.21
Spray-On Fire Proofing	0.2
High-Density Board	0.06
Pipe Insulation	0.03

Product Description	Time-Weighted Average (TWA)* Exposure Levels (f/ml)** Mean (Average)
Rock and Slag Residential[3]	
Removal	0.13
Miscellaneous[1,4]	
Fabrication with Hand-Held Power Cutting Tools	0.15

NOTES
* Sample Duration of 240 Minutes or Longer.
** As Evaluated by the NIOSH 7400 "B" Sampling and Analytical Methodology.

[1] Johns Hopkins University Study
[2] Rock and Slag Wool Installers Study
[3] Fluor Daniel Study of Worker Exposures during Removal of SVF
[4] NAIMA Member Company Studies
[5] Insulation Contractors Association of America Installers Study
[6] NAIMA/Clayton Study

4.2.1 Summary of activities with typical concentrations above 0.2 fibres/ml

From the highlighted lines in the Table of data from NAIMA, it appears that the end user activities associated with typical 8 hour time-weighted-average concentrations greater than 0.2 fibres/ml are:

- Blowing wool without binder, about 0.8 fibres/ml;
- Blowing wool with binder, about 0.3 fibres/ml;
- Removal of board or blanket, about 0.4 fibres/ml;
- Compressed air cleanup after removal, about 0.6 fibres/ml;
- Duct wrap, about 0.35 fibres/ml;
- Power tools, about 0.35 fibres/ml;
- Ceiling tiles, installation about 0.25 fibres/ml;
- Cavity wall fill insulation, about 0.2 fibres/ml.

(Note, concentration values reported here are rounded to the nearest 0.05 fibres/ml.)

All the other tasks showed geometric mean time weighted 8-hour concentrations that did not exceed 0.2 fibres/ml. In particular, this includes installing blankets or batts.

4.3 DATA AS PUBLISHED BY MARCHANT AND COLLEAGUES

4.3.1 Variation within results

The fact sheets downloadable from the NAIMA web site provided mean concentrations for the range of tasks as listed in Table 4.1 above. However, it is also important to consider the spread in concentrations that arise for particular tasks. The paper by Marchant *et al* (2002) included the standard deviation, the median and the range of concentrations. They commented on the summary statistics used in their paper. They stated that their data were presented

> "*using the following summary statistics: arithmetic mean, standard deviation (S.D.), median, and range (i.e., minimum and maximum). As is common for many occupational exposures, the SVF occupational exposure data reported here are highly skewed, with the vast majority of measurements well below 1 f/cc,* ***but with occasional data points significantly higher****. With such data sets*

that appear to be lognormally distributed, the EPA recommends presentation of both the arithmetic mean and either the median or the geometric mean.[(32)] *The median and geometric mean are typically nearly equal for such distributions, and are substantially lower than the arithmetic mean. Accordingly, both the arithmetic mean and median are presented in the exposure data tables below*."

Data for installation activities from Marchant *et al* have been extracted and they are summarised in the Tables 4.2 and 4.3 below. It is noteworthy that the ranges (from minimum to maximum values recorded) are much larger for some product types or activity. For example, the data for blowing wool without a binder shows a very wide range (0.01 to 7.49 fibres/ml). The wide range for blowing wool without binder may be partly due to the fact that the large number of samples (133) makes it more likely that outliers would be encountered. Conversely, however, a task with very variable concentrations (as shown by the standard deviation) is where a high number of samples should be taken, so the number of samples may indicate that this approach was adopted.

Table 4.2 Data from Marchant *et al* (2002), their Table III, "*Glass wool installation: Glass wool fiber exposures by product type*" (Only installation activities are quoted here). Activities with mean concentrations above 0.2 fibres/ml are highlighted.

Product type	**Number of samples**	**Exposure (fibres/ml)**			
		Mean	**Standard deviation**	**median**	**range**
Blowing wool with binder	10	0.30	0.30	0.24	0.04-1.13
Blowing wool without binder	133	0.79	1.02	0.50	0.01-7.49
Cavity loose fill insulation	12	0.15	0.12	0.11	0.04-0.47
Pipe insulation	28	0.05	0.05	0.03	0.01-0.19
Insulation batts & blankets	62	0.17	0.10	0.16	0.01-0.46
Other	25	0.05	0.04	0.02	0.01-0.16

Data for Mineral wool installation from Marchant *et al* are shown in Table 4.3 below. In this case, the maximum values for the ranges are all less than 1 fibre/cc.

Table 4.3 Data for mineral wool installation from Marchant et al (2002), their Table IV "*Mineral wool manufacturing and installation: Mineral wool fiber exposures by product type*". Activities with mean concentrations above 0.2 fibres/ml are highlighted.

Product type	Number of samples	Exposure (fibres/ml)			
		Mean	Standard deviation	Median	Range
Installation					
Ceiling panel/tile	33	0.23	0.21	0.17	0.02-0.82
Spray-on fireproofing	15	0.08	0.10	0.05	0.02-0.42
Insulation batt & blanket	12	0.09	0.04	0.08	0.04-0.16
Other installation [A1]	14	0.11	0.11	0.06	0.02-0.40

[A1]-Includes air handling board, appliance insulation, blowing wool with binder, cavity loose fill insulation, pipe insulation, and blanket and board.

In Tables 4.4, it is apparent that the maximum values of the ranges extend to relatively high values for some jobs, such as *installer* (top of range =7.49 fibres/ml) and **feeder** (top of range =2.18 fibres/ml). These ranges are for large numbers of samples (respectively, 232 and 63 samples for these two cases). Maximum values from ranges can be a poor guide to the typical variation, as the more samples are collected the more chance of an anomalously high value being obtained. Therefore, there would be value in considering the best ways to derive a more robust statistic that will be more stable as the number of samples increases, e.g. a 95th percentile, as recognised by Marchant et al their 2009 publication (discussed later in Section 4.3.2 of this report).

Table 4.4 Data from Marchant et al (2002), their Tables VII and VIII "*Glass wool installation and end-users: Glass wool fiber exposures by job description*". Activities with mean concentrations above 0.2 fibres/ml are highlighted.

	No samples	Exposure (fibres/ml)			
		Mean	S.D.	Median	Range
Glass Wool installation and end users					
Assembly	34	0.04	0.06	0.02	0.01–0.35
Feeder	63	0.36	0.37	0.20	0.01–2.18
Installer	232	0.45	0.85	0.18	0.01–7.49
Other[1]	9	0.16	0.14	0.07	0.03–0.37
Mineral wool installation:					
Installers	65	0.16	0.17	0.10	0.02–0.82
Other installation[2]	9	0.09	0.12	0.05	0.02–0.40

[1] Includes cutting/sawing with power tools and maintenance.
[2] Includes assembly, cutting/sawing with power tools, vehicle driver production, warehousing, feeder, and general labourer.

Marchant et al (2002) summarised their findings by stating that:

> "*All job categories in the glass wool and mineral wool installation sectors have* ***arithmetic mean exposure levels below 0.50 f/cc****, with* ***median exposures at or below 0.20 f/cc****".*
>
> *"No TWA measurements above 1 f/cc have been recorded in the database for mineral wool*

installation, whereas both the feeder and installer categories for glass wool installation include TWA measurements above 1.0 f/cc."

Their detailed results for installation of glass wool insulation and mineral wool insulation (Tables 4.2 to 4.4 above) show that the majority of individual measurements were below 2 fibres/ml. The maximum value of the range exceeds 2 fibres/ml for two of the job descriptions (Glass wool feeder and installer), but that is based on very large numbers of samples and the mean and standard deviation indicate that more than about 95% of samples had respirable fibre concentrations below 2 fibres/ml.

4.3.2 The 2009 update by Marchant and colleagues

Marchant and colleagues (Marchant et al, 2009) have recently updated the information on the NAIMA data base. This recent publication shows 95th percentiles rather than just simple ranges. Table 4.5 below (from their Table 1) shows the aggregate exposure levels and the 95th percentiles for the fibre concentrations, by industry sector. They comment that "*The 95th percentile highest exposures are well below the voluntary 1 fibre/cm^3 voluntary PEL, with the single exception of glass wool installation.*"

Table 4.5 The aggregate Synthetic Vitreous Fibre (SVF) exposures levels by industry sector in the US, as reported by Marchant *et al* (2009).
The values for the installation sector are highlighted.

Industry	Sector	N	Exposure (fibres/ml)			Percent <LOD (%)
			Mean	Median	95%	
glass wool	Primary manufacturing	1565	0.06	0.02	0.20	*17.3*
	Secondary manufacturing	403	0.03	0.02	0.10	*19.9*
	Fabrication	336	0.16	0.05	0.60	*7.7*
	Installation	596	0.39	0.19	1.30	*6.0*
	Retrofit/removal	6	0.26	0.21	0.63	*16.7*
	All glass wool	2915	0.13	0.03	0.61	*14.3*
rock/slag wool	Primary manufacturing	511	0.18	0.11	0.54	*0.8*
	Secondary manufacturing	25	0.03	0.03	0.05	*8.0*
	Fabrication	5	0.15	0.20	0.24	*0.0*
	Installation	133	0.17	0.10	0.58	*0.0*
	Retrofit/removal	2	0.10	0.10	0.11	*0.0*
	All rock/slag wool	676	0.17	0.10	0.55	0.9
	Total	***3591***	***0.14***	***0.10***	***0.55***	***11.8***

5 LITERATURE REVIEW

5.1 INTRODUCTION

The literature review described in this chapter describes data on exposure to mineral wool and glass wool during installation and removal processes from 17 documents. Data has been summarised taking into account the specific material used, activities of the individuals under exposure, and the methods used for measurement.

Most of the reviewed studies included in the IARC monograph on MMMF were conducted in the 1980s and 1990s and therefore cannot be assumed to represent current exposures. Furthermore, studies from the 1980s did not provide the duration of every task (e.g. Head and Wagg 1981) and some studies did not distinguish between fibre types (e.g. Hallin, 1981, Schneider, 1984). Three studies from the UK, two conducted in the 1980's (Head and Wagg, 1981, Dodgson *et al* 1987) and one conducted in the 1980s (Jaffrey *et al (1989)*, were identified. Two exposure databases, NAIMA and COLCHIC developed in the USA and France respectively provide relatively recent information on exposure data.

A summary of the exposure data is shown in Table 5.1.

5.2 LITERATURE SEARCH METHODOLOGY

Information on exposure data prior to 2002 was retrieved from the IARC monograph of MMVF (IARC, 2002).

A systematic search of the electronic databases PubMed, British Online Library (BOL), and Highwire Press (Stanford University) was undertaken to identify studies on exposure to mineral wool from 2003. The search terms were mineral wool/ fibrous/fibre insulation material/MMMF and exposure.

Searches were undertaken of the APPA EURIMA Man-Made Mineral Fibres and Organic Fibres Database using a range of relevant terms. These terms included: Mineral wool; Machine made mineral fibres; Man made mineral fibres (fibers); MMMF; Glass fibres, Glass Fibers; Synthetic vitreous fibre; SVF; Rock wool; Slag wool; Man-made vitreous fibres, MMVF; Synthetic mineral fibres; fibre glass / fiber glass.

