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A Low-Cost Real-Time Detector for Airborne Asbestos Fibers

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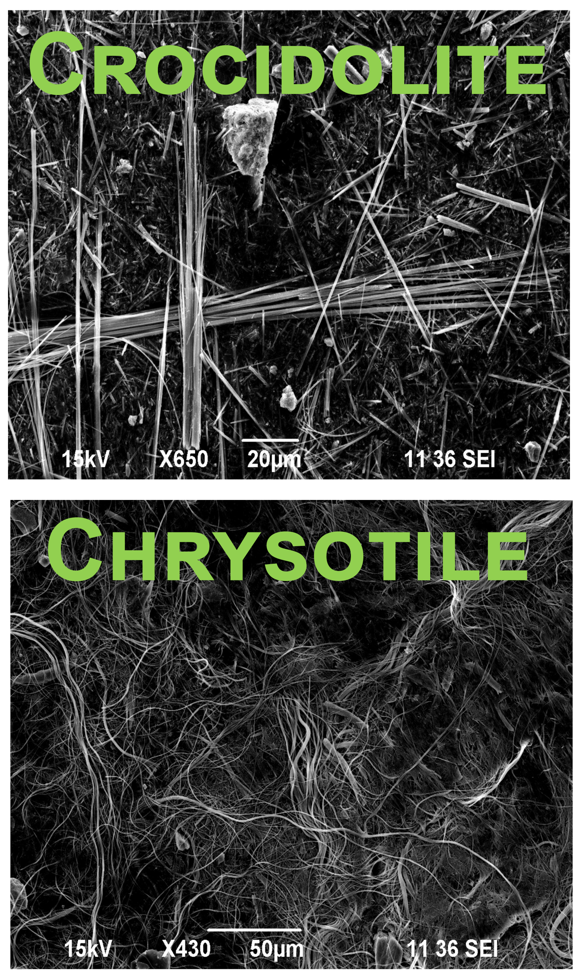

Figure 1: SEM images of asbestos fibers

Introduction

Inadvertent inhalation of carcinogenic asbestos has become a leading cause of work related deaths throughout the industrialized world. The World Health Organisation estimate 100,000 deaths per year worldwide due to occupational exposure [1]. The US National Institute for Occupational Safety and Health (NIOSH) state there is "no evidence for a threshold or 'save' level of asbestos exposure" [2]

Airborne asbestos fiber concentrations are currently determined via sampling of ambient air through a filter. The filter is then analysed in-situ by phase contrast microscopy to see if fibrous particles are present and then sent for EDAX (energy dispersive x-ray) analysis off site to ascertain whether the fibers are of asbestos or not. This process can take from several hours to several days, during which time inadvertent exposure of personnel to asbestos may occur.

Until now there has been no real-time method for determining the presence of airborne asbestos.

Methodology

A sample airflow is drawn from the ambient environment and sheathed in clean particle-free air before being delivered through a measurement space in single file (Figure 2). The measurement space is crossed by two laser beams (660nm, 25mW) separated vertically by 3mm. Each particle crossing the first laser beam will scatter light in manner dependent on its size, shape, and orientation (Figure 3). This pattern of scattered light is interrogated using a pair of linear 512-pixel CMOS arrays, from which we can determine both the particle morphology (i.e. whether or not a particle is fibrous) and, if fibrous, the angle of orientation of the fiber with respect to the airflow. If the particle is deemed not to be fibrous, it is ignored and the system awaits the next particle. The space between the two laser beams is permeated by a magnetic field (at 45° to the airflow) produced by two neodymium rare-earth magnets. Asbestos fibers are unique in responding to a magnetic field by trying to align with the field [3,4]. Thus, an asbestos fiber passing between the beams will rotate by a measurable amount which can be determined from the scattering pattern produced when the fiber passes through the second laser beam. The whole measurement process takes <2ms, allowing up to ~600 particles/s to be analysed.

