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Dated 1 May 2002

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(54) Abstract Title
Method and apparatus for detection of asbestos fibres

(57) A fibre detector that is able to distinguish between fibrous and non-fibrous particles and discriminate between asbestos and non-asbestos fibres by reorientating the asbestos particles by a magnetic field. Figure 2 shows means for producing a magnetic field (2), an illuminating beam (3) and means for producing a stream of particles aligned in the direction of flow, consisting of a jet (5) and outlet (6), and arranged such that the magnetic field is non-parallel and non-perpendicular to the direction of the particle stream so that the asbestos particle are reorientated by preferably 45°. Scattered light (7) from a particle in the region of overlap (8) between the flow and the magnetic field is collected by a lens (9) and is projected onto a centrally symmetric optical detector assembly (11) and the spatial light-scattering patterns are analysed using a neural network.

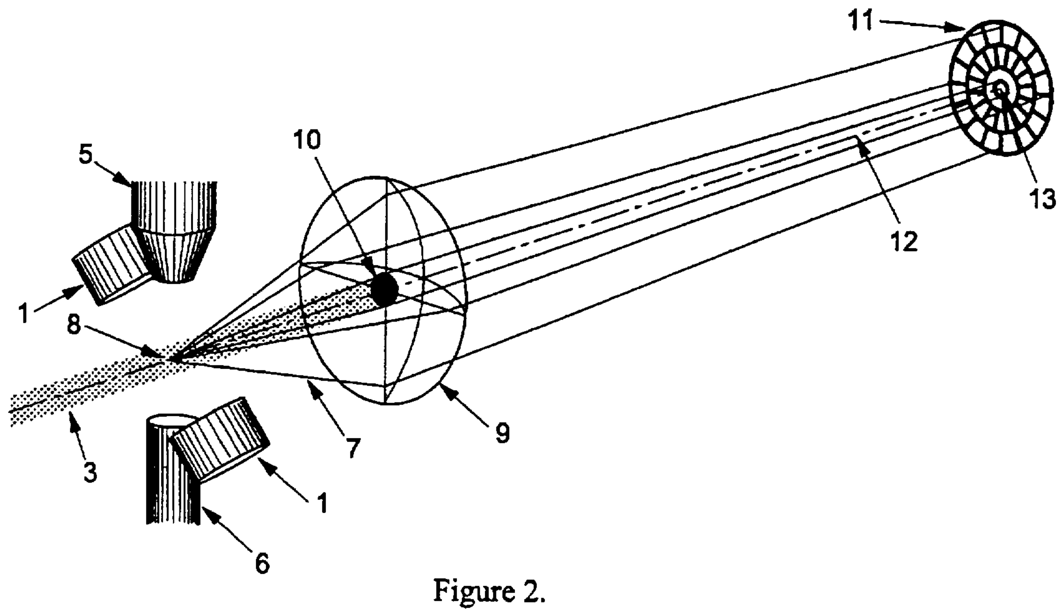

Figure 2.

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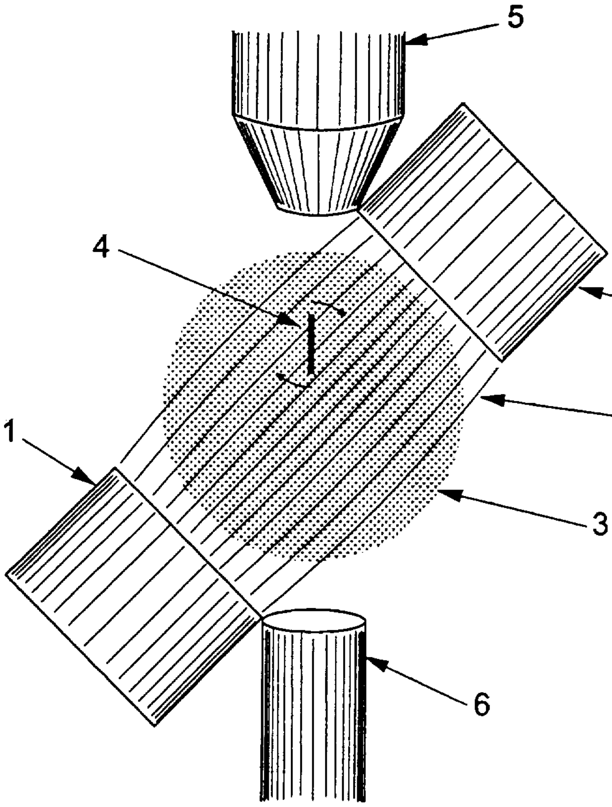

Figure 1.