The searches were undertaken in two stages:

- These terms were entered as search terms in the general search box for the full text of the database to ensure that all potentially relevant references were retrieved. The resulting list was then manually checked to identify relevant references. The database did not provide the facility to exclude less relevant references.

- The same search terms were then entered in the *extended search facility* of the database, as title and keyword searches, to highlight especially relevant articles. The results were then manually scanned for relevance.

Over one thousand references were retrieved in several searches, and some overlap in the references was identified in the results.

Attention was paid to the differences between UK and American spellings and both “fibre” and “fiber” were entered as search terms. It was not possible to refine the searches and thereby reduce the number of references by adding ‘AND’ exposure or ‘NOT epidemiology’ to the search terms. It should also be noted that not all the search terms we used appeared as keywords in the database (e.g. SVF, MMMF, MMVF were not available as key words in the database).

5.3 MEASUREMENT CHARACTERISTICS

Several factors need to be considered when comparing results from different studies.

Mass and number
Until the late 1960’s, exposure data on mineral fibres was reported in mass per unit volume of air, because that met the regulatory requirements. However, evaluation of the exposure data showed that the concentrations in terms of number of fibres for a unit mass concentration can be very variable depending on the diameter of the fibres (IARC, 2002).

Sampling period and type
The length of the sampling period (i.e. full-shift or short-term) as well as the sample type (i.e. personal or area) are important. The published data includes all these types of samples.

Microscopes
The most common methods for fibre quantification are Phase Contrast Optical Microscopy (PCOM) and Scanning Electron Microscopy (SEM). If the average fibre diameter is > 1 µm, then PCOM and SEM should give comparable results. However, if the average fibre diameter is less than1 µm, then SEM is likely to provide more accurate results (TIMA, 1993).

Counting methods
The most common counting methods used are those described by WHO (1996) and NIOSH 7400B (NIOSH, 1994).

- WHO (1996) defined a countable fibre as any particle that has a length > 5 µm, a length: width aspect ratio greater than or equal to **3:1** and a fibre diameter < 3 µm.

- NIOSH 7400B method defined a fibre as any particle that has a length > 5 µm, a length: width aspect ratio greater than or equal to **5:1** and a diameter < 3 µm (NIOSH, 1994). NIOSH 7400B has been accepted by government agencies in USA (OSHA, 1992) for measuring ambient concentrations of vitreous fibres. The NIOSH 7400B method differs from the above WHO method in the specification of the minimum aspect ratio, 5:1 (for NIOSH 7400B) compared to 3:1 (for WHO).

- Other methods generally used in the USA until the 1980s include the NIOSH 7400A method and its predecessor P&CAM (Physical Chemical analytical Method). The NIOSH 7400A method defined fibres as those particles with a ratio length: width of at least 3:1 and no upper diameter bound.

The NIOSH 7400B gives lower fibre concentration than the NIOSH 7400A method because some fibres are excluded, by either the upper diameter bound (in 7400B) or the higher aspect ratio (5:1) required in 7400B. The difference in concentration measurements depends on the bivariate fibre size distribution (Breysse et al., 1999). For samples of airborne glass and rock (stone) wool fibres, the NIOSH 7400A gave approximately 70% higher results than the NIOSH

7400B (Breysse et al., 1999). However, the difference between methods was only about 8% for fibres measured during insulation by blowing loose wool, without binder.

Due to the difference in the aspect ratio requirements, the WHO (1996) method gives higher results than the NIOSH 7400B method. Breysse et al. (1994) reported fibre densities on average 27% lower with the NIOSH 7400B than with the WHO method for counting the same set of pre-mounted slides. (Where counts on the same slides are compared, it is appropriate to compare the results in terms of the densities of fibres on the mounted samples, without converting the results to concentrations in air. However, higher densities on the slides obviously generally correspond to higher values for concentrations in air.)

Where concentrations were measured by very different methods, e.g. by Fowler et al (1971), the data are of limited value and only the overall summary value is quoted later.

Table 5.1 Fibre counting methods used by the sources of data that are summarised in this chapter. As described above, respirable fibre concentrations measured by the NIOSH 7400B method may be about 30% lower than respirable fibre concentrations measured by the WHO method. Measurements of respirable fibre concentrations concentrations from the USA are generally by the NIOSH 7400 B method.

Reference	Fibre counting method Average as GM (geometric mean) or AM (arithmetic mean)
Marchant et al 2002 and 2009, (USA)	NIOSH 7400B for 90% of the samples, other methods for the other 10% (the older data)
Verma (2004) (Canada)	WHO 1985 method
Breum et al. 2003 (Denmark)	WHO 1996
Breysse et al 2001 (USA	NIOSH 7400B PCOM (respirable fibres)
Yeung and Rogers 1996 Australia	Various
Koening & Axten 1995 (USA)	NIOSH 7400B PCOM respirable fibres
Lees et al. 1993 (USA)	PCOM respirable, AM
Julier et al. 1993 (Germany)	GM
Jacob et al. 1992 (USA)	Total: NIOSH 7400 Respirable NIOSH 7400 B
Perrault et al. 1992	WHO (1985) PCOM respirable fibres
Dodgson et al (1987), (UK)	WHO/EURO (1985) PCOM respirable fibres
Schneider (1984) (Denmark)	PCOM respirable
Esmen et al. 1982 (USA)	PCOM, Total fibre AM Respirable AM
Hallin, 1981 (Sweden)	Respirable GM
Head & Wagg, 1980 (UK)	<3µm diameter & > 5µm long. GM PCOM
Fowler et al. 1971 (USA)	PCOM, AM (total fibres only), Porton Graticule (i.e. not the Walton and Beckett graticule used in subsequent methods)

Means - geometric or arithmetic

The measurement statistic used to describe the data is also significant when interpreting the results. Arithmetic means (AM) or medians with standard deviations and sample ranges have been reported in some studies while geometric means (GM) with geometric standard deviations (GSD) were given in others.

Airborne fibre concentrations are better described by a log-normal than a normal distribution (Leidel *et a*l., 1977) and therefore geometric means are the preferred method of expressing the central tendency for log-normally distributed data sets. In practical terms, values for AM are generally higher than the corresponding GM due to the greater weight given to high values in an arithmetic mean compared to the geometric mean. The difference is greater if there are some outlying high values. For example, a simple illustration of averaging for three measurements shows when this may be important. For a set with values in a "narrow range" such as 1, 2, 3, the GM and AM are similar at respectively, 1.82 and 2. For a set such as 1, 2, 6, the GM and AM are less similar at respectively 2.3 and 3.

The cumulative exposure over the course of the year would be represented by the arithmetic mean (time-weighted) average concentration, not the geometric mean.

5.4 EXPOSURE DURING INSTALLATION PROCESSES

Summaries of published measurements airborne fibre concentration and dust concentration are given in Table 5.2.

These publications describe measurements of airborne concentrations during the use of glass wool and mineral wool products. The products include batts, rolls, loose insulation, cubes and milled insulation. There are some reports of concentrations from using materials without binders. The measurements were made in commercial and domestic properties.

Most papers were published before 2000. The National Toxicology Programme in the US recently published a document entitled "Final Report on carcinogens - background document on for Glass Wool Fibres" (U.S. Department of Health and Human Services, 2009) and this found a similar paucity of recent publications with data on concentrations. Nevertheless, it is apparent that concentrations have reduced in recent times. For example, in France, exposure concentrations to MMMF during cleaning and repair processes dropped from 0.34 fibres/ml in the period 1986-1996 to 0.048 fibres/ml in 1996-2004 (geometric mean values) (Kauffer and Vincent, 2007).

A large data base (not included in Table 5.2) has been developed In France by the Institut National de Recherche et de Sécurité National (National Institute for Research and Safety, INRS) with (COLCHIC). It contains data on exposure to asbestos fibres, ceramic fibres and MMMF other than ceramic fibres (http://www.inrs.fr/htm/fibrex.html). Data is expressed in number of fibres measured by PCOM and counted following the WHO method. Exposure information dates back to 1986. Data has been collected from French companies by the Caisses Régionales d'Assurance Maladie (regional health insurance funds, CRAM). The activity sector coding system is based on the French activity nomenclature.

The contents of the database (http://www.inrs.fr/htm/fibrex.html). have been described by Kauffer and Vincent (2007). There are concentrations for industry sectors, e.g. Kauffer and Vincent list results for periods 1986 to 1996 and from 1997 to 2004 in their Tables 9 and 10. For the Construction sector they have 34 and 43 samples of MMMF for these two periods respectively. Downloading data from the online database for the period, showed that (at the time of writing) there are 88 samples for glass fibres for the period 1986 to 2010. The database provides plots showing annual mean and annual median concentrations over the 22 year period, but this needs to be treated with care because the numbers of samples in some years are so low that the trends can be misleading (e.g. 1 sample in 2002 gives a high mean).

Measurements have been undertaken by Jaffrey of the Health and Safety Laboratory in the UK. Jaffrey (1990) reported concentrations in dwellings during installation of mineral wool blanket in attic spaces. He reported "*the details of airborne levels of man-made mineral fibres (MMMF) found during installation of loft insulation in 12 dwellings. About 250 samples of air were collected and analyzed by transmission electron microscopy (TEM)*". The main findings were:

> *Respirable fibre levels measured in static samples collected in the lofts during installation generally were < 0.1 f.ml^{-1}.*
>
> *Personal samples on the installers gave < 1 f.ml^{-1}, with the exception of a fine glass fibre blanket.*
>
> *In living spaces respirable fibre levels were< 0.006 f ml^{-1}.*
>
> *A few selected samples were also analyzed by phase contrast optical microscopy (PCOM) which showed lower values than those recorded by TEM.*
>
> *Static gravimetric concentrations in the lofts were in the 0.3–6.5 mg.m^{-3} range, and in the living spaces 0.11–0.44 mg.m^{-3}, but in both environments most of this dust was not MMMF.*

Results from this study were also reported by Jaffrey et al (1989), who listed the concentrations measured as personal samples on the installer of a range of products. The concentrations for the installer and in the attic reported by Jaffrey et al (1989) are listed below in Table 5.2.

Table 5.2 Concentrations measured in the UK during installation of mineral wool insulation Jaffrey et al (1989). The foot note comments on the one high concentration.

Site	Product	Respirable fibre concentration fibres/ml	
		Personal, installer	Loft
1	stone wool loose lay	0.41	0.02
2	stone wool blanket	0.20	0.024
3	stone wool blanket	0.085	0.04
4	glass fibre blanket	0.18	0.06
5	glass fibre blanket	0.25	0.005
6	glass fibre blanket	1.77†	0.15
7	stone wool blown	0.50	0.032
8	stone wool blown	0.55	0.029
9	glass wool blown	0.67	0.053
10	glass wool blown	0.50	0.74
11	glass wool blown	0.16	-
12	glass wool blown	0.15	<0.0002

Notes

†The personal samples were obtained from samples of 30 minutes duration, except that the high concentration of 1.77 fibres/ml was described as being from sampling for 5 and 10 minutes.