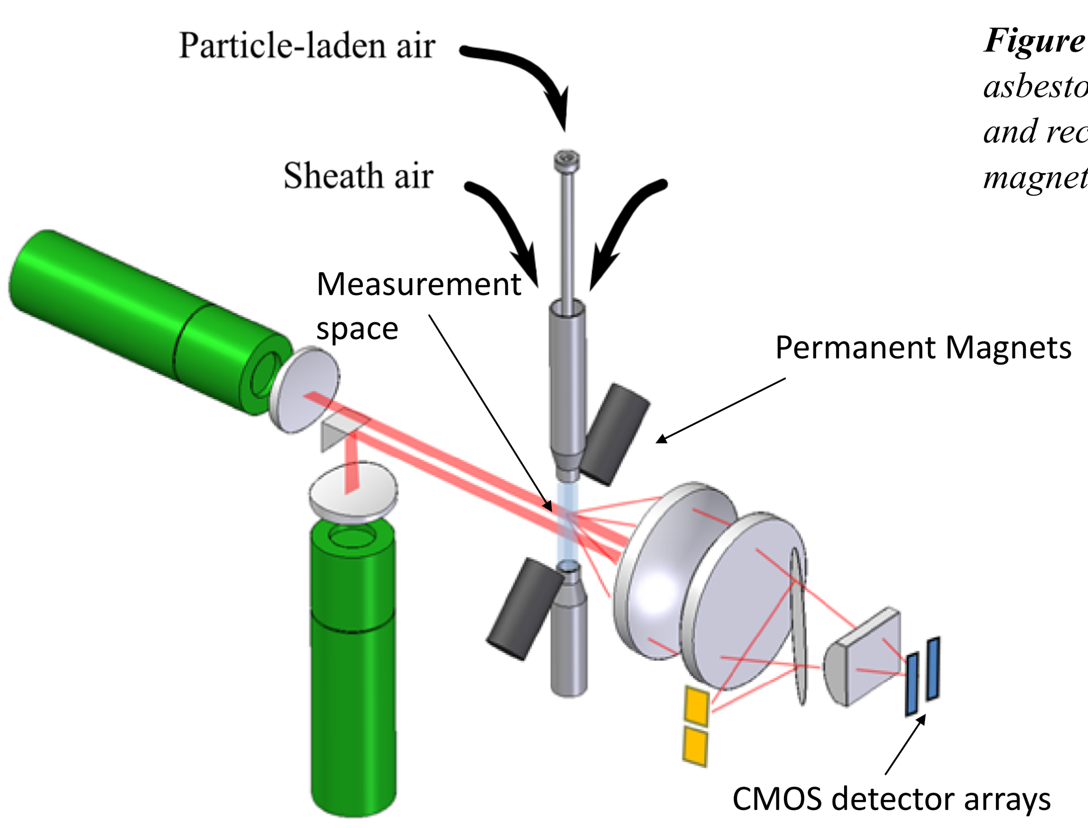

***Figure 2 (left):** Schematic diagram of the Dual-beam asbestos detection system. Forward scattered light is focused and recorded twice—once before and once after exposure to a magnetic field.*

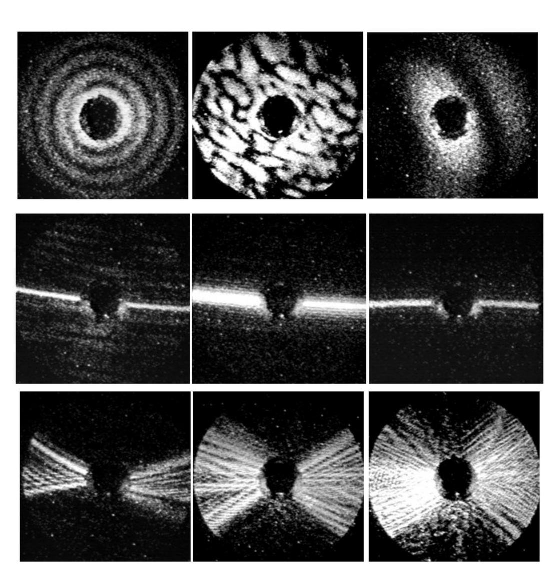

***Figure 3:** Exemplar forward scattering patterns.* Top row: *Background particles.* Middle row: *Crocidolite fibers.* Bottom row: *Chrysotile fibers*

Data analysis

A highly computationally efficient differentiation between fibers and non-fibers is required to allow the instrument to operate in dusty environments (such as construction or demolition sites). The dual CMOS linear arrays used to capture the scattering pattern (Figure 4) provide scattering information based on relatively few pixels, thus reducing the processing required. Evaluating a ratio of peak-to-mean pixel intensity (PTM) over each array allows rapid discrimination between fibers and non-fiber particles for (based on a PTM of >10). Fiber angle of orientation can also be determined geometrically from the vertical separation of peaks in each array.