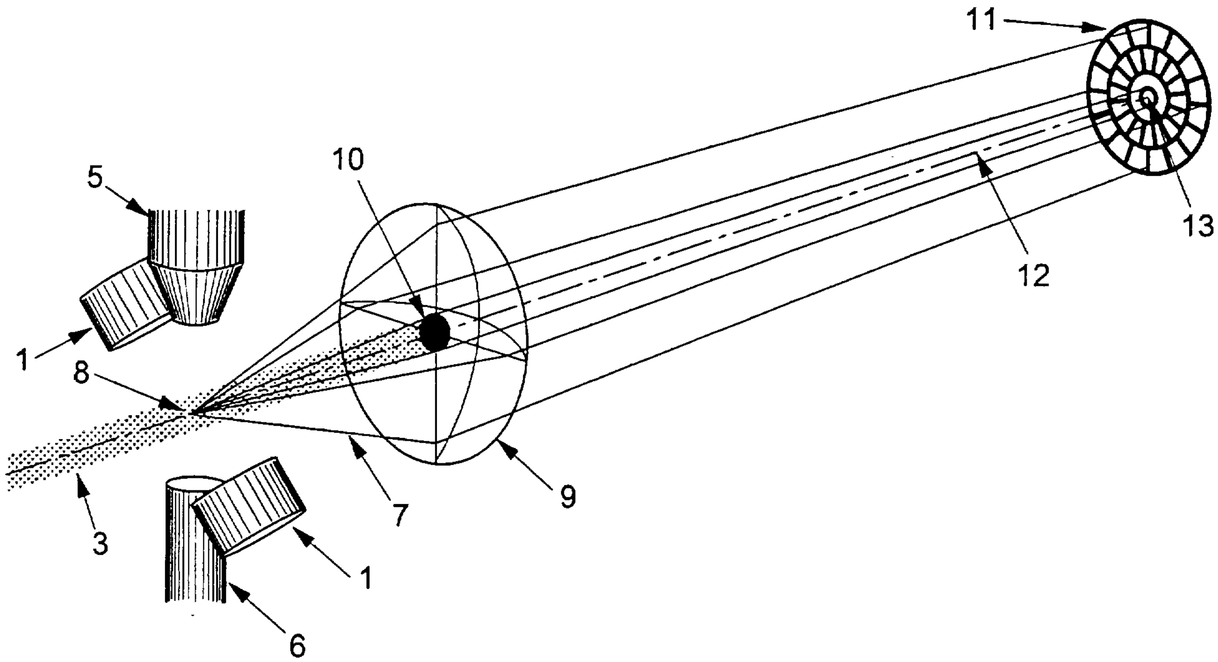

Figure 2.

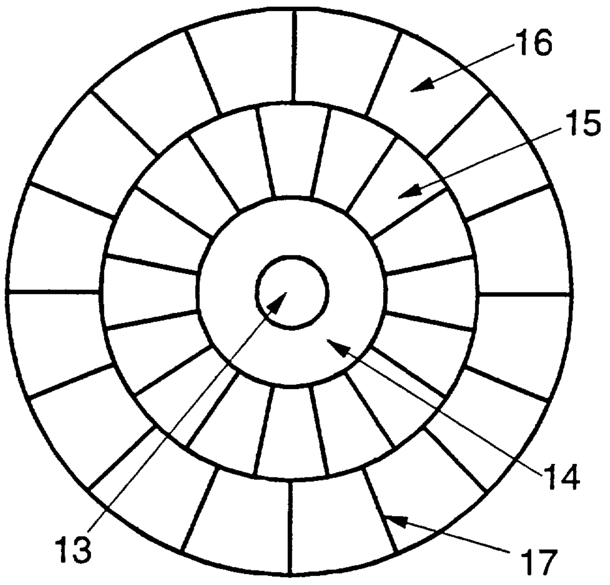

Figure 3: Possible configuration of the detector assembly.

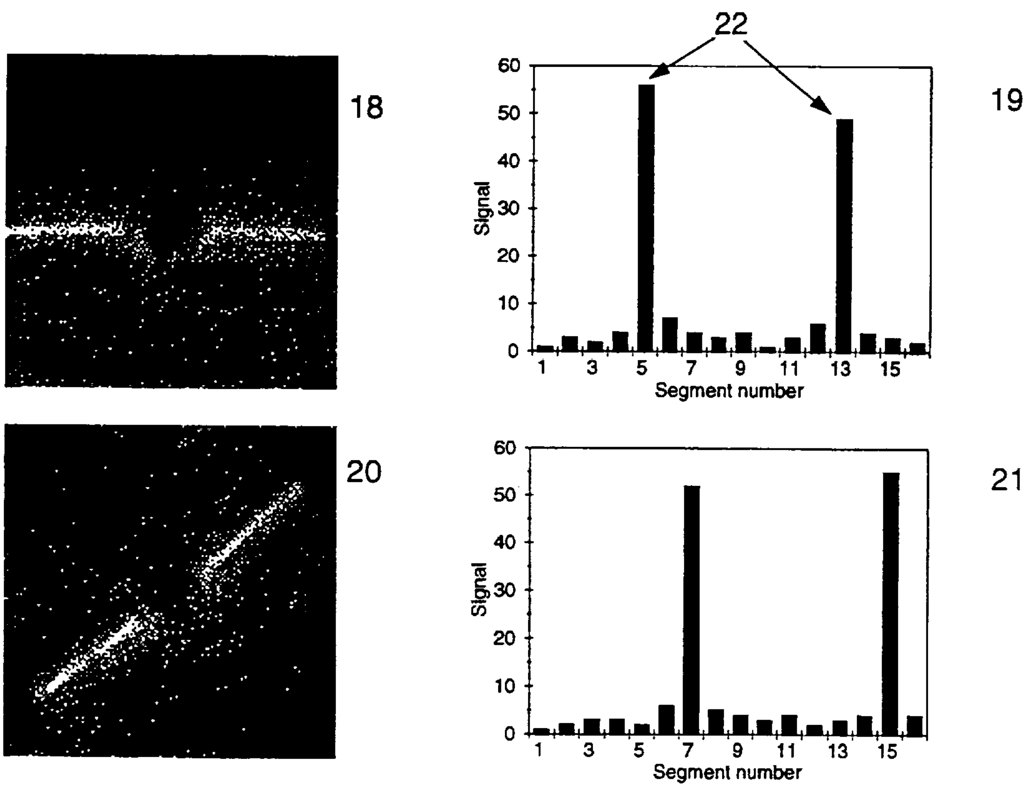

Figure 4: Images of typical spatial distributions of scattering from two fibrous particles with different orientations and the corresponding responses from a segmented ring detector having 16 segments.

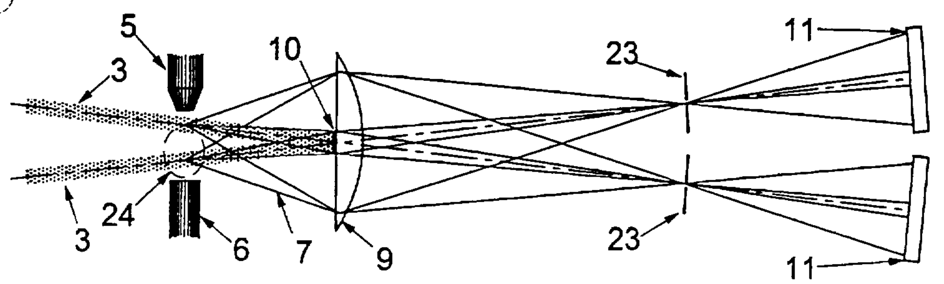

Figure 5.

