Real-time asbestos detector for outdoor monitoring of asbestos superfund sites

Project Background

Inhaled asbestos fibres are known to be extremely harmful to health, causing diseases such as lung cancer, asbestosis and mesothelioma. The Environmental Protection Agency (EPA) has been involved in remediating contaminated sites such as the BoRit Asbestos Superfund Site in Montgomery County, Pennsylvania. In this example, the construction of a cap over the entire site should, if left undisturbed, prevent the escape of harmful fibres to the air. However, monitoring the long-term efficacy of this, or any other remediation technique, means regular return trips to filter large volumes of air, followed by laboratory analysis of the filter. Asbestos releases at times other than those of periodic filter testing will clearly not be detected.

The University of Hertfordshire (UH) has developed technology that allows the real-time detection of airborne asbestos fibres. At present, this technology is not optimised for long-term field monitoring at the extremely low contamination levels that may be expected at sites such as BoRit. However, it can be optimised for such deployment.

Project Aim

The aim of this project, therefore, is to further enhance the UH asbestos detection technology through the development of a ***FIELD ASBESTOS MONITOR*** that would allow continuous and autonomous monitoring for airborne asbestos at BoRit, using a network of real-time detectors.

Specific Project Objectives

The Field Asbestos Monitor would incorporate the following developments:

1. To increase the sample flow-rate of our existing detection technology to allow asbestos detection at background clearance levels (0.01 fibres/ml) within a timeframe of a few minutes.
2. To further develop the statistical analysis used in the existing detection technology so as to allow quantitative estimation of asbestos concentration (in fibres/ml), thereby allowing direct comparison with statutory filter-based microscopy analysis (NIOSH 7400[1] & 7402 [2][1]).
3. To incorporate automated reporting / data telemetry into the existing technology to allow real-time continuous remote monitoring from a network of spatially distributed detectors. (If prevailing wind-speed and direction were known, this could also allow estimation of location of an asbestos release within the overall site).
4. To incorporate automated HEPA filter insertion into the sample flow so that, when the unit detects asbestos, the sample flow is directed through the HEPA filter for as long as the detection remains positive. The filter can subsequently be removed to allow conventional transmission electron microscopy (TEM) [2] or similar analysis.

Technological Background

Part of the reason that asbestos is so harmful is that it is fibrous. This has the dual effects of allowing the particle to remain airborne longer than a similar mass non-fibrous particle, and to make it harder for the body to expel from lung tissue. (Such retention in the lung is exacerbated by the body's inability to bio-chemically break down the trapped asbestos fibres. The 'half-life' of chrysotile fibres remaining in the lung is therefore estimated to be several years; that of crocidolite, many decades).

Spatial Light Scattering

Using imaging to identify an asbestos fibre in the appropriate size range (NIOSH 7400: longer than 5µm in length, and with length-to-width ratio greater than 3:1) requires a level of magnification that constrains the optical depth of field, and can be prone to optical aberrations. Using a light scattering technique captures essentially the same information as an image of the particle, but has the benefits of an unconstrained depth-of-field, fewer optical aberrations, and can be performed with moving particles in a wide airflow.

Spatial scattering techniques have therefore been developed by the University of Hertfordshire for the detection and classification of many types of airborne particle[3], including fibres. Fig. 1 shows a typical scattering geometry used to record these spatial scattering patterns, along with some example spatial scattering patterns from typical background particles, crocidolite fibres and chrysotile fibres. As the patterns in Fig.1 (middle row) suggest, straight fibres, such as those of the amphibole forms of asbestos, produce distinct linear scattering and, since the scattering is actually orthogonal to the fibre axis, the angle of the fibre can be determined from the angle of the scattering pattern. This is important in the UH detection technology, as explained below. Chrysotile fibres have a natural curvature and this results in 'bow-tie' scattering patterns of the type shown in Fig 1 (bottom row). Again, the angle of the 'bow-tie' is at 90° to the angle of the actual fibre axis.