A 2-sample test of proportions (Eq 1) statistical analysis is performed which compares the number of fibers that rotate beyond a threshold angle between a reference set of non-asbestos fibers and the test sample. Sensitivity is dependent on asbestos type (e.g. crocidolite has a larger magnetic anisotropy than chrysotile). For example, if crocidolite fibers are the only fibers present in the aerosol of background dust particles, then 99% confidence detection can be achieved with as few as ~10 fiber measurements.

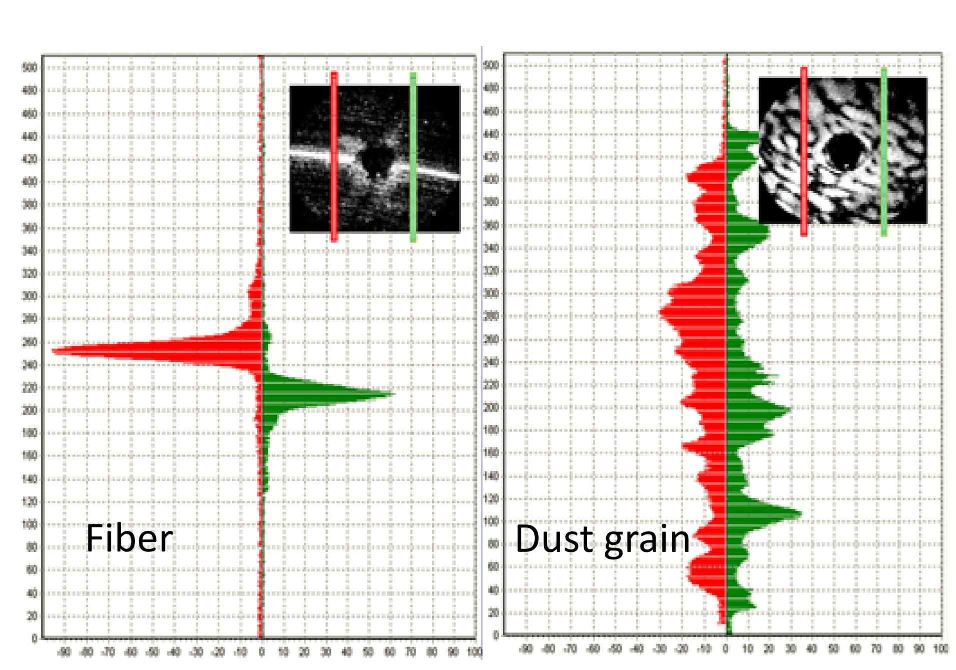

***Figure 4:** Example particle scattering patterns recorded from the dual CMOS linear arrays. For illustration only, the inserts show the positions of the two CMOS arrays (red and green bars) superimposed on the 2D light scattering patterns from similar particles to those that produced the array data.*

$$z = \frac{P_t - P_r}{\sqrt{PQ\left(\frac{1}{n_t} - \frac{1}{n_r}\right)}}$$

***Eq 1:** 2-sample test of proportions. P_t & P_r and n_t & n_r are the proportion and absolute number of fibers rotating by more than the threshold angle for test and reference populations. P is the pooled proportion, and Q=1-P.*

Laboratory testing

A three-level negative pressure laboratory was commissioned to safely aerosolise asbestos in order to record data from known crocidolite, amosite and chrysotile samples. Data were also recorded from non-asbestos fibers, such as gypsum, which could be used as a 'control' material to assess and minimise the extent of fiber rotation resulting from aerodynamic effects in the sample flow regime. Such rotation (which could be confused with magnetically-induced rotation) cannot be completely eliminated but, with careful flow arrangement, can be reduced to ~1/10th that of magnetic rotation.

Field Trials

Asbestos contractors employed to remove contaminated material from residential, public and commercial buildings have provided access to their sites for field trials of the instrument. Such sites included industrial, commercial and domestic buildings. In each case, the contractors made independent assessment of the presence of asbestos using the standard filter sampling and x-ray analysis.

Results

During each trial, a prototype asbestos detector instrument was positioned in the workplace environment and left to record data over several hours or days. Statistical population analysis (Eq 1) was computed for every 30, 60 and 90 detected fibers amongst the potentially millions of non-fiber particles. A typical data analysis output is shown in Figure 5 below.

