Institution: University of Hertfordshire

Unit of Assessment: Panel B (9): Physics

Title of case study: Detecting airborne bio-organisms

1. Summary of the impact (indicative maximum 100 words)

Since the 1990s, the threat from malevolent release of airborne pathogens has grown in military and civilian contexts. However, solid-state UV lasers, central to the preferred fluorescence detection technologies, were prohibitively expensive for use in 'low-cost' detectors. In 2001, Hertfordshire researchers proposed an alternative based on inexpensive xenon flashlamp sources, commonly used in disposable cameras. Between 2001 and 2006, they developed and optimised this approach, with the resulting 'WIBS' technology now a core part of the UK military's bioaerosol defence programme and patented worldwide. The technology's affordability also has led to its growing international use in areas such as atmospheric science, climate research, and occupational health. In 2012, a commercial licence was purchased by a leading US instrumentation company to exploit in the field of atmospheric and climate science; discussions with further licensees to exploit in other fields are continuing.

2. Underpinning research (indicative maximum 500 words)

After the attacks on the World Trade Center and the Pentagon on 11 September 2001, the perceived threat of terrorist bioaerosol attack on civilian targets increased significantly. In countering this risk, it was seen as imperative to have bioaerosol detection systems capable of providing a real-time warning of attack in sensitive or vulnerable areas such as underground rail networks, shopping malls and airports.

Existing real-time military bioaerosol detection technology, developed primarily for battlefields, was prohibitively expensive for widespread deployment in urban civilian situations. Such technologies were predominantly based on exploiting intrinsic particle fluorescence to provide real-time discrimination between biological and non-biological airborne particles in the ambient environment. A major part of the cost of these systems came from the expensive solid-state UV lasers (typically £10,000–£25,000 each) that were required to excite specific fluorophores, such as tryptophan, present only within biological particles. Indeed, since potential biological agent discrimination could be enhanced by using more than one UV excitation wavelength, frequently two or more such lasers were deployed.

In 2001, [text removed for publication] the US government launched its [text removed for publication], five-year Semiconductor UltraViolet Optical Sources (SUVOS) research programme, to seek the development of UV diode lasers or LEDs of sufficient power to be used for bioaerosol fluorescence detection. By its conclusion in 2006, SUVOS had resulted in the realisation of both diode lasers and LEDs down to the sub-300nm wavelengths required for tryptophan excitation; however, laser lifetimes and output energy densities remained too low to excite detectable fluorescence from targets as small as individual bacterial spores.

In parallel with the US SUVOS initiative, Professor Paul Kaye and colleagues Edwin Hirst and Warren Stanley in the university's Centre for Atmospheric and Instrumentation Research (CAIR) proposed in 2001 a radical alternative approach to the low-cost fluorescence excitation of single airborne biological particles – one based on the multi-UV-wavelength excitation from compact xenon flashlamps, relatives of those found in disposable camera 'flash' units.

Professor Kaye's investigations were funded by Dstl (Defence Science & Technology Laboratory) via a series of awards from 2001 to 2007. The research focused on overcoming the numerous technical challenges of using xenon flashlamps. These included: substantial improvement in the ‘blocking’ of radiation from the flashlamps outside the desired UV wavelength bands; design of compact high-efficiency optical systems both to deliver the UV radiation to the particle and capture the resulting fluorescence (this involved the use of custom-designed mirrors and coatings); aerodynamic modelling of aerosol delivery systems to ensure particles carried in the sample airflow were exposed individually to the UV radiation; and optically quenching unwanted fluorescence from other components within the instrument that threatened to dominate the ultra-weak fluorescence from the particles. One by one, these challenges were overcome, and the effectiveness of using xenon sources to achieve real-time discrimination of airborne biological particles was demonstrated in major field trials in both the UK and the US. These findings were disseminated via presentation at major international defence conferences and publication in refereed journals, and formed the basis of international patents (see Section 3).

