NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

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RTO TECHNICAL REPORT **TR-SET-098**

Laser Based Stand-Off Detection of Biological Agents

(Détection à distance des agents biologiques à l'aide du laser)

Final Report of Task Group SET-098/RTG-55.

Published February 2010

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Laser Based Stand-Off Detection of Biological Agents

(RTO-TR-SET-098)

Executive Summary

Biological weapons have become an increasingly important potential threat in today's military and civilian arenas. They are relatively inexpensive to produce and can yield a significant impact as a terrorist weapon. Early warning of a biological attack is essential to establish a timely defence and to sustain operational tempo and freedom of action. In addition, the mapping of a biological attack is needed to obtain intelligence on affected areas. For these reasons the need to develop methods to remotely detect and discriminate biological aerosols from background aerosols and ultimately to discriminate biological warfare agents from naturally occurring aerosols, is paramount.

Discriminating clouds that contain biological warfare agents from background aerosols with stand-off detection is extremely challenging because the distinction between innocuous, ambient bacteria and other biota and virulent microbes amounts to subtle differences in the molecular make-up. Since these subtle changes involve such a small percentage of the molecules, only a slight effect on their optical signatures is observed, making a high confidence detection and discrimination difficult. In addition, variations in growth media and contaminants associated with the processing of bio-warfare agents can affect their optical signatures, further exacerbating the task of analyzing and successfully discriminating the agent.

In order to address these fundamental challenges several stand-off technologies covering a broad region of the electromagnetic spectrum are being investigated under RTG-055. These technologies include spectrally resolved Ultraviolet Laser Induced Fluorescence (UV-LIF) at several different excitation wavelengths, Infrared Depolarization, and Long-Wave Infrared (LWIR) Differential Scattering (DISC). Each of these technologies offers its own strengths and challenges and all of them have demonstrated the ability to detect and discriminate biological aerosol clouds to varying degrees.

In order to compare the relative merits of each technology several trials have been conducted. In addition to the combined field trials we have conducted regular meetings to allow us to share information regarding ongoing biological stand-off detection research. A workshop was held in Quebec, Canada (9 November 2006) to review current national programs and Industry and University research applicable to laser based stand-off detection of BW agents.

Based upon the results of these activities the Task Group recommends that the best option for the near-term (2008 – 2010) application is UV-LIF. The choice of 266 nm or 355 nm excitation wavelength depends upon the range requirement, discrimination potential and day-time performance considerations. Spectrally resolved fluorescence improves the discrimination potential. Near infrared depolarization may be added to enhance the discrimination potential and improve day-time discrimination. Long-term options include infrared depolarization and LWIR DISC. These technologies have better day-time performance and LWIR DISC has the potential for combined CB detection. Finally, advanced algorithms such as Support Vector Machines can improve discrimination performance.

Détection à distance des agents biologiques à l'aide du laser

(RTO-TR-SET-098)

Synthèse

Les armes biologiques sont devenues une menace potentielle de plus en plus importante dans les arènes militaires et civiles actuelles. Elles sont relativement peu chères à produire et peuvent avoir un impact significatif si elles sont utilisées par les terroristes. La détection précoce d'une attaque biologique est essentielle pour mettre en place une défense en temps voulu et pour maintenir le tempo opérationnel et la liberté d'action. De plus, la cartographie de l'attaque biologique est nécessaire pour obtenir des renseignements sur les zones affectées. Pour ces raisons, il est primordial de développer des méthodes de détection à distance et de discrimination entre les aérosols biologiques et les aérosols d'environnement et en dernier lieu de faire une discrimination entre les agents biologiques de combat et les aérosols naturels.

Il est extrêmement difficile par détection à distance de faire une discrimination entre des nuages, qui contiennent des agents biologiques de combat et des aérosols d'environnement car la distinction entre des bactéries ambiantes inoffensives et d'autres biotes et microbes virulents repose sur de subtiles différences dans la structure moléculaire. Sachant que ces subtiles modifications ne concernent qu'un petit pourcentage des molécules, nous ne pouvons observer qu'un léger effet sur leurs signatures optiques, rendant difficiles une détection et une discrimination fiables. De plus, les variations dans les milieux de développement et les polluants associées au processus des agents de guerre biologiques peuvent affecter leurs signatures optiques, et exacerber d'autant plus le travail d'analyse et de discrimination efficace de ces agents.

Afin de faire face à ces défis fondamentaux, plusieurs technologies à distance recouvrant une large gamme de spectres électromagnétiques vont être étudiées par le RTG-055. Ces technologies comprennent la Fluorescence Induite Laser Ultraviolet (UV-LIF) de résolution spectrale à plusieurs longueurs d'ondes d'excitation différentes, la Dépolarisation infrarouge, et l'Eparpillement Différencié (DISC) Infrarouge Grandes Ondes (LWIR). Chacune de ces technologies offre ses propres possibilités et ses propres défis et toutes ont démontré leur capacité de détecter et de discriminer les nuages d'aérosols biologiques à différents degrés.