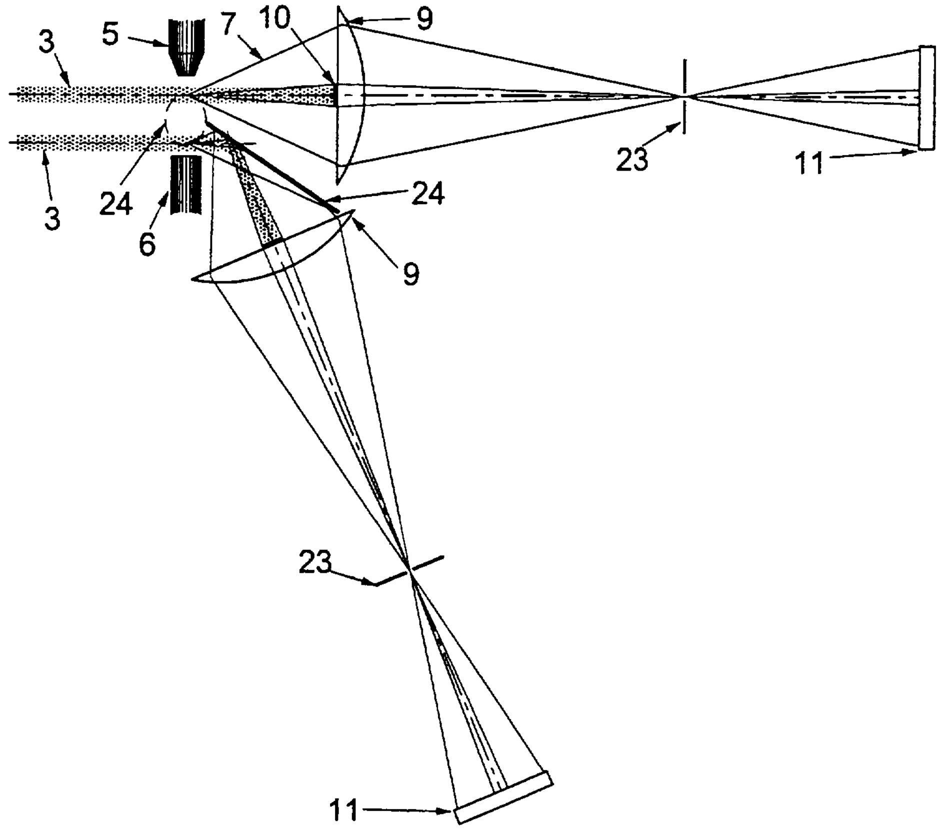

Figure 6.

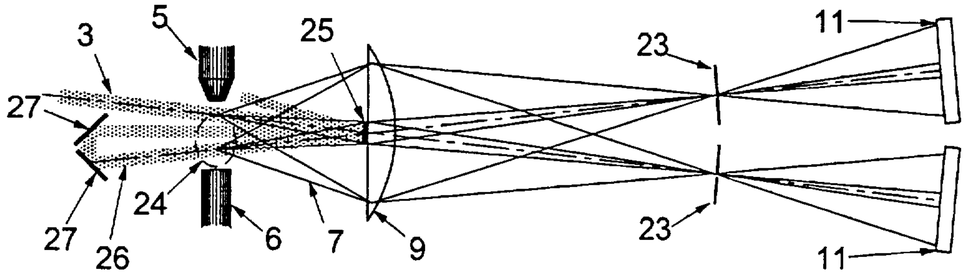

Figure 7.

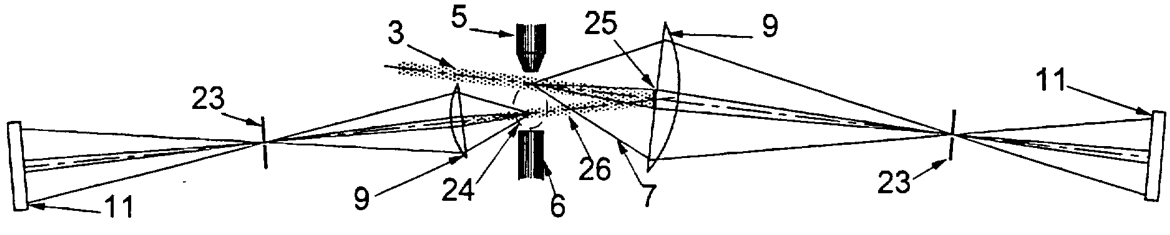

Figure 8.

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IMPROVED METHOD AND APPARATUS FOR DETECTION OF ASBESTOS FIBRES

Field of the Invention

The present invention relates to a method and apparatus for the detection of airborne particles. It is particularly applicable, but in no way restricted to discrimination between asbestos fibres and other fibre types using magnetic fields. In particular, the invention allows real-time detection of asbestos in an ambient environment.

Background to the Invention

The in-situ detection of potentially hazardous respirable fibres has become a growing concern as the health risks associated with these fibres have become more fully understood. The most commonly encountered hazardous fibres are of asbestos materials which, despite a widespread ban on their use for many years, are still present in vast quantities in buildings and industrial plant throughout the world. The most abundant type of asbestos, chrysotile (or white) asbestos, is present in over 95% of these installations. The second most commonly found variety is crocidolite (or blue) asbestos, with amosite (or brown) asbestos being a third, rarer form. Crocidolite and amosite belong to the amphibole class and are characterised by the fine, straight, needle-like fibres produced when the material is fragmented. Chrysotile asbestos belongs to the serpentine class of minerals and is characterised by a natural curvature in the fibres it produces. All three materials produce fibres which are capable of penetrating deep into the lungs and which, because of their shape, become entrapped there. Crocidolite and amosite fibres are known to be far more carcinogenic than those of chrysotile asbestos, and though the exact reasons for this are still not fully understood, the persistence of the fibres in the lung (a function of the body's ability to chemically dissolve the fibres) is believed to play a major role, since this may be measured in decades for amphibole fibres compared to months for chrysotile fibres.