The average concentration for the personal samples was 0.45 fibres/ml

5.5 RESPIRABLE FIBRE CONCENTRATIONS FOR SPECIFIC ACTIVITIES

5.5.1 MMVF exposures in Construction workers in Ontario

Verma et al (2004) reported on MMVF respirable fibre concentrations measured for work with MMMF products in the construction industry in Ontario.

They explained that work practices in Ontario determine which trade or occupation may be engaged in the installation work. The allocation of insulation work to specific trades may be different in the UK.

From their results (their Table II), we have selected those which cover the principal tasks directly involved with the MMMF installation and they are shown below in Table 5.3.

Verma *el al* concluded, *inter alia*, that:

> *"Based on this data set and our observations, it appears that full-shift occupational exposure to MMMF (excluding RCF) in Ontario is generally below the ACGIH TLV-TWA of 1 fibres/cc* (=1 fibre/ml) *and therefore should not present a significant hazard."*
>
> *"The actual exposure received by workers to MMMF including RCF would likely be lower than the measured concentration due to respirator usage."*
>
> *"The bystanders and other trades not directly involved, but in the vicinity of MMMF operations, generally have minimal exposure and therefore should not be of concern."*
>
> *"Both respirable and non-respirable fibres determined by the WHO method should be routinely measured since the method provides added information on total airborne fibres that is relevant from a skin and eye irritation hazard point-of-view."*

Table 5.3 Exposures associated with MMMF installation work in construction in Ontario from Verma *et al*

MMMF category	Major tasks	samples	Sample duration minutes		Respirable fibre concentration Fibres/ml		
		No, Type	min	Max	mean	min	max
Batt	installation	2, P[1]	47	59	0.12	0.06	0.18
	installation	7, P	41	97	0.19	LD[2]	0.59
	installation	1, A		83		LD	
	Installing, cutting handling	9, P	70	98	0.29	0.13	0.64
Blown	blowing	5, P	14	27	0.66	0.46	0.95
Ceiling tiles, labourer	cleaning	1,P		15			1.75
	helping	3,P	18	42	0.49	0.25	0.93
	removing	3,P	16	28	0.78	0.4	1.25
Duct wrap	Cutting, wrapping, pinning	9	12	167	- [3]	LD	0.07
Pipe wrap	wrapping	1, P		66			0.06
Sprayed fireproof	spraying	4, P	10	18	0.68	0.35	1.08
	Labourer assisting	7, P	25	73	-	0.11	0.36

Notes:
1 Sample type = P for Personal or A for Area
2 LD = Less than Detection limit
3 Mean not given where several data for similar activities is combined to show the overall range

5.6 EXPOSURE FROM SIMULATIONS

5.6.1 Full scale simulations

Simulations have the advantage that key factors can be controlled. Breum *et al* (2003), in Denmark, used a full scale simulation of a single storey house to measure dust release during insulation of an attic space and cavity walls. The simulation was contained in a large building and the tests were conducted under conditions that were more constant than in real life.

Breum (2003) concluded that a dust level of 6.1 $mg.m^{-3}$ was a useful proxy for screening exposure to WHO fibres in excess of 1 fibre/ml. They reported that exposure to WHO fibres were correlated with exposure to inhalable dust.

They also reported that for installers in attic spaces, risk of exposure was low for inhalation of dust and WHO fibres from slab materials of mineral wool or fibreglass. By contrast, they found that slab materials made from flax may cause high risk of exposure to endotoxin.

Their measurements of fibre number and dust mass concentrations are included in the measurements summarised in Table 5.4.

5.6.2 Small scale tests

Tests of dustiness can be a useful indicator of the relative dust release to be expected from different products. Breum *et al* (2003) included some laboratory tests of dustiness of products and reported that slabs of mineral wool and glass wool were of low dustiness (compared to other insulation products, e.g. organic fibre products). The approach is worthy of note but is not discussed further in this report.

5.7 EXPOSURE DURING REMOVAL PROCESSES

The literature with data for exposure to mineral wool during removal operations was scarcer than that found for installation processes.

- The mean of personal concentration of WHO fibres during disassembly of mineral wool insulation material at industrial sites in the European chemical industry and shipyards ranged from 0.05-0.77 fibre/ml with a mean value of 0.32 fibre/ml (Julier *et al*., 1993).
- In power plants, the concentration of inorganic fibres (excluding asbestos and gypsum) from personal measurements during disassembly of thermal insulation material was found to be between 0.21 and 0.99 fibre/ml (Böckler *et al*., 1995).
- Yeung and Rogers (1996) in a survey of exposure during installation and removal of mineral wool in Australia reported personal concentration of rock/slag wool during removal processes below 0.5 fibres/ml.

5.8 SITE CONDITIONS

Perrault *et al* (1992) comment that their measured concentrations were affected by both the nature of the materials and the confinement of the work sites. However, they noted that their "limited study" did not attempt to differentiate the contribution of product, type of application and natural ventilation conditions although they wrote that some of their results (e.g. for blown stone wool in an attic) are "*typical examples of the plausible effect of confined spaces on an increase in fibre concentration*".

The approach of Marchant et al (2009, 2002) and the NAIMA database is to take a large body of data as covering the range of conditions that installers will encounter. However, in our view, this does not help users to estimate the effect of the confined conditions where concentrations at the high end of the range will occur.

5.9 SUMMARY OF PUBLISHED CONCENTRATIONS

5.9.1 Regarding fibre number concentrations

The summary of published concentrations in Table 5.4 shows the data in chronological order of publication starting from most recent. A scan down the list therefore gives an impression of how concentrations have changed over time. However, the interpretation of any trends has to take into account that some studies measured 8-hour time-weighted concentrations (or the equivalent) whereas some studies measured concentrations measured over the task duration. In principle, 8-hour time-weighted averages will be lower than task averages because the task concentrations are the values in the periods when exposure takes place. Nevertheless, even with that complication, the trends in Table 5.4 are apparent. The concentrations in the relatively recent studies (Breum et al 2003, Breysse *et al* 2001), are much lower than concentrations reported in the 1990s. The values from Breum *et al* (2003) and Breysse *et al* (2001) for fibre number concentrations are generally consistent with the order of the values reported by Marchant *et al* (2009, 2002).

It is clear that the mass concentrations reported by Breum *et al* (2003) are generally much less than those measured in the 1980s. The mass concentrations reported by Breysse are not as low as those reported by Breum *et al,* but they are also much lower than those reported during the 1980s.

It also appears from the averages and the ranges in the values reported by Breum *et al,* that mass concentrations will exceed the exposure limit of 5 $mg.m^{-3}$ before the fibre number concentration exceeds 2 fibres/ml or even 1 fibre/ml. This comment also applies to the results from Breysse *et al* (2001).

5.9.2 Regarding mass concentrations

The mass concentrations reported by Breum *et al* (2003) were inhalable dust measurements, and therefore the type of measurement that would be directly relevant to the UK mass concentration limit. The mass concentrations measured by Breysse *et al* were Total Dust concentrations.

Table 5.4 Summary of concentrations reported in the published literature

Reference	Application	User	Material /product	Sampling details	Measure of central tendency	Respirable fibre conc mean (range) fibres/ml	Total Fibre Concentration) fibres/ml	Mass concentration $mg.m^{-3}$
Marchant *et al* 2009 and 2002, (USA)	**See Chapter 4**							
Verma *et al* 2004 (Canada)	**See Section 5.5**							**GM, inhalable dust**
Breum *et al.* 2003 (Denmark)	Simulation: **Attic-roll** material	**Installer**	**glass**, **rol**l	Task average	median	0.036 (0.030-0.042)		1.3 (1.0-1.6)
	Simulation: **Attic-**roll material	Helper	glass, roll	Task average	median	0.02 (0.018- 0.022)		1.1 (0.8-1.6)
	Simulation: **Attic-slab** material	**Installer**	glass, **slab**	Task average	GM	0.023 (0.0089-0.058)		0.8 (0.6-1.1)
	Simulation: **Attic-**slab material	Helper	glass, slab	Task average	median	0.024 (0.021-0.027)		0.4 (0.2-0.9)
	Simulation: **Attic**-slab material	**Installer**	**mineral**, slab	Task average	GM	0.016 (0.0078-0.032)		1.8 (0.4-7.0)
	Simulation: **Wall** slab material	**Installer**	**glass**, slab	Task average	GM	0.0057 (0.003-0.011)		0.5 (0.1-2.5)
	Simulation: **Wall** slab material	Helper	glass, slab	Task average	GM	0.0023 (0.000098-0.052)		0.3 (0.1-0.5)
	Simulation: **Wall** slab material	**Installer**	**mineral,** slab	Task average	GM	0.0055 (0.0049-0.015)		0.6 (0.3 -1.3)
								AM, Total Dust
Breysse *et al* 2001 (USA)	Duct board		glass	Task average		0.03 (0.02-0.05)		nm
	Duct liner		glass	Task average		0.32 (0.28-0.42)		nm
	Pipe & vessel insulation		glass	Task average		0.04 (0.01-0.21)		0.4
	batts		glass	Task average		0.19 (0.16-0.26)		7.6
	Ceiling tiles		rock / slag	Task average		0.24 (0.08-0.48)		4.6
	Loose fill		rock / slag	Task average		0.13 (0.06-0.20)		nm

Reference	Application	User	Material /product	Sampling details	Measure of central tendency	Respirable fibre conc mean (range) fibres/ml	Total Fibre Concentration) fibres/ml	Mass concentration mg.m^{-3}
Yeung and Rogers 1996 (Australia)	not specified		glass	not specified		0.06 (0.01-0.8)		nm
	not specified		glass	not specified		0.03 (<0.01-0.2)		nm
Koening & Axten 1995 (USA).	Attic Insulation **(open)**	helper	rock / slag	Task average	AM	0.09 (0.04-0.62)		nm
	Attic Insulation **(confined)**	blower	rock / slag	Task average	AM	0.24(0.02-0.30)		nm
Note: they described areas as either confined,	Attic Insulation **(open)**	helper	rock / slag	Task average	AM	0.05 (0.05-0.13)		nm
or moderately open (m. open);	Attic Insulation **(confined)**	blower	rock / slag	Task average	AM	0.19 (0.02-0.30)		nm
or open	Sound attenuation blanket **m. open**	Cut/place	rock / slag	Task average	AM	0.17 (0.11-0.24)		nm
	outdoor pipe insulation **-open**	Cut, install, cover	rock / slag (pre-formed pipe insulation)	Task average	AM	0.04 (0.02-0.05)		nm
Note: The 8-hour TWA concentrations are shown in Appendix 3	Spray on fire proofing **open**	Nozzle man	rock / slag	Task average	AM	0.3 (0.03-1.1)		nm
	Spray on fire proofing open	labourer	rock / slag	Task average	AM	0.07 (0.01-0.29)		nm
	Spray on fire proofing **Open**	Pump operator	rock / slag	Task average	AM	0.03 (0.01-0.07)		nm