The x-axis shows experiment time (hr:min:sec). The y-axis (green) indicates the size of the fiber sample (30,60,90) being used in the analysis. The y-axis (blue) gives the value of the calculated z-statistic. When Z>Zcr we can be 99% confident of the presence of asbestos. In the example given, therefore, it can be seen that this threshold was reached after just the first 30 fibers were detected, and positive asbestos detection continued except for a brief period around 14:12. In this case, the instrument was able to identify asbestos fibers within very high non-fibrous particle concentration (~57,000 litre^{-1}), even when the fibrous particle concentration was low (12 litre^{-1}).

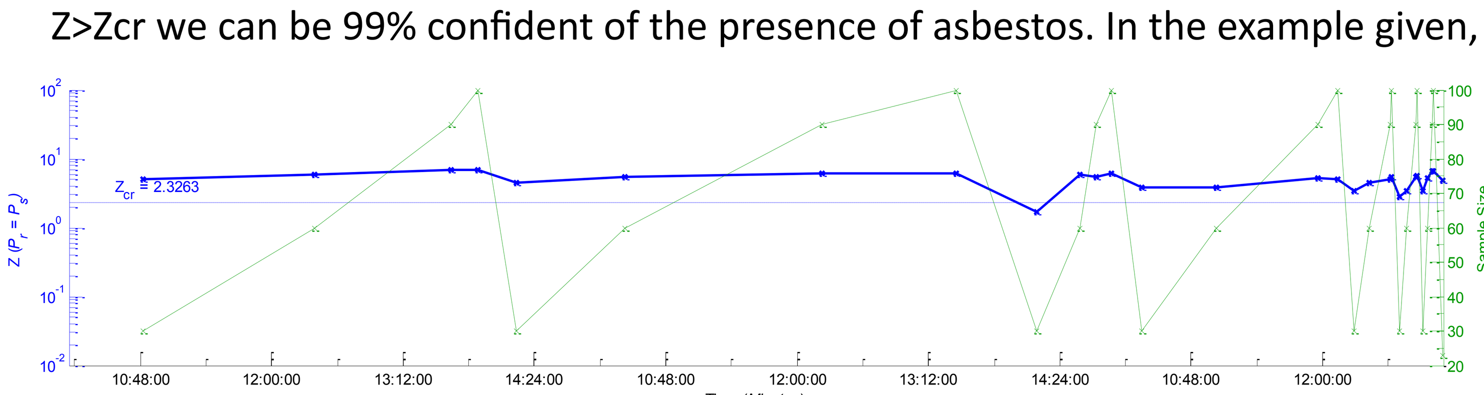

***Figure 5:** Example data from a field trial. Green line indicates sample size (30, 60, or 90 detected fibers), and blue line indicates the calculated z-statistic. When Z>Zcr we can be 99% confident of the presence of asbestos.*

Discussion

The prototype real-time instrument has demonstrated its ability to correctly detect the presence or absence of airborne asbestos fibers (determined from independent filter sample testing) in a wide range of test environments [5]. Amphiboles, such as crocidolite and amosite, can be positively detected with as few as ~10 fibers (depending on the quantity of non-asbestos fibers present). Chrysotile has a lower magnetic anisotropy than amphiboles and rotates less in a magnetic field. This requires more chrysotile fibers to be measured for a positive detection. To overcome this, we are adding a further measurement, based on the detection of the characteristic 'bow-tie' scattering produced by these curved chrysotile fibers (Figure 3), to complement the existing fiber-rotation measurement and enhance detection confidence to similar levels to the amphiboles.

Work towards the production by a of a compact, low-cost, version of the prototype instruments, aimed at trades-people, is due to commence shortly.

References:

[1] World Health Organization, Factsheet Number 343 – July 2010. http://www.who.int/mediacentre/factsheets/fs343/en/index.html

[2] Testimony of NIOSH on occupational exposure to asbestos, tremolite, anthrophyllite and actinolite. 29CFR, Parts 1910 and 1926. 9 May, 1990.

[3] V. Timbrell, "Alignment of respirable asbestos fibers by magnetic fields," Ann. Occup. Hyg. **18**, 299-311 (1975).

[4] Z. Ulanowski and P. H. Kaye, "Magnetic Anisotropy of Asbestos Fibers," Appl. Phys. 85, 8, 4104-4109, (1999).

[5] C. Stopford *et al*, "Real-time detection of airborne asbestos by light scattering from magnetically re-aligned fibers" Opt. Express, **21**(9) , 11356-11367 (2013)

Acknowledgements

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Further Information

For more details on this and related work see:

http://go.herts.ac.uk/PID