Airborne asbestos fibre is a significant health hazard. Peto *et al.*, for example, (J Peto, J T Hodgson, F E Matthews and J R Jones, *The Lancet* 345, March 4, pp.535-539, 1995) highlight the continuing increase in mesothelioma mortality in Britain as a result of respirable asbestos fibres generated during clearance operations or routine building maintenance work. The unambiguous confirmation of the presence of airborne asbestos fibres within an occupational environment can normally only be achieved by the use of filter cassette sampling of airborne particles followed by electron microscopy and, to determine chemical identity, a technique such as energy dispersive X-ray analysis. These processes are laborious and expensive to perform, and perhaps most importantly, provide results only many hours after the sample acquisition and possible personnel exposure has occurred. Several attempts have therefore been made to address methods by which real-time or in-situ detection of airborne asbestos may be achieved.

Rood *et al* (A P Rood, E J Walker and D Moore, *Proc. Int. Sym. Clean Air at Work*. Luxembourg, Royal Soc. of Chem.. pp.265-267, 1991) for example, have described a low cost portable fibre monitor developed at the UK Health & Safety Executive laboratories. This device is based on the differential light scattering produced by fibrous particles which are deposited electrostatically in uniform alignment onto a glass substrate. The device is capable of detecting fibrous particles but is not designed to detect individual particles, relying on the summation of scattering signals from a substantial number of deposited fibres in order to achieve a detectable signal. Rood states that the UK clearance limit for asbestos in buildings of 10 fibres per litre of air can be detected after about 300 minutes sampling time. This does not therefore constitute a real-time detection technique.

Another example is the comparatively widely used FAM-7400 Fibrous Aerosol Monitor (Mie Inc., Bedford, Massachusetts) developed originally by Lilienfeld *et al.* (P Lilienfeld, P Elterman and P Baron, *Am. Ind. Hyg. Assoc. J.* 40, pp.270-282, 1979). This instrument draws air containing the airborne particles into a laser scattering chamber where the particles are carried along a horizontal glass tube coaxial with an illuminating laser beam. The particles remain in the beam for a comparatively long period, (approximately 0.1 seconds), and many particles may be illuminated simultaneously. Around the glass tube is a quadruple electrode arrangement. By applying a time varying signal to the electrodes, the electric field within the tube causes electrically conducting fibres present in the air-flow to oscillate. The consequent cyclic variation in light scattered by the fibres to a single light detector at the side of the chamber is used to assess fibre concentration in the air. The FAM-7400 has several limitations (described in, for example "*Aerosol Measurement*" by K Willeke and P A Baron, Van Nostrand Reinhold, 1993, pp.403-408) : its sample volume flow rate through the laser beam is very low, resulting in comparatively long response times at low fibre concentrations (typically requiring 10 minutes to count 10 fibres at a concentration of 100 fibres/litre); it may classify as fibres non-fibrous particles which happen to oscillate in the applied electric field; since more than one fibre may be present in the beam at a given time, it can only estimate the number of fibres by the magnitude of the oscillation signal, and this requires some assumptions about the sizes of the fibres present; and it has reduced sensitivity for fibres which exhibit a natural curved morphology, such as the most common asbestos form, chrysotile.

Existing real-time monitoring methods can distinguish between fibrous particles from non-fibrous ones up to a point. In addition, some techniques allow limited degree of discrimination between asbestos and non-asbestos fibres and between different types of asbestos. One such method is based on real-time analysis of spatial light scattering patterns produced by individual particles in flow as described in GB 97 18675.3 (University of Hertfordshire). This represents the closest prior art known to the applicants. The patterns contain information on morphological characteristics of the particles, allowing classification of detected particles into several categories. In order to allow sufficiently fast data processing, detection of the spatial patterns is accomplished using segmented ring detector arrays containing typically 16 segments per ring (see P H Kaye, E Hirst and Z Wang-Thomas, *Applied Optics* 36, pp. 6149-6156, 1997). However, even the best currently available detection techniques based on particle morphology do not allow unambiguous detection of asbestos, with categorisation results being much less clear than for the fibrous vs. non-fibrous particle case. For example, thin fibres of glass or some man-made mineral fibres could be erroneously classified as crocidolite and curved fibres could be misinterpreted as chrysotile, leading to "false positive" identification.

The present invention relates to apparatus and methods for overcoming such ambiguity.

Such ambiguity could be overcome by the use of a method that is sensitive to a property unique to asbestos fibres. Magnetic alignment was first applied to studying asbestos by Timbrell (see e.g. V Timbrell, *J. Appl. Physics* 43, pp.4839-4840, 1972), with further work done by Riis *et al.* and Willey. In all that research the response of asbestos fibres to magnetic fields was used for the alignment of ensembles of fibres in small quantities of liquids, followed by an examination of stationary samples under a microscope or using light scattering. Most asbestos fibre types were found to be aligned with their long axis parallel to the direction of the magnetic field. However, some types, such as amosite can contain mixtures of fibres, some of which align parallel, while others perpendicular to the field. Despite fairly extensive previous work the mechanism by which asbestos fibres are aligned in magnetic fields remained unclear. It was variously suggested that the alignment was due to: magnetite particles in the chrysotile fibres and "the presence of paramagnetism in the direction of the fibre axis" or normal to the axis in amphibole asbestos (V Timbrell, *Ann. Occupational Hygiene* 18, pp.299-311, 1975) and anisotropy of magnetic susceptibility (P Riis and E J Chatfield, NBS Special Publication 619, Proc. NBS/EPA Asbestos Standards Workshop, pp.108-120, 1982). Also, the existence of a permanent magnetic moment was implied (R J Willey, *IEEE Trans. Magnetics* 18, pp.1794-1795, 1982).

It is highly unlikely that glassy fibres would exhibit magnetic properties similar to those of asbestos unless they contain high levels of ferromagnetic impurities, such as iron compounds. Crystalline fibres can show magnetic anisotropy and could, in principle, be confused with asbestos. An example is carbon fibre which is magnetically anisotropic but its occurrence in the ambient environment is not likely to be widespread. Therefore, the measurement of fibre alignment in magnetic fields potentially offers a method of unambiguous detection of asbestos particles.