Afin de comparer les mérites relatifs de chaque technologie, plusieurs essais ont été conduits : Des réunions régulières ont été organisées en plus des essais combinés sur le terrain pour nous permettre de partager les informations concernant la poursuite des recherches sur la détection biologique à distance. Un atelier s'est tenu à Québec au Canada (9 novembre 2006) pour passer en revue les programmes nationaux actuels et la recherche industrielle et universitaire applicable à la détection à distance des agents biologiques de combat à l'aide du laser.

Au vu des résultats de ces activités, le groupe opérationnel recommande l'UV-LIF comme étant la meilleure option pour une application à court terme (2008 – 2010). Le choix des longueurs d'ondes d'excitation 266 nm ou 355 nm dépend de la portée requise, du potentiel de discrimination et de la prise en compte des performances diurnes. La fluorescence de résolution du spectre augmente le potentiel de discrimination. Il est possible d'ajouter une dépolarisation infrarouge proche pour améliorer le potentiel de discrimination et augmenter la discrimination diurne. Les options à long terme comprennent la dépolarisation infrarouge et le LWIR DISC. Ces technologies ont de meilleures performances diurnes et le LWIR DISC a le potentiel pour détecter les CB combinées. Finalement, des algorithmes évolués comme les Machines de Support de Vecteur peuvent augmenter la performance de discrimination.

LASER BASED STAND-OFF DETECTION OF BIOLOGICAL AGENTS

1.0 INTRODUCTION

Biological weapons have become an increasingly important potential threat in today's military and civilian arenas. They are relatively inexpensive to produce and can yield a significant impact as a terrorist weapon. Early warning of a biological attack is essential to establish a timely defence and to sustain operational tempo and freedom of action. In addition, the mapping of a biological attack is needed to obtain intelligence on affected areas. For these reasons the need to develop methods to remotely detect and discriminate biological aerosols from background aerosols, and ultimately, to discriminate biological warfare agents from naturally occurring aerosols, is paramount.

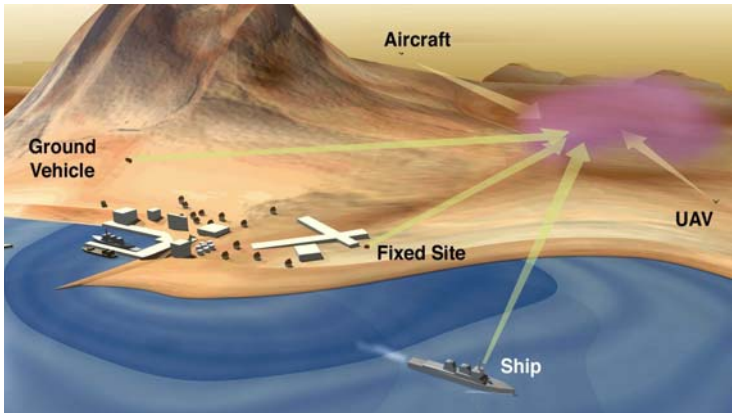

Figure 1: Stand-Off Detection for Early Warning of a Biological Attack.

Discriminating clouds that contain biological warfare agents from background aerosols with stand-off detection is extremely challenging because the distinction between innocuous, ambient bacteria and other biota and virulent microbes amounts to subtle differences in the molecular make-up. Since these subtle changes involve such a small percentage of the molecules, only a slight effect on their optical signatures is observed, making a high confidence detection and discrimination difficult. In addition, variations in growth media and contaminants associated with the processing of bio-warfare agents can affect their optical signatures, further exacerbating the task of analyzing and successfully discriminating the agent.

In order to address these fundamental challenges several stand-off technologies covering a broad region of the electromagnetic spectrum are being investigated under RTG-055. These technologies include spectrally resolved Ultraviolet Laser Induced Fluorescence (UV-LIF) at several different excitation wavelengths, Infrared Depolarization, and Long-Wave Infrared (LWIR) Differential Scattering (DISC). Each of these technologies offers its own strengths and challenges and all of them have demonstrated the ability to detect and discriminate biological aerosol clouds to varying degrees. Annex A documents the brief review conducted at the start of this TG of the lasers that were available and suitable for use in these systems. Annex B documents a portion of the market survey conducted to evaluate the scientific validity of the technology for short range stand-off biological detection. Annex C contains the final presentation of RTG-055 given to the SET Business Panel in May 2008.