Reference	Application	User	Material /product	Sampling details	Measure of central tendency	Respirable fibre conc mean (range) fibres/ml	Total Fibre Concentration) fibres/ml	Mass concentration mg.m^{-3}
Lees *et al.* 1993 (USA) Note AM values quoted here; Lees *et al* also reported GM.	batts	installer	**glass**	task average	AM	0.14 (0.02-0.41)	0.14 (0.02-0.52)	3.94 (0.06-8.96)
	batts	installer	**mineral wool**	task average	AM	0.17 (0.07-0.39)	0.24 (0.13-0.55)	2.18 (2.11-2.24)
	loose-fill Insulation **with binder**	Installer	glass	task average	AM	0.55 (0.17-2.88)	0.85 (0.18-3.10)	11.1 (0.35-46.3)
	loose-fill Insulation **with binder**	feeder	glass	task average	AM	0.18 (0.06-0.67)	0.26 (0.06-1.01)	2.75 (0.05-12.3)
	loose-fill insulation **without binder**	installer	glass	task average	AM	7.67 (1.32-18.4)	8.13 (1.49-20.7)	12.2 (0.43-46.5)
	loose-fill insulation **without binder**	feeder	glass	task average	AM	1.74 (0.06-9.36)	1.62 (0.06-7.72)	2.49 (0.18-16.9)
	loose		rock / slag	task average		1.94 (0.32-6.16)		12.2 (3.58-24.5)
Jacob *et al.* 1992 (USA)	Installation of batt insulation		glass	not specified		0.042 (0.032-0.052)	0.13 (0.099-0.016)	nm
	Installation of cubed blowing-wool insulation		glass	not specified		0.30 (0.24-0.35)	0.68 (0.60-0.76)	nm
	Installation of milled blowing-wool insulation		glass	not specified		0.82 (0.53-1.3)	1.7 (1.2-2.5)	nm
	Installation of cubed blowing-wool insulation		glass	not specified		0.084 (0.06-0.10)	0.20 (0.17-0.23)	nm

Reference	Application	User	Material /product	Sampling details	Measure of central tendency	Respirable fibre conc mean (range) fibres/ml	Total Fibre Concentration) fibres/ml	Mass concentration mg.m^{-3}
Perrault *et al.* 1992 (Canada)	not specified		glass	Fixed point sampling. 30 mins to 4 hours, adjusted seeking suitable sample density.	GM (GSD)	0.01 (1.9)		nm
	Blown		rock / slag		GM (GSD)	0.32 (1.4)		nm
	Sprayed on					0.15 (1.7)		nm
Jaffrey *et al* *(1989)* *(UK)*	Loft insulation (various see text above)	installer	Glass and mineral wool	Personal, task length average		0.45 (0.09-1.8)		15
Dodgson et al (1987), their Tables 2.1 and 3.1.	Loft insulation, **blown**		glass / rock	not specified, sample volume normally greater than 0.5m^3		1.02 (0.72-1.58)		3.6
	Loft insulation, **slab**		rock, slab			0.30 (0.19-0.37)		3.6
	loft insulation, **roll**		rock, roll			0.84 (0.70-0.97)		0.8
	loft insulation, **roll**		glass, roll			0.93 (0.76-1.10)		9. 8
Schneider (1984) (Denmark)	Attic insulation **old** buildings		NS	not available		not available		26.8
	Attic insulation **new** buildings		NS	not available		0.1		12.6
	Attic insulation: Technical insulation		NS	not available		0.35		7.1

Reference	Application	User	Material /product	Sampling details	Measure of central tendency	Respirable fibre conc mean (range) fibres/ml	Total Fibre Concentration) fibres/ml	Mass concentration mg.m^{-3}
Esmen *et al.* 1982 (USA)	Attic insulation	Roofer	glass	not specified	AM	0.31 (0.07-0.093)	0.37 (0.09-0.95)	4.04 (1.75-26.2)
		Blower	glass	not specified	AM	1.8 (0.67-4.8)	2.8 (0.86-5.8)	11.9 (5.1-20.0)
		feeder	glass	not specified	AM	0.70 (0.06-1.48)	0.75 (0.083-1.5)	9.35 (2.1-22.0)
		Roofer	rock / slag	not specified	AM	0.53 (0.04-2.03)	0.70 (0.078-2.7)	6.12 (2.39-14.0)
		Blower	rock / slag	not specified	AM	4.2 (0.50-14.8)	6.7 (0.62-23)	32.8 (7.65-13.6) – as published
		feeder	rock / slag	not specified	AM	1.4 (0.26-4.4)	1.8 (0.33-0.45) - as published	7.77 (3.33-19.67)
	Acoustical ceiling	installer	NS	not specified	AM	0.003 (0-0.0056)	0.01 (0.002-0.03)	0.91 (0.15-2.08)
Hallin, 1981 (Sweden)	Insulation existing buildings		mineral	Full shift	GM	1.11		GM 11.6 (1.7-21.7)
	Insulation new buildings		mineral	Full shift	GM	0.57		GM 2.63 (05-11.1)
	Technical insulation		mineral	Full shift	GM	0.37		GM 3.14 (0.4-25)
	Acoustical insulation		mineral	Full shift	GM	0.15		GM 1.8 (1.7-1.9)
	Spraying		mineral	Full shift	GM	0.51		GM 13.5 (1.3-43.7)
								<u>Total dust</u>
Head & Wagg, 1980 (UK)	Loft insulation		glass	4-hrs	GM	0.38 (030-0.54)		35 (18.5-90)
					GM	1.02* (0.24-1.76)		36.2 (8.2-71)
	Loft insulation Loose fill		mineral	4-hrs	GM	8.19 (0.54-20.9)		30.9 (5.0-59.7)
	Fire protection structural steel		mineral	4 hrs	GM	0.77 (0.16-2.17)		17.2 (1.9-51.5)

Reference	Application	User	Material /product	Sampling details	Measure of central tendency	Respirable fibre conc mean (range) fibres/ml	Total Fibre Concentration) fibres/ml	Mass concentration mg.m^{-3}
Fowler *et al*. 1971 (USA)	Duct wrapping, Wall and plenum insulation, Pipe insulation Fan-housing		glass	20 to 60 mins	AM		1.8 (0.5–8)	nm

6 UNPUBLISHED DATA

6.1 DATA AVAILABLE FROM FILMM

6.1.1 Background

Information for this report has been kindly provided by FILMM, the association formed by the French industries manufacturing mineral wool insulation (FILMM stands for Fabricants d'Isolants en Laines Minérales Manufacturées). FILMM was formed in 1997, and further information about the organisation is available from http://www.filmm.org/page_quisommesnous.php.

The report provided by FILMM was produced for them by *ITGA-PRYSM* (www.**itga**.fr) and *LHCF Environnement (http://www.eurofins.fr/contacts/lhcf-environnement.aspx)* .

The data provided by FILMM comprise:

- a summary table of airborne fibre and dust concentration measurements from 2007,
- an interpretation report (no FIL 07/06/2299 BPS) explaining some of the samples in the above table;
- a detailed report from 2006.

As we were seeking to form a view of current concentrations, it was useful to consider the more recent data (from 2007), and then examine the more detailed report on the 2006 data. This order also arose because we received the 2007 data first, undertook and reported the first comparison before we received the fuller report on the 2006 data. Additionally, the 2007 data is the more relevant to the objectives of our review as it included mass concentration data. The 2006 report contained only very limited information (and no data) on mass concentrations.

The 2007 information, comprising tables of the measurements, did not state the sampling and analysis methods. On enquiry, it was clarified that the 2007 mass concentration measurements were for inhalable dust. The Inhalable dust sampling was undertaken following the French standard NF X 43-257, and gravimetric measurement of the dust collected (de Reydellet, private communication, September 2010).

However, the 2006 FILMM report gave information on the method used for sampling to determine fibre number concentrations and that indicates that samples were taken for evaluation by phase contrast optical microscopy. In the 2006 report, some additional evaluation of samples was undertaken by scanning electron microscopy to determine the relative proportions of calcium silicate fibres relative to glass fibres.

The 2006 report did not include sampling to determine dust mass concentration..

6.2 THE 2007 EXPOSURE CONCENTRATIONS SUPPLIED BY FILMM

6.2.1 Fibre concentrations

The data (for 2007) provided by FILMM included concentrations during specific tasks as well as 8 hour time weighted average (8 hour TWA) concentrations. It appears that 11 separate situations were monitored. The data for concentrations of fibre number and dust mass concentration are provided in Table 6.1

The concentrations in the table include a valuable breakdown of concentrations for specific tasks, such as for the cutting of composite panels with a circular saw, as well as an overall 8-hour time weighted average concentration. The times for the individual task components were not stated. However, in the example with the circular saw, it would appear (from the concentration values) that the exposure from cutting with the saw must have been for about a third of the 8 hour averaging period. (The concentrations during cutting with the saw were measured at just above or below 1.5 fibres/ml, and the 8-hour shift time weighted average was about 0.5 fibres/ml.)

For blowing insulation, it is recorded that respiratory protection was used. The exposure concentrations are less than the ambient environmental concentrations measured during the task. The concentrations for blowing reported by FILMM are about a tenth to twentieth of the values reported for nominally the same activity by Verma *et al* (2004) (see Section 5.5.1).

The use of masks is also recorded for work on installing 60 m^2 of ceiling, and the concentrations are again about a twentieth of those reported by Verma *et* al (2004) for what is nominally the same activity.

The reports did not state explicitly whether the operator exposure concentrations had (or had not) been adjusted to allow for the protection afforded by the use of respiratory protection. Therefore, we enquired and were informed (de Reydellet, private communication) that the concentrations reported had not been adjusted for the protection afforded by the use of respiratory protection.

It was important to know if a protection factor had been applied, as an adjustment for a protection factor would have explained the difference between the Canadian data and the French data for the above tasks, and it would also have explained why very low exposures were reported for tasks where respiratory protection had been used and presumably deemed necessary. However, a protection factor is not the explanation and therefore the FILMM data do indeed show that exposure concentrations for these tasks can sometimes be very low.

The range between the French and Canadian data may be an indication of the importance of having data from within the UK.

6.2.2 Mass concentrations

The mass concentrations were reported in the FILMM report in $\mu g/m^3$. The values are shown here in $mg.m^{-3}$. (The conversion is 1000 $\mu g/m^3$ to 1 $mg.m^{-3}$.)

The 8-hour time-weighted dust mass concentration reported for the composite panel (which includes cutting with the circular saw) was a very high value (206.5 $mg.m^{-3}$). The interpretation report (report number FIL 07/06/2299 BPS) commented that such a high result was inconsistent with the other results because it was so much higher although it is not impossible for a circular saw to generate such a result. For this sample, the sampling cassette had been full of fibres and other debris. These fibres were in the form of a wad that appeared consistent with originating from a circular saw dispersing fibres and plaster into the air. The possibility of a falsified sample due to the operator filling the cassette was considered unlikely due to both the shape of the wad of fibres on the filter and the quantity of material found in the cassette.

The interpretation report noted that the use of a powered circular saw for cutting this product (Calibel, composite board) produces a very high concentration aerosol of dust and fibres. The product contains a layer of plaster. These fibres and dust, once deposited on the floor, become re-dispersed by the passage of operators and by currents of air. This was apparently the reason for the very high dust exposure concentration for the operator.