The first methods of asbestos analysis based on magnetic alignment were limited to characterisation of stationary (deposited) samples, whereby predominant orientation angles of fibres or orientation angle distributions were determined. Also, relatively large numbers of fibres were required to produce a meaningful result. Therefore, the methods were not suitable for real-time asbestos detection and monitoring.

A further method was proposed by Lilienfeld ("Method and apparatus for real-time asbestos monitoring", US Patent 4,940,327, July 1990). The system closely resembles the FAM series fibre monitors, except that using a magnetic, instead of an electric field, is suggested. The system relies on the creation of a time varying magnetic field which periodically changes direction to cause asbestos fibres passing through it to rhythmically tilt in time with the field (non-asbestos fibres would not show such behaviour). The fibres are illuminated by a laser beam propagating along the direction of the flow and scattering from oscillating fibres produces flashes of light on a detector placed alongside the beam. The path of the fibres through the magnetic field must be relatively long to allow them to reorientate themselves several times so that a periodic signal can be detected. Importantly, this system has a number of disadvantages, the most serious ones being as follows. Strong, time-varying magnetic field must be produced in a large volume, requiring substantial amounts of electric power to operate the system, with consequent reduction in portability. Sensitive detection circuits have to be positioned in proximity to the magnetic field, leading to interference, particularly so because the frequency of the field coincides with the frequency of the signal which needs to be detected. As a consequence of a relatively large sensing volume and long particle transit time (required to observe several cycles of fibre oscillation) the particle throughput of the system would be very low (probably even lower than for the FAM series of fibre monitors) and sampling times at low fibre concentrations would be excessively high. These disadvantages seriously limit the potential for practical exploitation of the system. In fact, no production models have been made available during the decade since US 4,940,327 was first filed. This would indicate that the method is just not workable, possibly for the reasons outlined above.

Despite extensive attempts to develop a real-time asbestos detection technique and despite the previous research into magnetic alignment of asbestos fibres, the need for a practicable real-time detection method for airborne asbestos has not yet been satisfied.

Summary of the Invention

According to a first aspect of the present invention there is provided a fibre detector assembly comprising:-

(i) a scattering chamber body;

(ii) means for drawing particles through said body chamber in the form of a particle stream, said means being adapted such that the particles tend to travel in single file with the longitudinal axis of particles with elongate shape substantially aligned with the direction of the flow;

(iii) means for illuminating the particle stream within the chamber body;

(iv) an optical detector adapted to intercept and collect a portion of the light scattered by particles passing through the illuminating beam;

(v) data processing means adapted to capture and process the signals from the optical detector;

wherein the apparatus further comprises a means for applying a magnetic field across the particle stream, the magnetic field lines of the magnetic field being non-parallel to the direction of the particle stream and non-perpendicular thereto.

Since only asbestos fibres will re-orientate in the magnetic field this arrangement greatly increases the accuracy of the instrument by virtually eliminating false positive readings.

Preferably the angle between the direction of the particle stream and the magnetic field lines is substantially within the range 85° - 30°.

Further preferably the angle between the direction of the particle stream and the magnetic field lines is substantially within the range 80° - 45°.

In a particularly preferred embodiment the angle between the direction of the particle stream and the magnetic field lines is substantially 45°.

Preferably the assembly is further adapted to collect a portion of the scattered light scattered by particles at the region of entry of the particle stream into the magnetic field and from another region located where the stream has crossed a substantial part of the magnetic field and, therefore, been affected by it. Only those elongate particles which give a different scattering profile between the two locations can be asbestos.

Preferably the scattered light is detected by at least two optical detectors.

Preferably the illuminating means comprises at least two beams of light.

Preferably the beams are derived from a single beam by means of reflection after the single beam has passed the particle stream.

The portions of the light scattered by the particles are suitably collected by one optical element and directed towards separate optical detectors.

Preferably the scattered light passes through an aperture before reaching the optical detector.

Preferably the magnetic field means generates, in use, a substantially constant magnetic field.

Preferably the detector comprises one or more concentric annular rings of detector elements.

Preferably, where there are a plurality of annular rings, the first or innermost annular ring comprises a single detector and the second and any subsequent annular rings each consist of a plurality of detector elements.

Preferably the radial interfaces between detector elements in adjacent annular rings are out of phase.

Preferably the radial interfaces between detector elements in adjacent annular rings are out of phase.

Preferably the optical detector comprises three annular rings and the two outermost rings are divided into multiple elements.

Preferably the annular rings of detector elements in the optical detector are substantially circular.

Preferably the data processing means incorporates a pattern classifier.

Preferably the pattern classifier comprises a neural network.

Preferably the neural network is a radial basis function neural network.

Description of the Drawings

The invention will be further described by way of example only with reference to the accompanying drawings in which:-

Figure 1 illustrates diagramatically a magnetic field applied across a particle stream;

Figure 2 illustrates diagramatically a fibre detector system according to a first embodiment of the invention;

Figure 3 illustrates a typical detector assembly;

Figure 4 illustrates images of typical spatial distributions of scattering from two fibrous particles with different orientations and the corresponding responses from a segmented ring detector having 16 segments;

Figures 5 to 8 illustrate various alternative optical detector and light beam arrangements.

Description of the preferred embodiments

The invention will now be described by way of example only.

The invention incorporates a means of producing a magnetic field in a region through which a stream of a fluid i.e. gas or liquid medium, such as, for example, air, containing particles is drawn. The invention also contains a means of measuring the change of orientation of the particles consisting of a means of illuminating the particles and producing one or more beams of circularly polarised or unpolarised light (usually from a laser or lasers) propagating in a direction essentially transverse to the direction of the lines of the magnetic field, a means of collecting the light scattered by the particles and directing this onto one or more optical detector assemblies having multiple zones of sensitivity which are essentially centrally symmetric and are characterised in that the image of the axis of any of the light beams as obtained through the light collecting means is essentially passing through the centre of symmetry of any one detector assembly.

The preferred operating conditions are chosen such that for a significant proportion of time scattered light from not more than one particle is received by any one detector assembly.