The resulting technology developed at the university was initially named the Wide Issue Bioaerosol Sensor (WIBS) (modified to ‘Waveband Integrated Bioaerosol Sensor’ in civilian application fields) to reflect its potential for deployment in networks of sensors throughout areas vulnerable to bio-terrorism. [text removed for publication]

3. References to the research (indicative maximum of six references)

– *The top three publications are indicated by* ******

1. A low-cost multi-channel aerosol fluorescence sensor for networked deployment. Kaye P.H., Hirst E., Foot V.E., Clark J.M., and Baxter K., *Proc. SPIE European Symposium Optics/Photonics in Security and Defence*, 388–398, London, Oct. 2004. doi: 10.1117/12.578283 (PDF available on request.)

2. A dual-wavelength single particle aerosol fluorescence monitor. Kaye P.H., Stanley W.R., Foot V E., Baxter K., and Barrington S.J., *Proc. SPIE Conference on Optically Based Biological and Chemical Sensing for Defence II, Bruges Sept. 2005*. Eds Carrano J C. and Zukauskas A., vol. 5990, 59900N-1 to 59900N-12, 2005. doi: 10.1117/12.629868 (PDF available on request.)

3. A single-particle multichannel bio-aerosol fluorescence sensor. Kaye P.H., Stanley W.R., Hirst E., Foot E.V., Baxter K.L. and Barrington S.J. *Optics Express* 13, 10, 3583–3593, 2005. doi: 10.1364/OPEX.13.003583 ******

4. Measurements and comparison of primary biological aerosol above and below a tropical forest canopy using a dual channel fluorescence spectrometer. Gabey A.M., Gallagher M.W., Whitehead J., Dorsey J.R., Kaye P.H. and Stanley W.R., *Atmospheric Chemistry and Physics*, 10, 4453–4466, 2010. doi: 10.5194/acp-10-4453-2010 ******

   – *REF2 Output*

5. Cluster analysis of WIBS single-particle bioaerosol data. Robinson N.H., Allan J.D., Huffman J.A., Kaye P.H., Foot V.E. and Gallagher M. *Atmospheric Measurement Techniques*, 6, 337–347, 2013. doi:10.5194/amt-6-337-2013 ******

   – *REF2 Output*

Patents

Patent examples (both documents available on request):

1. US7436515, Fluid borne particle analysers, inventors Kaye P.H. and Hirst E.

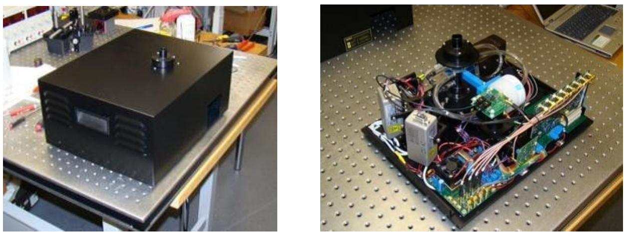
2. US20100328665, Fluid-borne particle detector, inventors Kaye P.H. and Stanley W.R.

Key Research Awards

Dstl	RD031-929596	[text removed for publication]	Low-cost Fluorescence Detector	2001–4
Dstl	RD031-09362	[text removed for publication]	WIBS2 (Wide Issue Bioaerosol Sensor)	2004–5
Dstl	RD031-012620	[text removed for publication]	WIBS2s Bioaerosol Smart Sensor	2005–6
Dstl	RD031-014543	[text removed for publication]	WIBS3 Technology Advancement	2006–7
Dstl and US Army	TP10 programme	[text removed for publication]	Joint US/UK biosensor development	2007–9

[text removed for publication]

4. Details of the impact (indicative maximum 750 words)



A UH-designed WIBS4 instrument

Since 2008, the WIBS technology developed by the university has been widely adopted by diverse organisations in the UK and overseas. Developed primarily as a device to help protect against bio-terrorism, the generic bioaerosol detection capabilities of the technology have proven to be equally successful for detecting and classifying other, non-pathogenic, airborne biological particles such as pollen grains and fungal spores. It has therefore been used extensively by members of the atmospheric science and environmental monitoring communities to aid research into the behaviour of natural bioaerosols that play such a prominent role in areas such as public health (allergens, Farmer's Lung, etc) and the impact of bioaerosols in areas of cloud microphysical processes, precipitation and, ultimately, climate change (see, for example, Section 5, Reference 4). This has led to a far broader exploitation base for the WIBS technology than originally envisaged.