The FILMM data also included environmental concentrations before, during and after the works. The environmental dust mass concentration was 5.6 $mg.m^{-3}$ during the task, and 6.8 $mg.m^{-3}$ after the task. These environmental concentrations are clearly high but much less than the reported personal concentration of 206 $mg.m^{-3}$. It is very unusual for a personal concentration to be about 30 times the environmental level. In our opinion, this may reflect localised high concentrations, possibly of coarse dust and fibre, near the circular saw and its operator.

As the ratio of dust mass concentration to fibre number concentration was much higher for this sample than for the other measurements, much of the dust must have been from the other components of the composite board rather than the mineral wool. That is also indicated by the description in the interpretation report quoted above.

The one other dust measurement for work with composite panel, but without use of a circular saw, also reported a high dust mass exposure concentration of 12 $mg.m^{-3}$.

All the other reported mass concentrations were below the 5 $mg.m^{-3}$ level that is the Inhalable Dust mass concentration exposure limit in the UK for mineral wool.

The results also suggest that, if dust concentrations are maintained below 5 $mg.m^{-3}$, then the airborne fibre concentrations will be much less than 2 fibres/ml, (the current UK fibre concentration occupational exposure limit for MMVF).

6.2.3 Comparing mass and fibre number concentrations for "blowing"

There are three sets of data for "blowing" and the first two relate to the same quantity of material (155 kg). The third set was placed lower in the original list and therefore may be for a different site, and would at least appear to be for a different occasion (even if on the same site). The third set related to blowing 300 kg. It might be expected that, if other factors were constant, then the set with the greater quantity of material would have the higher time-weighted average fibre exposure concentration. However, the third set gave a lower 8-hour TWA (0.02 fibres/ml) compared to the first two sets (0.03 and 0.04 fibres/ml); that may reflect the fact that fibre used on the third site is understood to be a fibre with binder whereas the other two were for a fibre without binder (de Reydellet, private communication 2010).

Interestingly, the dust mass concentrations (0.07, 0.23 and 0.66 $mg.m^{-3}$) do increase with more material being blown.

6.2.4 General atmosphere (area) concentrations

It is noteworthy that the general atmosphere concentrations in the FILMM data before the specific tasks were undertaken ranged from <0.01 to about 0.05 fibres/ml. As a consequence, some of the measured concentrations associated with tasks may have a non-trivial contribution from the concentrations that were present prior to the task being started. The background concentrations are therefore part of the uncertainty in determining concentrations arising from individual tasks.

The FILMM data shows that environmental concentrations are clearly higher during tasks than before tasks, and remain slightly higher in the period after the tasks but not as high as during the tasks. That is consistent with the concentrations attributed to the specific tasks being mainly due to those activities.

6.2.5 Factors determining exposure levels

The information given on the "tools" and on the "indicators" (amount of material and activity) provide a basis for attempting to predict concentrations. There was no comment on the extent of either confinement or dilution by ventilation.

Where information on whether there was ventilation or windows or doors were open (providing natural ventilation), it appeared that in most instances there were open windows or doors. In the exception where doors and windows were closed, the concentration appeared to be one of the higher values. The result is of course, as would be expected. The limited data do not really help clarify how much influence can be attributed to natural ventilation.

On enquiry as to whether the three sets of data for blowing refer to mineral wool with binder or mineral wool without binder, we were informed that mineral wools with binder and mineral wools without binder were used. The limited data (only three measurements in total) were consistent with mineral wool with binder giving lower fibre number concentrations.

Table 6.1 Airborne fibre and dust concentrations measured in 2007 made available from FILMM. Values as reported, except that exposure to dust in µg/m³ has been converted to mg/m³

Type of Building site	Tools used for cutting			Indicators		Fibre concentrations		Exposure to dust
	Cutter/ Knife	Saw blade	Saw jig / circular	Number/ quantity/ area of articles treated	Cleaned	fibres/ml		mg/m³
						during task	8 hour TWA Exposure	8 hour TWA
Metal frameworks	X			13 Rolls	Sweeping	0.127 0.0659 0.0426 < 0.0452	0.062	1.39
Metal frameworks				16 rolls		0.23 0.31 0.14 0.19	0.210	3.3
Metal frameworks	X			42 Rolls	Dirty floors	0.216 0.379 0.348	0.296	2.6
Composite panel			X	120 m², 2.5 Pallets		1.69 (cut with circular saw) 1.32 (cut with circular saw) 0.0738 0.0798	0.520	206.5
Composite panel		X		120 m²		0.093 0.30 0.19 0.31	0.200	12

Type of Building site	Tools used for cutting			Indicators		Fibre concentrations		Exposure to dust
	Cutter/ Knife	Saw blade	Saw jig / circular	Number/ quantity/ area of articles treated	Cleaned	fibres/ml		mg/m³
						during task	8 hour TWA Exposure	8 hour TWA
Blowing, fibre without binder				155 kg	half masks, MP3 cartridges		0.030	0.07
Blowing, fibre without binder				155 kg	half masks, MP3 cartridges	< 3 µm > 3 µm 0.60 0.76	0.040	0.23
Blowing, fibre with binder				380.6 kg	half masks, MP3 cartridges	< 3 µm > 3 µm 0.08 0.59	0.020	0.66
Ceiling				60 m²	Mask FPP3 during drilling	0.036 0.016	0.026	2.9
Ceiling				15 m²	X	< 3 µm > 3 µm 0.10 0.01	0.050	0.3
Ceiling				160 m²		0.11 0.068 0.070 0.14	0.091	2.7
Ceiling				530 m²		0.0706 0.0650 0.0470 0.0881	0.062	0.91

Note: the 8 hour time weighted average exposure to fibres for the ceiling work are approximately equal to the means of the concentrations during the tasks. The small differences from simple averages are presumably due to slight differences in sample durations.

Table 6.2 Environment (area) concentrations measured before, during and after the tasks for which exposures were measured (see Table 6.1). Values as reported from FILMM.

Type of Building site	Environment (i.e. area) concentrations fibres/ml		
	Before task	**During task**	**After task**
Metal frameworks	Not possible	0.0714 < 0.0213 0.0233	< 0.0238
Metal frameworks	0.0157	0.124 0.0914 0.18	0.0228
Composite panel	< 0.0239	0.369	0.0523
Blowing	0.08 0.04	0.44 0.24	0.0100
Blowing	0.05 0.03	0.62 0.37	< 0.01
Metal frameworks	0.0270	0.11 0.10 < 0.042 0.057	< 0.0053
Ceiling	0.0530	0.091 0.026 0.018 0.14	0.0180
Composite panel	< 0.020	0.18 0.25 0.21 0.22	< 0.012
Ceiling	0.01 < 0.01	0.01 < 0.01	< 0.01
Blowing	0.03 < 0.01	0.06 0.59	< 0.01
Ceiling	0.0570	0.035 0.026 0.063 0.073	0.0320

6.2.6 Comparison between FILMM data and NAIMA data

The airborne fibre concentrations reported by FILMM appear to be similar to the values given by NAIMA, as shown by the table of comparisons below (table 6.3). Note that, while reporting on the NIAMA data, Marchant et al (2009) described wide variations in concentrations within individual activities. By inspection, the ranges in the NAIMA data appear wider than those reported by FILMM but this may simply reflect the larger numbers of samples on which the NAIMA data are based.

The NAIMA data appear to be concentrations without any adjustment for the protection afforded by the use of respiratory protection. We obtained clarification that the data from FILMM did not include any adjustment for the use of respiratory protection. These data from NAIMA have been discussed earlier in this report, see Section 4.2.1.

Table 6.3 Comparison between 8-hour TWA fibre concentrations supplied by FILMM and those from NAIMA

Task as defined by NAIMA list	Airborne fibre concentration from NAIMA Fibres/ml	Equivalent Task in FILMM	Airborne fibre concentration from FILMM Fibres/ml	Comment
Blowing wool without binder Blowing wool with binder	0.8 0.3	"Blowing wool" Apparently some sites used wool with binder and some used wool without binder. It is not certain which were sampled here.	0.02 to 0.04	The 8 hour TWA concentrations from FILMM are clearly lower than those from NAIMA. However, concentrations measured during the task from FILMM were close to the NIAMA 8-hour TWA.
Power tools	0.35	Composite panel cut with circular saw	0.52	
Cavity wall fill insulation	0.2	"Metal frameworks"	0.06. 0.2 0.3	Assuming that this task means cavity wall fill insulation
Ceiling tiles, installation	0.25	"ceiling"	0.03 0.05 0.09	

6.2.7 Comparison of FILMM data with data from Canada

Work on ceilings is the one application in common between the data from FILMM and the data of Verma (2003) from Canada, described earlier in this report (see Section 5.5.1). However, the summary below shows that in this instance there is about **a tenfold difference,** with the data from FILMM showing consistently lower concentrations, in terms of the mean and the maximum values.

This comparison may be an illustration of the contrasts that can arise, and why there is a need to obtain data with UK products and UK use rather than assume that data from elsewhere will transfer across consistently.

Other factors that could be important in determining concentrations in this type of investigation are the selection of sites for sampling (Verma may have sampled problem sites) and improved procedures being followed in Europe in recent years.

Table 6.4 Contrasting data from FILMM and from Verma (2003)

Verma (2003) data Sampling times 16 to 42 minutes				FILMM data Sampling times 2 hours			
Labourer working on ceiling	mean f/ml	min f/ml	max f/ml	f/ml	mean† f/ml	min f/ml	max f/ml
cleaning			1.75	Ceiling 1	0.026	0.016	0.1
helping	0.49	0.25	0.93	Ceiling 2	0.05		0.10
removing	0.78	0.4	1.25	Ceiling 3	0.097	0.068	0.14
				Ceiling 4	0.066	0.047	0.081

† Note: the mean given above is the direct arithmetic mean of the individual samples, which for the last two values above is slightly different from the reported 8-hour TWA.

6.3 DATA FROM 2006 SUPPLIED BY FILMM

6.3.1 Overview

The interprétation report (« *Exposition des plaquistes aux fibres de verre: Presentation des mesures 2006* ») gives a great deal more detail on the sampling and analysis methods and useful statistical interpretation of the results. The statistical analysis gives indications that concentrations are highly unlikely to exceed the 1 fibre/ml level. There is also useful information on the practical detail of the tasks.

6.3.2 Sampling and analytical methods

The 2006 sampling included samples taken before and after installation work, with such samples being taken for a duration of 2 hours. It appears that 24 situations were monitored.

There were two types of samples taken during the course of installation work.

- The first type was sampling for the total period at the place of work, in which case the measured concentrations were equal to the 8-hout time weighted average concentration.
- The second type was sampling for the tasks concerning the installation of mineral wool. Concentrations during other periods were taken to be zero. The 8-hour time-weighted average concentration was calculated by dividing the sum of cumulative exposures (concentration multiplied by sampling time) for the tasks within a day and then dividing by the reference period (i.e. by the 8 hours).

6.3.3 Data and statistical analysis

The data analysis took two approaches following NF EN 689, i.e. the French version of a European standard.