The invention will now be further described with reference to the attached drawings. Figure 1 shows a possible arrangement of the means 1 of producing the magnetic field 2, the illuminating beam 3 (shown at right angles to the page) and a means of producing the flowing medium containing particles 4, consisting in this example of a jet 5 and an outlet 6. One possible embodiment of the invention is shown as a schematic diagram in Figure 2. An arrangement similar to that in Figure 1 is used, as described above. The scattered light 7 from a particle in the region of overlap 8 between the flow and the magnetic field is collected by a lens 9. The illuminating beam 3 is separated from the scattered light 7 by a beam stop 10 placed near the lens 9. The scattered light 7 is projected onto a centrally symmetric optical detector assembly 11 in such a way that the image 12 of the axis of the light beam 3 as obtained through the lens 9 is essentially passing through the centre of symmetry 13 of the detector assembly 11. The scattered light 7 is directed onto the optical detector assembly 11 without loss of information relating to the spatial distribution of the intensity of the light scattered by the particle.

Essentially any suitable optical detector can be used but a preferred embodiment of the optical detector assembly is a photosensitive array containing one or more annular photodetector rings. The rings are concentric if more than one ring is present. At least one of the rings is divided into segments, each segment giving output proportional to the power of the light falling on it. In a preferred configuration two or more rings are divided into segments and the interfaces between segments on one of these rings are placed at azimuth angles which are out of phase with the angular positions of the interfaces on another one of the rings. This phase difference eliminates the possibility of fine scattering from an elongated particle being undetected in the event that it falls on the interface between two adjacent segments ("dead zone"). In a particularly preferred configuration the detector array also possesses an inner ring the output from which is proportional to all the scattered light falling on it. Therefore, it need not be (but can be) divided into segments. As such it will receive scattered light no matter what the orientation of the scattering particle and it can be used for triggering the system and for particle sizing.

Figure 3 depicts one of many possible embodiments of the detector assembly. The detector comprises a central circular area 13 surrounded by three annular rings, 14, 15, and 16. The central circular area 13 can be opaque to incident light so that it can act as a beam-stop for the illuminating beam of light; the first annular ring 14 is continuous and as such will receive scattered light no matter what the orientation of the particle in the beam (the output from this detector ring can be used for particle size determination); the second ring 15 is divided into 16 segments, each giving an output signal proportional to the light falling on that segment; the third ring 16 is similarly divided into 16 segments, but the rotational arrangement of these segments is out of phase with those of the second ring 15. The detector can be a photodiode array manufactured upon a single silicon wafer for reasons of compactness, robustness, dimensional accuracy, and the ability to define light-sensitive areas of any desired shape with minimal "dead-zones" 17 in between.

The detector shown in Figure 3 consists of three circular, annular, segmented rings. But this is not the only arrangement possible and other variations will occur to those skilled in the art. The number of the segments or the rings, the shape and the relative positions of the segments can all be modified. The detector assembly can also consist of discrete, separate detectors arranged in essentially circular or elliptical shape around a central point.

A detector assembly as heretofore described can be used to measure accurately the angle of orientation of fibrous particles or its change in time. Figure 4 shows a spatial distribution 18 of light scattered from a fibrous particle orientated vertically, with a corresponding response 19 from an annular detector with 16 segments, and a spatial distribution 20 from a particle rotated by 45° counterclockwise with respect to the first particle, with a corresponding response 21 (the images 18 and 20 show scattering as projected onto a distant screen centred on the direction of unscattered light). With reference to Figure 4, for fibrous particles the spatial distribution of scattered light is a function of the orientation of the particles with respect to the direction of propagation of the incident light. Furthermore, for such particles the rotation of the particle around the axis of the illuminating beam will result in an identical rotation of the spatial pattern of scattering on the detector manifesting itself as a shift of the zones of maximum illumination 22 around the circumference of the detector and a progressive reduction of the signal produced by some segments with a corresponding increase of the signal produced by adjacent segments. These changes can be processed to obtain the angle of rotation of the fibre. The secondary purpose of the detector assembly is to allow particle classification on the basis of morphology, thus narrowing down particle identity even further. By measuring the spatial distribution of the scattered light the detector assembly provides information which, following processing, can be used to classify particles into broad classes, most notably into non-fibrous, fibrous or particles having morphological characteristics usually associated with specific asbestos types (such as crocidolite and chrysotile). This processing can take the form of an explicit mathematical algorithm or it can be carried out by training an artificial neural network to perform the classification on the basis of examples of data, essentially as described previously (see P H Kaye, E Hirst and Z Wang-Thomas, *Appl. Optics* 36, pp.6149-6156, 1997). Furthermore, the intensity of the light falling on the detector assembly aids the sizing of the particles. The innermost light sensitive section of the assembly is eminently suited to this purpose by virtue of being sensitive to forward scattering, which is a good measure of particle cross-section.

Asbestos fibres such as crocidolite produce spatial distributions of scattered light characterised by the presence of long, narrow bands (see Figure 4). Therefore, if a ring detector as described herein is provided that has sufficiently narrow segments, then very small orientation angle changes can be measured. Observing several fibre reorientation cycles, as previously proposed for asbestos detection, would no longer be necessary to achieve fibre characterisation and classification. On the contrary, a fast measurement can be carried out while a fibre is undergoing very small reorientation, comparable in magnitude to the angle subtended by a single segment of the detector. A further increase in angular resolution can be obtained by using more than one segmented, concentric detector rings with the segments being out of phase, as heretofore described. These arrangements allow particle transit time to be kept short which, consequently, can lead to increased particle counting rates and reduced sampling times at low particle concentrations. This constitutes an important advantage of the present invention over existing methods of asbestos detection.

Research carried out by the applicants, some of which is summarised below, has indicated that asbestos fibres are aligned in magnetic fields predominantly due to the presence of anisotropy of magnetic susceptibility. The torque on an object characterised by axially symmetric magnetic anisotropy and placed in a magnetic field of intensity H can be written as:

$$\Gamma_a = 1/2\ \mu_0 V H^2 \Delta\chi \sin 2\theta \qquad (1)$$

where

μ_0 - permeability of vacuum,

V - particle volume,

$\Delta\chi$ - anisotropy of magnetic susceptibility (dimensionless),

θ - angle between the principal axis of the susceptibility and the magnetic field vector.