4.1 2008 onwards: Biological Organism Detection

WIBS core technology incorporating the use of xenon flashlamps to excite potential bio-fluorophores in sampled environmental aerosol was licensed by Biral Ltd, Portishead, Bristol, for use in their Verotect military bioaerosol sensor and AFS Standalone Fluorescence Sensor, the latter for use in areas such as disease transmission research, environmental monitoring, etc. These instruments continue to be marketed worldwide.

4.2 2008–10: Government Strategic Planning – Defence

[text removed for publication]

4.3 2008 onwards: Atmospheric Science and Environmental Monitoring

Public dissemination of the capabilities of WIBS technology (including those in Section 3) quickly led to interest from other fields in which the ability to detect and classify airborne biological particles in real time was urgently required. These included:

- Atmospheric science, where WIBS for the first time allowed measurement of time-varying bioaerosol fluxes into the atmosphere. These naturally occurring bioaerosol ‘plumes’ play a vital role in cloud formation and subsequent precipitation patterns, radiative cooling of the atmosphere;
- Industrial hygiene, where monitoring bioaerosols in, for example, food production facilities, clean-rooms, and hospital theatres is a priority;
- Indoor and outdoor environmental monitoring of airborne allergens, such as pollens and fungal spores, and airborne pathogens.

See Section 5 for representative end-user publications.

As part of this wider deployment of WIBS technology, specific variants were commissioned from the university by governmental and other research organisations in the UK, Eire, Germany, the US and Japan.

4.4 2009–11: Application in Vulnerable Civilian Contexts

[text removed for publication]

4.5 2012: Intellectual Property and Commercial Exploitation

The international patents and patent applications covering the WIBS technology name University of Hertfordshire researchers Paul Kaye, Warren Stanley, and Edwin Hirst as inventors. Since the underpinning research for WIBS was funded by Dstl, the patents were automatically assigned to the Secretary of State for Defence, with royalties payable to the University of Hertfordshire upon commercial exploitation. A licence to commercially produce WIBS instruments has since been granted by Ploughshare Innovations Ltd (Dstl’s intellectual property exploitation arm), to Droplet Measurement Technologies (DMT) Inc., Boulder, Colorado, a world-leading manufacturer of atmospheric measurement instruments. Ploughshare are continuing discussions with commercial organisations regarding licences in fields other than atmospheric science.

5. Sources to corroborate the impact (indicative maximum of 10 references)

Example WIBS End-User Publications (no University of Hertfordshire authorship)

1. Aerosol fluxes and dynamics within and above a tropical rainforest in South-East Asia (2010). J.D. Whitehead, M.W. Gallagher, J.R. Dorsey et al. *Atmospheric Chemistry and Physics*, 10, 19, 9369–9382. doi: 10.5194/acp-10-9369-2010
2. Measurement of the particle counting efficiency of the ‘Waveband Integrated Bioaerosol Sensor’ model number 4 (WIBS-4) (2012). David A. Healy, David O’Connor and John R. Sodeau. *Journal of Aerosol Science*, 47, 94–99. doi: 10.1016/j.jaerosci.2012.01.003
3. The online detection of biological particle emissions from selected agricultural materials using the WIBS-4 (Waveband Integrated Bioaerosol Sensor) technique (2013). D.J. O’Connor, D.A. Healy, and J.R. Sodeau, *Atmospheric Environment,* 80, 415–435.

   doi: 10.1016/j.atmosenv.2013.07.051.
4. Fluorescent biological aerosol particles measured with the Waveband Integrated Bioaerosol Sensor WIBS-4: laboratory tests combined with a one year field study (2013). E. Toprak and M. Schnaiter, *Atmospheric Chemistry and Physics,* 13, 225–243.

   doi:10.5194/acp-13-225-2013

End-User Corroboration

Contact details for individuals and organisations who can corroborate the impact described in paragraphs 4.1 to 4.5 have been supplied separately.