The first approach classified situations in to five categories as in the list below, by exposure level index (I) defined as exposure as a percentage of the exposure limit. We note that under this scheme, a single sample has to be less than 10% of the exposure limit in order to reach a conclusion that a situation does not present a risk.

Situation	Evaluation from 3 measurements [†]	Evaluation from 1 measurement
Situation at risk	I>100	
Situation requires improvement	I<100 and at least half of results > 50	Conclusion not possible
Situation requires surveillance and/or improvement	I<100 and at least half of results < 50	Conclusion not possible
Situation requires surveillance	I<50	Conclusion not possible
Situation without risk	I<10	I<10

Notes

[†] The heading refers to 3 measurements, but the criteria clearly apply to 3 or more. With substantially more than 3 measurements, the second approach becomes appropriate.

The second approach was to use an analysis of variance to take account of the factors which determine the level of exposure, such as the work methods, the characteristics of the work place, etc. The situations were then classified in terms of the probability of exceeding the exposure limit.

Situation	Probability (P) of a measurement exceeding the exposure limit of	Comment
Situation at risk	P>5%	
Situation requires surveillance and/or improvement	0.1% < P < 5%	
Situation without risk	P < 0.1%	

6.3.4 Descriptions of installation tasks

The report supplied by FILMM contains descriptions of four installation tasks

(a) Installation of slabs of glass wool on metal frameworks for wall application

The principal task was described as comprising:

- the operator cuts the mineral wool following the sides;
- he also makes equally important cuts to adapt the slabs to fit into the space and shape,
- he places the first piece of mineral wool on the metal framework (that is already installed),
- when he has placed the first piece, he lays the next slab horizontally next to it securing it with the aluminium mounting that has been cut in advance.

(b) Installer of "complexe de doublage" double layer of mineral wool slabs.

The principal task was described as comprising:

- the operator cuts the sheets (slabs) of glass wool with a hand saw, a knife (cutter), or a jig saw to fit the correct dimensions.
- he makes other equally important cuts to make the mineral wool match the contours of windows for example.
- he applies adhesive to the backs of the sheets (slabs) (the drying time of the adhesive being more than 1 hour).

- similarly, he applies adhesive to the walls.
- the slabs are applied to the walls and held in position as firmly as possible.

The report noted that in the instance where this was sampled, no personal protection was being used on that installation, except that one operator used hearing protection during the cutting of the panels.

(c) Installing blown glass wool

The principal tasks was described as comprising:

- the operator feeds the machine with mineral wool and proceeds to regulate machine.
- the mineral wool is applied across the surfaces within the roof. In these instances, the surfaces ranged from 96 to 127 m^2.

(d) Installing glass wool by crawling

The principal task was described as comprising:

- the operator supplies the area with rolls of glass wool;
- he cuts lengths of the material with a knife and spreads the material;
- in these instances, the surfaces ranged from 96 to 127 m^2.

6.3.5 Concentrations during tasks

The individual fibre concentrations measured during applications of mineral wool insulation products were listed in two tables (two pages) in the report provided by FILMM (their table 5.1.1). There are two pages of results in the FILMM 2006 report, and there is more information about the details of the tasks, in particular the cutting tools used, on the first page than on the second. The second page has more information about the duration of exposure in the day and has the task-length average concentration as well as the 8-hour TWA. These results are shown below in, respectively, Table 6.5 and Table 6.6.

We have re-ordered the rows so that the data are grouped by task (second column) and in sequence of ascending 8-hour TWA exposure (third column).

We note that the first two rows of the Second table are additional data for one of the tasks listed in first Table (metal framework). The report provided by FILMM gives a statistical treatment which takes the average of the results for metal framework and for complex doubling but uses only the results from the first table. The average 8-hour TWA from the 6 results for metal framework in the first table is 0.06 fibres/ml, whereas the two results in the second Table are above the maximum of the first six results and have an average of about three times the level of that for the first six results. It is not apparent why the statistical treatment in the FILMM report did not give the average 8-hour TWA from all the 8 results for metal framework, which is 0.096 fibres/ml compared to the 0.062 quoted.

The FILMM report notes that the 8 hour TWA exposure of operators ranged from 0.022 to 0.31 fibres/ml. From their analysis, they concluded that certain types of work gave rise to higher concentrations, the "*complex doubling*" gave higher exposure than "*metal framework*"

From their results in Table 6.5 and 6.6, the ranges for these applications (0.022 to 0.23 fibres/ml for metal framework and 0.053 to 0.31 fibres/ml for complex doubling) show greater variation (ten fold or six fold) than the difference (about two fold) between the tasks.

The FILMM report assesses the influence of factors such as the type of tool used for cutting and finds that the use of power tools is associated with higher exposures than hand tools. However, inspection of the table below shows that in the task where power tools were sometimes used, the highest exposure occurred with hand saw and knife. Clearly, there are multiple factors and variation is to be expected in small numbers of samples.

6.3.6 Evaluation of proportion of other fibres: complementary analyses of some samples by SEM

The FILMMM 2006 report stated that some samples were analysed by scanning electron microscope to determine the proportion of calcium silicate fibres in relation to the proportion of glass wool fibres.

Four comparisons were reported. The proportion of calcium silicate fibres found varied but was in the range 0 to 20% for each comparison, with the proportion of glass wool fibres being between 100 to 80%. This was interpreted as indicating that their measurements of fibre exposures would have over estimated the exposure to glass fibres due to the inclusion of calcium silicate fibres.

Table 6.5 Individual fibre concentrations from the 2006 FILMM report. The original sequence number in column 1 shows the order in which the data appeared in the original report (their Table 5.1.1); here the rows are in sequence of the type of activity and, within each activity, ascending 8-hour TWA exposure. The information reported includes the type of tools used in the cutting.

Original sequence number	activity	8 hr TWA exposure fibres/ml	Tools used for cutting: knife	hand saw	jig saw, circular saw	Quantity indicator (no of articles, area, etc)	cleaning
3	"complex doubling"	0.053		X		15 sheets installed	sweeping
5	"complex doubling"	0.062	X			20 sheets installed	sweeping
9	"complex doubling"	0.170			X	10 sheets installed	-
10	"complex doubling"	0.190	X	X	X	27 sheets installed	sweeping
11	"complex doubling"	0.300			X	gallery of 80 m at ground level	sweeping
12	"complex doubling"	0.310	X	X		23 sheets installed	sweeping
1	metal framework	0.022	X			12 rolls	sweeping
2	metal framework	0.036		X		71 strips of wool cut	sweeping
4	metal framework	0.055	X			?	-
6	metal framework	0.068	X			48 strips of mineral wool cut	-
7	metal framework	0.073	X			gallery of 90 m at ground level	-
8	metal framework	0.120	X			17 rolls	-

Table 6.6 Individual sample results from the FILMM report,. The original sequence number in column 1 shows the order in which the data appeared in the original report (second page of their Table 5.1.1); here the rows are in sequence of the type of activity and ascending 8-hour-TWA-exposure.

Original sequence	Type of work	Task-length concentration fibres/ml	duration of exposure in the day	8 hr TWA exp fibres/ml	Quantity or number of articles	cleaning
1	metal framework	0.160	8 hours	0.16	5 rolls	-
2	metal framework	0.230	8 hours	0.23	6 rolls	-
8	Blowing insulation wool	0.021	65 min	0.0028	about 300 kg	-
6	Blowing insulation wool	0.034	55 min	0.0039	about 300 kg	-
5	Blowing insulation wool	0.059	48 min	0.0059	360 kg blown	-
4	Blowing insulation wool	0.150	59 min	0.0184	315 kg blown	-
7	Blowing insulation wool	0.310	65 min	0.0420	about 300 kg	-
3	Blowing insulation wool	0.950	49 min	0.0970	315 kg blown	-
10	"crawling"	0.005	210 min	0.0022	25 rolls	-
12	"crawling"	0.005	86 min	0.0009	16 rolls	-
11	"crawling"	0.007	235 min	0.0034	25 rolls	-
9	"crawling"	0.014	120 min	0.0035	no information	-

7 DISCUSSION AND RECOMMENDATIONS

7.1 TYPES OF DATA AVAILABLE

Exposure concentrations have mostly been reported as fibre number concentrations, with much less data on mass concentrations. The published exposure concentrations are sometimes expressed as concentrations measured over the duration of specific tasks, whereas the NAIMA database and various publications give concentrations expressed as 8-hour time weighted averages.

The 8-hour time-weighted averages describe exposure over the course of a working shift and they are therefore required for risk assessments. Concentrations measured for tasks can also be used to derive 8-hour time-weighted average concentrations if the schedule of tasks in a shift is known. These task-based concentrations can be more powerful in risk assessment as they can be used to estimate 8-hour average concentrations in different circumstances where tasks can last for different periods of time. For example, Maxim *et al* (2003) develop estimates of the cumulative exposure for installers of mineral wool insulation taking account of factors such as the hours actually spent on the installation as opposed to travelling and set up time.

Maxim *et al* developed their estimates based on information for work in the USA, but similar approaches could be used in the UK.

Concentrations for tasks are also helpful in that short periods of high exposure concentrations can and should be alleviated by the use of respiratory protection.

7.2 EXISTING DATA

7.2.1 Recent data

Recent data on airborne fibre and dust concentrations during the application and use of mineral wool and stone wool products is available from measurements undertaken in the USA, Canada, Denmark and France.

In the USA, the insulation manufacturers' industry association has a database which gives fibre number concentrations for a range of tasks that are undertaken in the US. The database does not include mass concentrations. The fibre number concentrations are all for 8-hour time weighted average exposures.

Concentrations measured in the USA are determined by NIOSH 7400B method (NIOSH, 1994) which is likely to produce a lower fibre number concentration than the WHO PCOM method used in the UK (WHO, 1996), e.g. 30% lower than the WHO method in one assessment (as described earlier in this report). However, the difference will depend on the fibre size distribution. Although there is an absence of information on whether the difference is greater or less than 30%, it would be appropriate to make some allowance for this potential difference if attempting to extrapolate data from the US (NAIMA) to the UK.

The unpublished FILMM data is the most recent European data that were available for this report. The measurements were made in France, but there were small numbers of samples collected. Comparison between data from FILMM and the data from NAIMA suggests that there is some consistency but also some differences in the fibre number concentrations for the five tasks where comparison was possible.

The Canadian study by Verma *et al* (2004) provides respirable fibre number concentrations by the WHO method for the various installation tasks, as task length average concentrations. However, in the one nominally similar application (see Table 6.4 earlier in this report) where the data from Verma could be compared to that from FILMM, the FILMM concentrations were about ten fold lower than those reported by Verma. This illustrates the need to have direct data for work as undertaken in the UK in order to establish the extent to which extrapolation from the international sources summarised in this report can be deemed appropriate to the UK.

The mass concentrations that are part of the data from FILMM may be a useful indicator of the relative levels of mass and number concentrations, but need to be used with caution because of the noted differences between FILMM and other recent measurements of fibre concentrations.