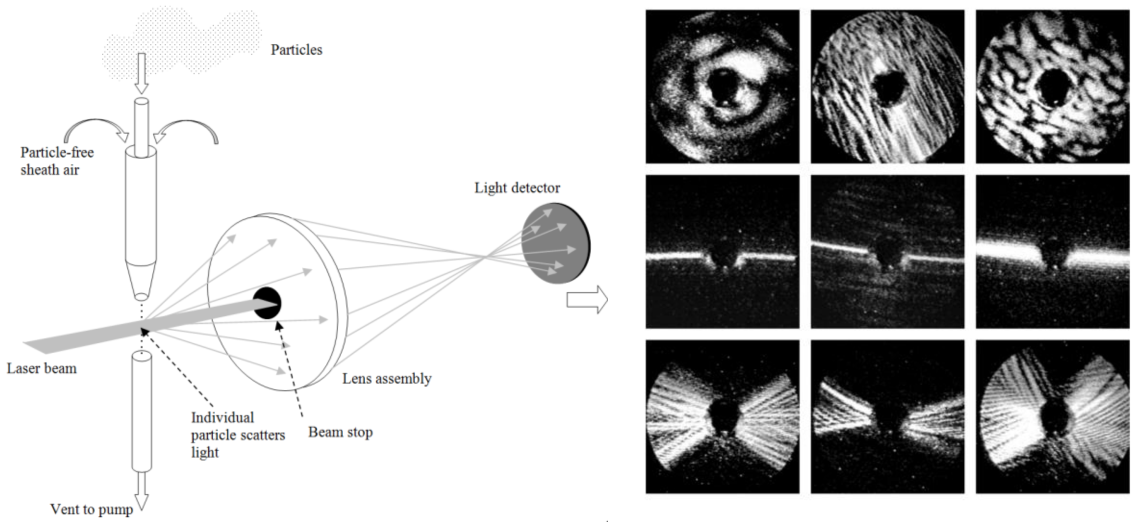

Figure 1: (Left) Schematic diagram of the scattering geometry used to capture scattering profiles from individual particles carried in an airflow. (Right) Examples of spatial scattering profiles recorded from individual airborne particles. Top row: typical background particles of mineral dust etc., Middle row: profiles from individual crocidolite asbestos fibres; Bottom row: profiles from individual chrysotile asbestos which, because of their natural curvature, produce unique 'bow-tie' patterns.

Magnetic properties of asbestos

Whilst the type of light scattering apparatus shown in Fig. 1 can be used for the efficient real-time detection of airborne fibres, it cannot distinguish between different types of fibre except where there is a distinct morphological feature, such as the curvature of chrysotile asbestos. It cannot therefore be used to discriminate, say, crocidolite asbestos fibres from other airborne fibres.

A range of fibrous materials may be encountered in the atmosphere. These include fibrous glass, mineral wool, refractory ceramic fibres, wood and other plant fibres, and synthetic organic fibres. Most of these fibres are not especially hazardous to health by inhalation both because of their relatively large diameters (compared to asbestos) which prevents their penetration deep into the lung alveoli, and because, even if trapped in the lung, most are effectively removed (dissolved) by the body's natural macrophage defences. It is important therefore not to classify such fibres as asbestos even in the rare event that their morphology resembles that of asbestos.

One feature that does distinguish asbestos from the other fibrous materials is that asbestos possesses a so-called paramagnetic moment. This means it is not itself magnetic, but it behaves like a magnet in a magnetic field and can therefore be aligned by a magnetic field [4][5][6]. The UH technology uses this phenomenon, along with light scattering pattern analysis, to discriminate asbestos fibres from other types of fibre in the air.

Current state of the art

In short, the UH technology uses a laser beam directed at particles carried in a sample airflow (as in Fig. 1). The detector assesses (in a few microseconds) the light scattering pattern of each individual particle (this may be at rates of hundreds of particles per second). If a particle is deemed to be a fibre, the instrument also measures the orientation angle of that fibre to the airflow. The particles then pass through a short region (about 3mm in length) in which there is a strong magnetic field. Fibres which are non-asbestos will not be affected by the magnetic field. However, asbestos fibres will try to align with the field and will therefore rotate through an angle (typically up to ~20-30°). As particles leave the magnetic field, a second laser beam illuminates them and again the detector determines which fibres have rotated and which are therefore asbestos.

The University of Hertfordshire published a paper in 2013 detailing the successful production of an instrument based on the above technology. It was unique in being able to detect asbestos fibres in the air in real-time. The instrument development was funded by the European Union and was targeted at providing tradespeople (plumbers, electricians, demolition workers, etc) who are at risk of disturbing asbestos unintentionally, with a compact ('wearable') unit that would rapidly alert them to the presence of airborne asbestos. The EU estimate that up to half a million tradespeople across Europe will die of asbestos related disease by 2030. The real-time nature of the UH instrument is unique in the field, with conventional detection methods being based on filter samples which are subsequently to be examined at a laboratory using TEM analysis.