For axially symmetric susceptibility the principal axis can be the direction of maximum or minimum susceptibility; for fibrous particles it is usually, but not exclusively, along the larger dimension of the particle. The crucial feature of the above expression is the dependence on sin 2θ. Firstly, this means that there is no torque if the susceptibility axis is either parallel or perpendicular to the external magnetic field - the relative orientation must be oblique. Secondly, the maximum torque will occur when the principal axis is at the angle of 45° relative to the magnetic field. Therefore, the optimum initial relative orientation angle for detecting fibre alignment in magnetic fields would be close to 45°, as at this angle maximum reorientation rate occurs. Another specific consequence of expression (1) is that the optimum angle is the same irrespectively of the sign of the anisotropy. If fibrous particles with anisotropies of opposite sign but same magnitude are subjected to a field at 45° with respect to the axes of anisotropy (say, the long axes of the particles), the directions of their reorientation will be opposite, but the amounts will remain the same and they will be close to the maximum possible. This is especially relevant to asbestos since some types, such as amosite, can contain mixtures of fibres, some of which align parallel while others perpendicularly to the magnetic field.

Therefore, in another embodiment the invention comprises a region where a magnetic field is created and through which a medium, such as air, containing particles is drawn in such a way that the particles are subjected to aerodynamic or other forces which are able to preferentially orientate those particles that exhibit elongated shape. The magnetic field is characterised in that the direction of the magnetic field lines or lines of magnetic flux is at a substantially oblique angle with respect to the preferred orientation of the particles. The embodiment also contains means of illuminating the particles and of measuring the orientation or the change of orientation of the particles, essentially as heretofore described.

Preferably the magnetic field is characterised in that the direction of the magnetic field lines is at an angle substantially close to 45° with respect to the aforementioned preferred orientation of the particles.

In another embodiment the magnetic field is characterised in that the direction of the magnetic field lines is at an angle larger than 45° but substantially smaller than 45° with respect to the aforementioned preferred orientation of the particles. The advantage of this particular embodiment is that as prealigned elongated particles change their orientation starting from an orientation angle larger than 45° with respect to the magnetic field, they pass through a range of angles where the torque due to the magnetic field has largest values, causing the fibres to undergo faster than otherwise reorientation.

Since quantitative data which would allow the prediction of the dynamics of single asbestos fibres in magnetic fields had also been lacking, the applicants determined the magnitude of the torque produced in magnetic fields and the magnetic anisotropy. To determine the torque a miniature rotating stage was constructed which allowed balancing the forces acting on individual fibres due to magnetism with those due to viscous drag in an immersion liquid. The fibres were observed, and their orientation angle measured, using an optical microscope. When reference samples of UICC (Union Internationale de la research Contre le Cancer) respirable crocidolite and chrysotile fibres were examined, it was found that neither of these materials showed evidence of significant permanent magnetisation and that their behaviour in magnetic fields was consistent with the existence of anisotropy of magnetic susceptibility. The measured anisotropy, together with calculated reorientation times in air, are given in Table 1 below.

Table 1. Typical properties of asbestos fibres

Property	chrysotile	crocidolite
mean susceptibility anisotropy (10^{-6})	0.40	83
calculated 10° reorientation time in air for flux density 0.5T (ms):		
mean	1.8	0.14
maximum	4.0	0.59
minimum	0.17	0.052

Reorientation of crocidolite asbestos fibres in magnetic fields was also observed in air, with gypsum crystals as a negative control. Fibres passing through an instrument constructed according to one of the embodiments described above were initially aligned predominantly with their long axis parallel to the air flow due to the action of an aerodynamic focusing system (sheath flow). Their orientation angle was then measured either after passing through a magnetic field directed at an oblique angle to the flow, or without the field. It was found that only crocidolite fibres subjected to the magnetic field showed marked reorientation and that the magnitude of the change in orientation was consistent with values calculated on the basis of the previously measured anisotropy - see Table 2. The difference of the mean orientation angles with and without the field was statistically significant for crocidolite (P=0.999) and not for gypsum, demonstrating that it should be possible to discriminate between airborne asbestos and other fibre types on the basis of magnetic properties, notably the anisotropy of susceptibility.

Table 2. Orientation angle of asbestos fibres in air sheath flow without (B=0) and with (B=0.26T) a magnetic field.

material	mean angle (degrees)		mean reorientation (degrees)		number of fibres (-)	
			measured	calculated		
B (T):	0	0.26	-	-	0	0.26
crocidolite	-1.05	7.77	8.81	7.70	1541	1606
gypsum	-1.63	0.07	1.70	0	9837	8900

Particularly if it is desired that fibres characterised by low anisotropy be detected, lower fibre reorientation rates may need to be detected than would the case for materials such as crocidolite or amosite (see Table 1). However, the simple solution of increasing particle transit time through the sensing zone would have the undesirable consequences of proportionately reducing maximum sampling frequency or increasing the sampling time at low particle concentration. For such circumstances another embodiment is provided which contains two or more illuminating light beams positioned in such a way that the flow containing particles successively passes through these beams and the zones where the beams overlap with the flow are separate and essentially on opposite sides of the region where the magnetic field is created. The light scattered from the particles is detected from each zone of overlap by separate detector assemblies, thus allowing measurements of fibre orientation angle to be carried out first before any given fibre enters the region of strong magnetic field and then one or more times after the fibre has been subjected to the field. The correspondence between scattered light signals originating from the same particle as it successively passes through the beams can be established from the knowledge of the separation between the beams and the average transit time of particles between the beams, thus allowing the reorientation angle due to the magnetic field to be measured. The general advantage of this embodiment is that while particle transit time through each beam sensing zone can be kept short, with all the advantages that this entails, the time during which the reorientation takes place can be much longer, allowing smaller reorientation rates to be observed. It will be noted that the collection of the scattered light can be accomplished using a common optical element, such as a mirror or a lens, for example as shown in Figure 5; or using separate elements for each beam, for example as shown in Figure 6; or by combining common and separate elements. In this embodiment and its variations it is advantageous to incorporate field apertures 23 into the paths of the scattered light preferably at conjugate points to the locations of the sensing zones. In a further variation of this embodiment, illustrated by way of example in Figures 7 and 8, two or more beams can be obtained by reflecting the illumination beam after its passage through the flow of the particles back towards the magnetic field region 24 in order to overlap the beam and the flow again at a different location and collecting the scattered light using either a common optical element (Figure 7), or separate elements (Figure 8). The folding of the beam can be achieved using a single mirror 25 or a set of mirrors 25 and 27.