7.3 ANALYSIS OF PRODUCT APPLICATIONS

7.3.1 Installation methods

The description of installation methods and the applications for mineral wool insulation products indicates that the key steps involved in the installation of most products are relatively similar. The differences between methods are generally in the tools used to cut the product to size. Knives or hand saws are used in the UK whereas, in France both hand tools or power saws (jig saws, or circular saws) are used. Other factors affecting concentrations include:

- the type and size of space where the work is done (open or confined – note that climate differences between the UK and France, and between the north and south of the UK, may affect practices);
- ventilation (general or local exhaust ventilation on tools);
- whether the product is being fitted into spaces from above, or below, into horizontal or vertical spaces;
- the specification of the material;
- the amount of material being handled
- how much cutting is required to fit the product to the required space.

This explains why there is as much variation within the concentrations measured for particular product group as between product groups. Some products appear to be more likely to be cut by power tools (e.g. composite board) and are liable to generate high concentrations
The installation of blown loose glass fibre is clearly a different process, and it is noteworthy that there are very different measurements of concentrations in Canada compared to those in France for nominally the same process. This is therefore a process for which UK-based data is particularly important.

7.4 TEMPORAL TRENDS IN CONCENTRATION

7.4.1 Temporal trends

Inspection of the data in Table 5.1 indicates that the concentrations as measured in numbers of fibres/ml are substantially lower in recent surveys than the values reported by Head and Wagg at the start of the 1980s. There is less data on mass concentrations but it appears that they too have dropped in recent years and this would fit within the general trend of decreasing workplace exposures (e.g. Creely et al, 2006).

7.5 DATA GAPS

The temporal trends discussed above indicate that it is important to have up to date information as products and procedures change.

- The published UK information is old and will not apply to current products and practices. The trends observed in the international measurements summarised in Chapter 5 of this report is persuasive evidence that concentrations have reduced over time and that therefore the current situation is likely to be better than shown by old UK information.

- The most recently published European information (Breum *et al,* 2003) was obtained by simulations of laying rolls or installing slabs in an attic. The data were produced at least 7 years ago, but we understand (from MIMA) that these products have changed relatively little in the last 7 years (compared to the changes since the published UK data) and therefore these results may well be relevant to current products. The geometric mean (GM) inhalable dust concentrations were in the range 0.3 to 1.8 $mg.m^{-3}$. The fibre number concentrations were all remarkably low, less than 0.1 fibres/ml. The indications are very positive but need to be supported by real field measurements.

- The unpublished FILMM data from France relate to modern products, but the data are based on small numbers of samples. There are some marked contrasts between the data from FILMM and the published data from Canada published by Verma. This unexplained difference indicates that there is a need to establish whether practices and exposure concentrations in the UK are similar to one or the other or neither.

- The available newer data does not cover the wide range of tasks and applications outlined in Chapter 2 and there is insufficient supporting information available to assess the applicability of the measurements to given situations. For example, there is clearly a lack of data on concentrations encountered in the UK during installation of current mineral wool and stone wool insulation and fire protection products.

- The concentrations generated by installers / end user tasks will depend on factors such as the characteristics of the locations where the material is being installed. Locations where natural ventilation is restricted is likely to give rise to relative high concentrations. Some of the end user applications identified by MIMA include situations in some of which there might be restricted ventilation (e.g. installation under floors, in attics). Note also that climate differences between, for example, France and the North of the UK may mean that there is more work undertaken in the UK in enclosed areas with restricted ventilation.

- The data published by Marchant *et al* (2002, 2009) gives extensive coverage of respirable fibre number concentrations (but not mass concentrations) during use of mineral wool products. They recognised the need to update to ensure that estimates are relevant to current products and practices.

- Our limited comparisons between the FILMM data and the data from NAIMA indicate that it is reasonable to expect that, in the majority of instances, the installation and use of mineral wool and stone wool products will, on average, give respirable fibre number concentrations that are of the same order as those reported by Marchant *et al,* with 8-hour time weighted average concentrations likely to be below 1 fibre/ml.

- The marked contrast between the data from FILMM (France) and the Canadian data from Verma *et al* (2004) suggests that important (tenfold) differences can arise in average concentrations for nominally similar activities.

- There are few measurements of mass concentrations. If the merits of using gravimetric concentrations are to be promoted, then it is necessary to have a current and representative set of data for fibre number and mass concentrations during installation of the products.

7.6 RECOMMENDATIONS

7.6.1 Verifying inter-study consistency in fibre counting

While differences in fibre number concentrations have been discussed above in terms of the values as reported in the various studies, we suggest that it would be worthwhile to investigate whether the differences may be attributable to differences between laboratories in fibre counting. IOM has considerable experience of running inter laboratory comparisons in fibre counting, and it would be useful to establish if such inter-laboratory differences might help to explain the apparent differences between studies that have been described above.

7.6.2 Measurements in the UK

The description of methods for installing mineral wool insulation products indicates that there are four basic methods for installing rolls or slabs (coded in chapter 2 as A, B, C and F with some further sub methods coded as A1, A2 and A3). These are used for a range of different products in new build or retrofits.

There are two installation tasks (coded as methods D and E in chapter 2) associated with installing blown loose fibres. These are the feeder of fibres into the machine and the installer who delivers the blown fibres.

A valuable addition to the data described here would be to obtain airborne fibre concentration data in the UK for the six basic tasks (A to F) as listed above, for a selection of the modern products. Ideally the data would be obtained for at least three sites for each method, i.e. 18 sets of measurements. The product types could be a mixture from slab to roll, glass wool to stone wool.

If MIMA wishes to promote the value of airborne mass concentrations in future as a method for controlling exposure as fibre number concentration, then any fibre number concentration measurements should be accompanied by simultaneous measurement of airborne dust mass concentrations.

As noted in the FILMM report, the key factors for installing rolls or slabs are expected to be the types of cutting tools, the degree of enclosure and/or ventilation, the position of the installation relative to the installer (above, below or to the vertical wall). This information must be recorded during any measurement surveys so that the impact of these variables can be assessed.

The questions to address would be:

1. are fibre number concentrations in applications of mineral wool insulation in the UK consistent with those reported by NAIMA (US), Verma (Canada) and/or FILMM France from real applications?

2. how do concentrations in the UK compare to the low mass and number concentrations from simulations for attic installations from Breum (Denmark)?

3. to what extent is airborne fibre number concentration related to airborne dust mass concentrations across a range of modern mineral wool product types and working methods?

Analysis of the results from this type of exercise could be used to help focus guidance around the control measures that are most effective for modern work practices and materials.

7.6.3 The value of linking UK data to the international data

It would be logical to expect that concentrations for mineral wool insulation in the UK would be similar to the values in the body of international data, if work practice, building conditions, and products used are not too different. However, as described above, there are enough differences between the various international data sets that collecting some UK fibre concentration data for comparison and verification is essential.

7.7 CONCLUSIONS

7.7.1 On the existing measurements of fibre in air concentrations

There is a substantial body of airborne fibre concentration data from international sources but very limited data from the UK. Average fibre number concentrations for modern products appear to be below 1 fibre/ml, with the exception of blowing loose wool.

The variation in concentrations for some tasks can be relatively large, and this may reflect differences in the circumstances of specific sites. The FILMM reports confirmed that factors such as ventilation, confined spaces, quantity of product and type of tools affect the concentration

7.7.2 On the dust mass in air concentrations

There is less data in the international sources for dust mass concentration than for fibre number concentration. The data that is available demonstrates that (i) it appears that controlling dust mass concentrations to below 5 $mg.m^{-3}$ keeps fibre number concentrations below 1 fibre/ml, and (ii) it appears that excessively high dust mass concentrations can arise even with fibre number concentrations controlled to below 1 fibre/ml. Therefore, controlling to a mass concentrations may in practice prevent exposure to either mineral wool fibres or dust mass, but controlling to fibre number concentrations may not control exposure to high dust mass concentration.

7.7.3 On acquiring current UK data

The review indicates that there is a clear supposition to test, namely that concentrations in the UK are not going to exceed those summarised in this report, if conditions (ventilation, enclosure, work pattern) are not too different. Sampling from a modest number of representative sites should be enough to clarify the extent to which current installation of mineral wool insulation products meets that supposition. The review of the data shows that substantial differences do arise between sets of national data and it is for that reason that a validation survey is needed.

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APPENDIX 1 - FIBRE NUMBER AND MASS COMPARED IN 1980

A1.1 MEASUREMENTS BY HEAD AND WAGG

Head and Wagg (1980), reported concentrations dust and fibres during manufacture of mineral wool fibres and for some applications using mineral wool fibres. For this report, we draw on their measurements during the various uses of mineral wool.

Head and Wagg tabulated their data in terms of the average concentrations of numbers of “Total fibres”, i.e. fibres with aspect ratio greater than 3 to 1 but with any diameter, “Respirable Fibres” (the subset of fibres with diameter less than 3 µm), and mass of “Total Dust”. “Total dust” was the dust collected using an open-face sampling head, and the samples for determination of fibre number concentrations were also collected on open-face sampling heads.

A1.2 CONCENTRATIONS DURING APPLICATIONS OF MINERAL WOOL

Head and Wagg reported “respirable fibre” concentrations and dust mass concentrations for measurements during various uses of mineral wool. Their values for mean concentrations are plotted in Figure A1.1. The bars represent the range of values. Individual estimates of concurrent mass concentrations and number concentrations were not available. There may well have been correlation (between number and mass) within the set of samples.

The results show that for products as made and used in the UK in the 1970s:

- installation of glass fibre blanket could give rise to high mass concentrations (greater than 30 mg.m^{-3}) while fibre number concentrations remained below 2 fibres/ml;
- installation of loose fill mineral wool could give rise to high concentrations by mass and number,
- sprayed mineral wool fibre gave rise to high mass concentrations while mean fibre number concentrations were less than 2 fibres/ml and the ranges indicate that almost all fibre number concentrations were less than 2 fibres/ml;
- the application in engine exhausts gave low concentrations by number and mass.