In the UH technology, the decision as to whether or not asbestos is present in a sample of fibres is based on a statistical analysis of a number of detected fibres, typically ~10 to 50 in number. This method is ideal in the context of tradespeople where they need immediate warning of exposure to inhalable asbestos made airborne by their actions (eg: drilling, sanding, etc) and the requisite number of fibres would be sampled in a short time. However, in its current form, the UH technology is not ideal for 'background' monitoring for asbestos at a site such as BoRit where the concentration of fibres may be only a few per cubic metre of air. This is because the sample flowrate (ie: the volume of air drawn into the instrument for testing) is comparatively low at approximately 100 ml/min and sampling sufficient numbers of fibres would take a prohibitively long time. (For example, if a fibre release event lasted just a few minutes and the fibres were carried past the detector on the prevailing wind, potentially insufficient numbers of fibres would be sampled in that time to make a positive detection).

A second technological limitation of the UH technology in its present form is that it makes no attempt to specify the concentration of asbestos fibres detected (tradespeople just want to know if asbestos is there or not!). In a background monitoring situation, an estimate of the actual concentration of asbestos would be required to allow comparison with statutory exposure limits, as determined by TEM.

Addressing the technological hurdles

We believe that the current limitations of the UH technology are surmountable and that it can be developed and optimised in a Field Asbestos Monitor to provide effective, continuous background monitoring for sites such as BoRit. The elements of this optimisation are outlined below:

Increased sample flowrate

For a background monitoring application, a sample flowrate of 1 litre/minute or more would be necessary, ie: ten times the present flowrate use in the UH ‘tradesman’s’ instrument. We believe such an increase is achievable. It would require computational fluid dynamics modelling as well as some laboratory experimentation in order to retain aerodynamic control over fibre orientation while increasing the volume of air sampled to the desired level. In practical terms, it would mean increasing the diameter of the sample flow from 1 mm to approximately 3 mm whilst maintaining the same flow velocity.

Correlation with standard testing procedures

Standardised concentration measurement is currently performed by trained operators that measure and count fibrous particles according to the NIOSH 7400 standard [1]. This standard acknowledges that there is a +213% and −49% upper and lower confidence value for the mean for a 100-fiber count in inter-laboratory comparison. By further optimisation of the UH technology to maximize asbestos fibre rotation and angle measurement accuracy, it should be possible to augment the analysis it uses and yield asbestos detection at the individual fibre level. This, coupled with further refinement of the data analysis underpinning the technology, should allow the determination of asbestos concentrations to the same or better level of accuracy as NIOSH 7400 & 7402 – something hitherto impossible without using a technique such as x-ray diffraction microscopy (TEM).

Automated reporting

The real-time nature of the UH technology means that it would be possible to inform the appropriate authorities virtually instantly of the presence of asbestos. To this end, we would propose the developed fieldable monitoring instrument would will be able to connect to the local cell-phone network and report particle, fibre, and asbestos concentrations (subject to the above optimisations) both periodically and in the event of a raised level of airborne asbestos being made. The reporting mechanism may take the form, for example, of a text or email to the appropriate authorities.

Filter capture verification

In order to verify an asbestos detection event and to establish the mineralogical form of that asbestos, we propose to incorporate into the Field Asbestos Monitor a removable, triggerable cellulose ester membrane filter module. The sample airflow would be directed through this filter only when the Monitor registered a positive asbestos detection. This would not only prolong the filter life by minimizing unnecessary filter clogging, but, would allow the filter to be taken for asbestos verification via conventional laboratory optical and/or TEM analysis.

Costings and timeline

The development of the Field Asbestos Monitor is expected to take 12 months with the application of two full-time research engineers at UH. The total cost would be USD $120,000 (includes staffing, materials and consumables, and University overheads).

For the production of 8 identical Monitors along with an analysis of their optimal locations based on dispersion modelling of the local area, a further $110,000 dollars and six months would be required.

References

[1] NIOSH 7400: http://www.cdc.gov/niosh/docs/2003-154/pdfs/7400.pdf

[2] NIOSH 7402: http://www.cdc.gov/niosh/docs/2003-154/pdfs/7402.pdf

[3] University of Hertfordshire Particle Instruments Group. http://go.herts.ac.uk/pid

[4] V. Timbrell (1975) Alignment of respirable asbestos fibres by magnetic fields, Ann. Occup. Hygiene, 18 (4) 299-311.

[5] Z. Ulanowski and P. H. Kaye (1999) Magnetic anisotropy of asbestos fibres. J. Appl. Physics 85 (8) 4104-4109

[6] C. Stopford et al (2013) Real-time detection of airborne asbestos by light scattering from magnetically re-aligned fibers, Opt. Express, 21 (9), 11256-11267

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