These are only some of the possible optical arrangements. The invention is intended to encompass all arrangements in which one or more beams of electromagnetic radiation are directed through a particle stream and focused onto one or more detectors.

It is further contemplated, by taking into consideration the data shown in Tables 1 and 2, that compact permanent magnets, such as rare earth ones, can be used in the present invention to produce sufficiently strong magnetic fields, thus allowing a particularly small, portable apparatus to be built which in addition does not require substantial sources of electric power. The magnets should preferably be part of a magnetic circuit containing materials of high magnetic susceptibility and formed essentially in the shape similar to the letter "**C**" where the open part of the circuit coincides with the region through which the particles are flowing, although other configurations are possible and will be apparent to those skilled in the art.

It will also be apparent to those skilled in the art that many variations to the embodiments heretofore described are possible and that features of some of the embodiments can be incorporated into other embodiments. By way of example, a modification can be obtained by incorporating into the light collecting means a mirror with an aperture to separate the illuminating beam from the scattered light; yet further modification is possible by way of using illuminating beams characterised by different wavelengths and separating the scattered light using optical filters.

It will be readily apparent that the asbestos detector according to the present invention has many advantages over existing methods: it allows real time detection, it can simultaneously provide good discrimination between both fibrous and non-fibrous materials and between asbestos and non-asbestos, it has small sensing volume resulting in high particle throughput and short sampling time, it does not require large amount of electric power to produce a magnetic field and it can be the basis of a portable instrument.

For the avoidance of doubt as to the generality of this disclosure certain points should be emphasised. The angle of the magnetic flux with respect to the particle stream is not necessarily critical to a degree or so. The important criterion is that the angle and arrangement is such that the asbestos particles rotate by a measurable amount then that is sufficient.

Furthermore any type of detector can be used with any form of electromagnetic radiation of any suitable wavelength.

Any suitable fluid medium can be used and air is described by way of a convenient example The fluid could be a liquid.

CLAIMS

1. A fibre detector assembly comprising:-

(i) a scattering chamber body;

(ii) means for drawing particles through said body chamber in the form of a particle stream, said means being adapted such that the particles tend to travel in single file with the longitudinal axis of particles with elongate shape substantially aligned with the direction of the flow;

(iii) means for illuminating the particle stream within the chamber body;

(iv) an optical detector adapted to intercept and collect a portion of the light scattered by particles passing through the illuminating beam;

(v) data processing means adapted to capture and process the signals from the optical detector

wherein the apparatus further comprises a means for applying a magnetic field across the particle stream the magnetic field lines of the magnetic field being non-parallel to the direction of the particle stream and non-perpendicular thereto.

2. A fibre detector assembly as claimed in Claim 1 wherein the angle between the direction of the particle stream and the magnetic field lines is substantially within the range 85° - 30°.

3. A fibre detector assembly as claimed in Claim 2 wherein the angle between the direction of the particle stream and the magnetic field lines is substantially within the range 80° - 45°.

4. A fibre detector assembly as claimed in Claim 3 wherein the angle between the direction of the particle stream and the magnetic field lines is substantially 45°.

5. A fibre detector assembly according to any preceding claim wherein the assembly is further adapted to collect a portion of the scattered light scattered by

particles at the region of entry of the particle stream into the magnetic field and from another region located where the stream has crossed a substantial part of the magnetic field.

6. A fibre detector assembly according to Claim 6 wherein the scattered light is detected by at least two optical detectors.

7. A fibre detector assembly according to Claim 6 or 7 wherein the illuminating means comprises at least two beams of light.

8. A fibre detector assembly according to Claim 7 wherein the beams are derived from a single beam by means of reflection after the single beam has passed the particle stream.

9. A fibre detector assembly according to Claim 6, 7 or 8 wherein the portions of the light scattered by the particles are collected by one optical element and directed towards separate optical detectors.

10. A fibre detector assembly according to Claim 7 or 8 wherein the portions of the light scattered by the particles are collected by separate optical elements and directed towards separate optical detectors.

11. A fibre detector assembly according to any preceding claim wherein the scattered light passes through an aperture before reaching the optical detector(s).

12. A fibre detector assembly as claimed in any preceding claim wherein the magnetic field means generates, in use, a substantially constant magnetic field.

13. A fibre detector assembly as claimed in any preceding claim wherein the detector comprises one or more concentric annular rings of detector elements.

14. A fibre detector assembly as claimed in Claim 13 wherein, where there are a plurality of annular rings, the first or innermost annular ring comprises a single

detector and the second and any subsequent annular rings each consist of a plurality of detector elements.

15. A fibre detector assembly as claimed in Claim 13 or 14 wherein the radial interfaces between detector elements in adjacent annular rings are out of phase.

16. A fibre detector assembly as claimed in claim 13, 14 or 15 wherein the optical detector comprises three annular rings and the two outermost rings are divided into multiple elements.

17. A fibre detector assembly as claimed in any preceding claim wherein the annular rings of detector elements in the optical detector are substantially circular.

18. A fibre detector assembly as claimed in any preceding claim wherein the data processing means incorporates a pattern classifier.

19. A fibre detector assembly as claimed in Claim 18 wherein the pattern classifier comprises a neural network.

20. A fibre detector assembly as claimed in Claim 19 wherein the neural network is a radial basis function neural network.

21. A fibre detector assembly substantially as herein described with reference to and as illustrated in the accompanying drawings.

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Application No: GB 9902017.4 **Examiner:** Rosie Hardy
Claims searched: 1-21 **Date of search:** 26 April 1999

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.Q): G1A (ADMP)

Int Cl (Ed.6): G01N 15/02 15/10 27/72

Other: WPI EPODOC JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	US 4940327 LILIENFELD See whole document and figs 1-4	

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
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