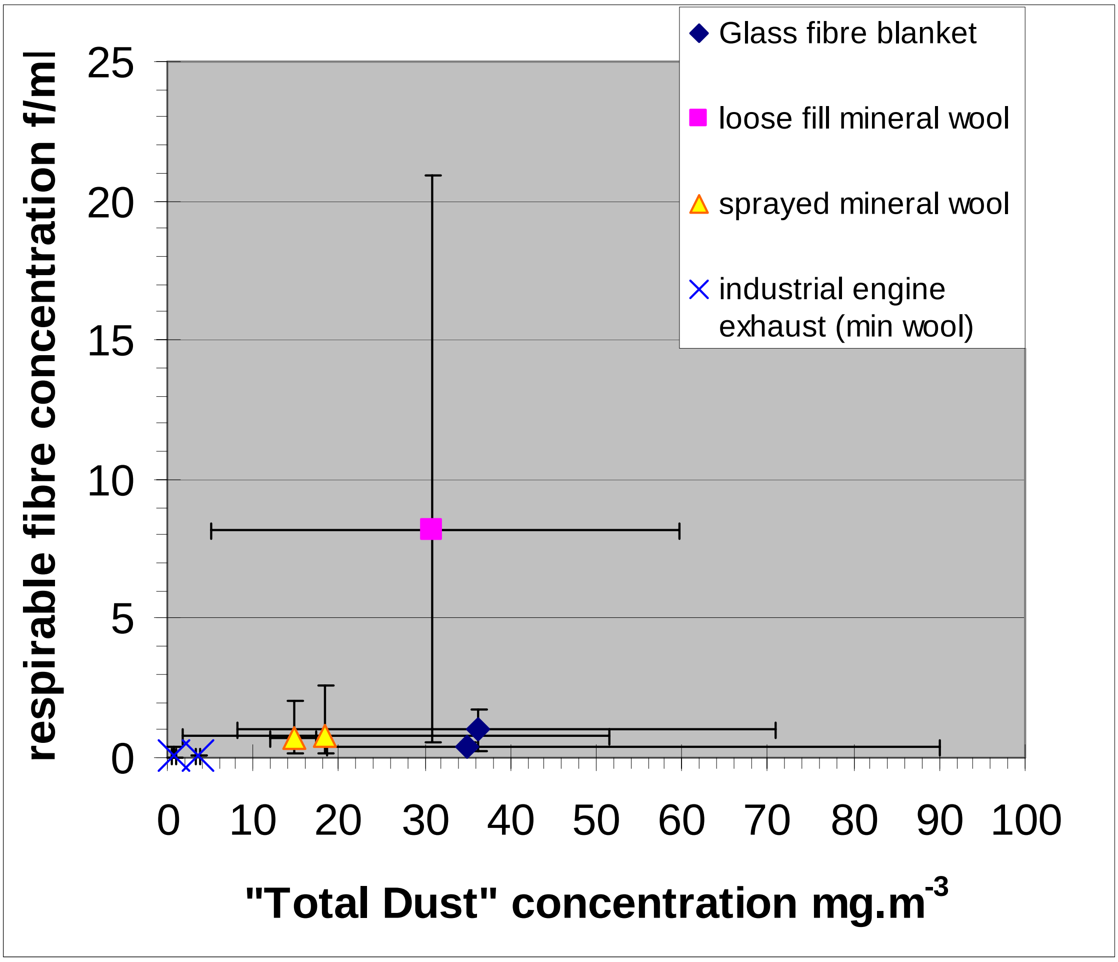

Figure A1.1 Respirable fibre concentrations compared to mass dust concentrations, as reported by Head and Wagg (1980), for domestic loft installation with glass fibre blanket, and then with loose fill mineral wool, fire protection of steel with sprayed mineral wool, and application in industrial engine exhausts. Note that the bars represent the ranges of values.

APPENDIX 2 - BACKGROUND TO THE NAIMA DATABASE

Marchant *et al* describe the origins of the "Health and Safety Partnership Program (HSPP)":

> *"In 1995, OSHA identified SVFs as one of 18 priorities in its Priority Planning Process, based on the number of potential workers exposed to SVFs.(3) This OSHA planning process was undertaken for the purpose of prioritizing potential occupational safety and health hazards for formal rule-making or other agency action. Five of the 18 priorities were designated for formal rulemaking and added to OSHA's regulatory calendar. SVFs were not included in this rulemaking category, but, instead, were identified by OSHA, along with 12 other substances or categories, as candidates for voluntary or cooperative efforts to encourage worker protection without developing new regulations."*

It is noteworthy that the reason for the SVFs being included as one of 18 priorities was stated as being due to the number of workers potentially exposed. Given the range of applications in the UK (listed in the previous chapter), and the likely similarity between the US and UK in extent of the use of such products, there may be a similar proportion of the working population engaged in such work in the UK

Marchant *et al* (2002) described how the US Health and Safety Partnership program had developed in response to OSHA as indentifying mineral fibres as one of 18 priorities for voluntary (rather than regulatory action). They stated

> *"In response to this development, the North American Insulation Manufacturers Association (NAIMA), a trade association of manufacturers of glass wool and mineral wool, began discussions with OSHA to develop a voluntary occupational safety program for workers involved in the manufacture, fabrication, installation, and removal of glass wool and mineral wool products. These negotiations culminated in a 1999 agreement involving OSHA, NAIMA, and two trade associations representing insulation installers (the National Insulation Association [NIA] and the Insulation Contractors Association of America [ICAA]), to establish a voluntary Health and Safety Partnership Program HSPP).(4) Refractory ceramic fiber manufacturers are not included in the HSPP, but have developed their own exposure monitoring program as part of a consent agreement with the U.S. Environmental Protection Agency (EPA), which is described in Maxim et al. (1997).(5) Textile glass fibers are also not included in the HSPP because they are generally non-respirable (nominal fiber diameter of 6–15 µm).(6)*
>
> *The HSPP is* ***a comprehensive and voluntary workplace safety partnership being implemented by the SVF industry under OSHA's oversight to promote the safe manufacture and handling of glass wool and mineral wool products****. The program is being phased in over a three-year implementation period that commenced in May 1999. This implementation period will be followed by an initial five-year compliance period from 2002–2007. OSHA's administrator praised this voluntary program as "creative" and "innovative," and an "important step towards further improving worker protection." He also identified the program as "a possible model for future collaborative efforts of this type."*

Marchant *et al* stated:

> *"Given the limitations of the existing published exposure data for SVFs, an important component of the HSPP is the commitment of NAIMA to develop, with the assistance of*

its member companies, a database of representative exposure levels for the ***manufacturing and end-use applications*** *of glass wool and mineral wool products.* ***This exposure database includes exposure data collected from the individual companies and other sources, and will be updated with additional data collected as part of the HSPP. The HSPP commits industry to collect approximately 400 samples per year in the period from 2002 to 2007 to ensure that the database contains sufficient data to document current exposures for specific product types and job functions****. As part of this sampling program, the HSPP commits NAIMA to develop and begin implementing by 2001 a sampling strategy designed to target specific tasks with higher potential exposures and limited published exposure data. Ten such tasks identified in the HSPP are batt insulation installation, compressed air cleanup, fabrication with hand-held power cutting tools, loose fill insulation installation, mineral wool manufacturing, mineral wool ceiling tile installation, removal activities combined with demolition, removal of high temperature unjacketed insulation exposed to service temperatures above 177°C/350°F, tasks involving handling of special application fibers, and applications in tightly enclosed, poorly ventilated spaces.* ***NAIMA has also committed in the HSPP to develop a sampling strategy designed to verify exposures during*** *manufacture, fabrication****, or use of products with traditionally low potential exposures, as well as to assess exposure levels of new produc****ts.*

The SVF exposure database will serve several purposes. First, it will provide a comprehensive overview of exposure levels in the industry as well as exposure levels for specific product types or job functions. The database is constructed to permit a user to select exposure data for any specific combination of.fiber type, industry sector (i.e., manufacturing, fabrication, installation), product type, and job description. The database will also permit tracking of significant changes or trends in exposure levels over time.

Second, the exposure database will be used to provide representative exposure estimates to installation contractors and other industry participants for specific product type/job function combinations. Most job functions and products are generally narrowly defined and standardized, producing relatively consistent exposure levels over time and between sites for the same product type and job function*. By collecting and making available exposure data for a particular job function and product type, the exposure database will provide a convenient service for contractors and other companies to ensure that their workers are within the voluntary 1 f/cc PEL without requiring those companies to undertake their own burdensome exposure monitoring program.*

Third, the exposure database will identify specific job tasks that involve exposures near or above the voluntary 1 f/cc PEL, and therefore may warrant additional exposure reduction or other worker protection. As part of the HSPP, NAIMA identified selected tasks where respirators will be recommended unless and until exposure data indicate occupational exposures are consistently below the voluntary 1 f/cc PEL. Specifically, under the HSPP, a worker must wear a NIOSH-certified dust respirator (N-95 series or better) in the following tasks: (1) blowing SVF insulation in an attic or for cavity; (2) in the immediate area of blowing SVF insulation in an attic or for cavity; (3) dumping or pouring unbonded, bulk, specialty filtration .fiber products where engineering controls are absent; and (4) removing SVF products during significant repair or demolition activity. As mentioned above, the industry will also institute a program to measure worker exposures in other specified tasks with the potential for high fiber exposures, including workers in the manufacturing setting.

Finally, the SVF exposure database will provide additional benefits beyond the HSPP. For example, OSHA's 1998 respiratory protection standard requires employers to evaluate workplace exposures, typically through exposure monitoring, to determine appropriate respirator use for employees.(25) Such exposure monitoring can be very burdensome for small employers, such as many of the contractors that install SVF products. Recognizing this potential burden, OSHA in its preamble to the final respiratory protection standard (29 CFR § 1910.134) provided that ***appropriate industry-wide exposure surveys or databases could be used in lieu of company-specific exposure monitoring to estimate exposure levels for the purpose of determining respiratory protection requirements****. OSHA noted that* ***such industry-wide surveys "must have obtained data under conditions closely resembling the processes, types of materials, control methods, work practices, and environmental conditions in the workplace to which it will be generalized, i.e., the employer's operation****." Specifically referring to NAIMA's SVF exposure database, OSHA stated that, "It is clear that such programs can often* ***assist employers to estimate workplace exposures reliably enough to make correct respirator choices without the need for employee monitoring.****" The SVF* ***exposure database developed by NAIMA and its members under the HSPP therefore represents an innovative and pioneering approach for enhancing worker protection while at the same time reducing compliance burdens, particularly for small businesses****. As OSHA has noted, the HSPP including the SVF exposure database may serve as a model for other industries. This article describes the design and implementation of the SVF exposure database by NAIMA and its member companies. It also summarizes the exposure data collected to date, which consists of approximately 6000 TWA exposure samples mostly collected over the past decade, the vast majority of which were previously unpublished, making it the largest and most current occupational exposure data set reported for glass wool and mineral wool."*

APPENDIX 3 - THE 8-HOUR TWA CONCENTRATIONS OF KOENIG AND AXTEN (1995)

Reference	Application	User	Material /product	Sampling details		Respirable fibre conc mean (range) fibres/ml		Range in task measurements Fibres/ml
Koening & Axten 1995 (USA).	Attic Insulation (open)	helper	rock / slag		AM	0.03		(0.04-0.62)
	Attic Insulation (confined)	blower	rock / slag	8 hr TWA		0.07		(0.02-0.30)
	Attic Insulation (open)	helper	rock / slag	8 hr TWA		0.05		(0.05-0.13)
	Attic Insulation (confined)	blower	rock / slag	8 hr TWA		0.19		(0.02-0.3)
Note: specified area as either confined, or Moderately open (m. open); or open	Sound attenuation blanket m. open	Cut/place	rock / slag	8hr TWA		0.16		(0.11-0.24)
	outdoor pipe insulation -open	Cut, install, cover	rock / slag (pre-formed pipe insulation)	8 hr TWA		0.04		(0.02-0.05)
	Spray on fire proofing open	Nozzle man	rock / slag	8 hr TWA		0.28		(0.03-1.1)
	Spray on fire proofing open	labourer	rock / slag	8 hr TWA		0.05		(0.01-0.29)
	Spray on fire proofing Open	Pump operator	rock / slag	8hr TWA		0.03		(0.01-0.07)

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