2.0 WORKSHOP

A one-day workshop/open session was held in Quebec, on November 9th 2006 during the 4th SET-098/ RTG-055 meeting. This open session involved all the TG members and diverse parties from the industry and the academic communities and other DRDC scientists (see Table 1), all working on various subjects related to laser based biological detection. The CAN, NOR, UK and USA TG members gave an overview of their respective national up-date. Dr. Roy presented a new technique for evaluating the bioaerosol particle size based on a multiple-Field-of-View LIDAR technique. Mr. Levesque from INO gave an overview of their expertise in LIDAR and biophotonics. Dr. Chin from Laval University gave a stimulating talk on femtosecond filamentation in an optical medium and its potential application in the chemical-biological remote sensing area. M. Verreault from Hospital Laval presented their work on the relation between the bacteria fluorescence and viability. Mr. Déry, actually doing his Ph.D. at Laval University in cooperation with DRDC, gave a talk on the spectral information of bioaerosols obtained with his home-built lab-size chamber. M. Farley from Telops, introduced their fluorometer technology and a brief overview of their chemical-biological stand-off detection expertise. Finally Dr. Lahaie gave a talk on the spectral processing architecture for BioSense, the future Canadian bioaerosol stand-off sensor. After these presentations, discussion and exchange on the different technologies and obtained results took place.

Table 1: Participants and Their Subject Title Presented at the Open Session Held in Quebec, Canada in 2006, during the 4th SET-098/RTG-055 Meeting

CAN National Update	Dr. S. Buteau	TG Member
NOR National Update	Dr. H.C. Gran	TG Member
UK National Update	Ms. V. Foot	TG Member
US National Update	Mr. R. Vanderbeek	TG member
Stand-Off Measurement of Bioaerosols Size	Dr. G. Roy (DRDC)	DRDC
LIDAR and Bio-Fluorescence Detection Activities at INO	Mr. M. Levesque (INO, Quebec, CAN)	Industry
Remote Sensing of Chem.-Bio Agents Based upon Intense Femtosecond Laser Filamentation	Dr. See Leang Chin (Laval University)	Academia
Autofluorescence as a Viability Marker in Bacillus Spores: Application to the FLAPS Technology	M. Daniel Verreault (Hospital Laval)	Academia
Spectroscopic Characterization of Fluorescent Aerosols in a Closed Chamber	Mr. B. Déry (Laval University, DRDC)	Academia
Overview of Fluorometer Technologies at Telops	M. Vincent Farley (TELOPS, Quebec, CAN)	Industry
Spectral Processing Algorithms for BioSense TD	Dr. P. Lahaie (DRDC)	DRDC

3.0 ULTRAVIOLET LASER INDUCED FLUORESCENCE (UV-LIF)

Light Detection And Ranging (LIDAR) techniques have the potential to detect particulate aerosols remotely at distances of many kilometres [1]. They can provide spatially resolved measurements in 'real-time'. Ranges of several kilometres to several tens of kilometres can be achieved, dependent upon several factors such as wavelength, laser power, ambient conditions and the optical configuration.

When ultraviolet (UV) radiation is used as the illumination source in a LIDAR system, the radiation may induce fluorescence from aerosolised material within the light beam path. This laser induced fluorescence (LIF) can indicate that a cloud is biological in nature [2]. However, other materials that may be present in the environment, such as pollens, plant debris, fuel oils [3] and agrochemicals can also fluoresce when excited by UV light. The choice of UV excitation wavelength is one of the most significant factors concerning LIF LIDAR detection range and efficiency. Currently, most prototype LIF LIDARs use either 266 or 355 nm UV light; both these wavelengths being easily derived from an Nd:YAG laser, which has a small footprint, relatively low maintenance and is readily available as a commercial component.

Opinions are divided as to which is the preferred wavelength: 266 nm UV excites fluorescence primarily from tryptophan, an amino acid present within the bacterial cell wall and tyrosine (also NADH and flavins to a lesser extent) [4] while 355 nm UV excites fluorescence primarily from NADH, a coenzyme found in all living cells, and also flavins but not tryptophan. The 266 nm is hence the most appropriate for tryptophan excitation and has a higher fluorescence cross section [5]. In counterpart, 355 nm excitation of NADH may be related to bacterial spore viability [6]. In addition, the attenuation of 266 nm light by atmospheric ozone is approximately 10 times greater than that of 355 nm and so 355 nm LIDAR systems may have a longer detection range.

Internationally, a large amount of defence research is currently being conducted to develop LIDAR technology to provide remote detection of a biological agent attack. The US DoD funded Joint Biological Stand-off Detection System (JBSDS) [7] is close to being fielded. JBSDS excites LIF in biological and fluorescent interferent material using a 355 nm laser. It performs cloud mapping and particle sizing with an IR laser and uses an algorithm to compare the magnitude of a single fluorescence band and elastically scattered IR returns to discriminate a biological release from interferent material. It is relatively small and can be installed on the back of a military vehicle requiring generator power.

Additional information can be gained by measuring the spectral information from biological material with a UV LIF LIDAR. The Canadian Stand-Off Integrated Bioaerosol Active Hyperspectral Detection (SINBAHD) system [8] (described in more detail in Section 3.1) uses a high energy (150 – 200 mJ) 351 nm excimer laser to induce fluorescence and collects high-resolution spectra from aerosols. It uses a trained algorithm to discriminate biological materials using these spectra, normalised to the atmospheric nitrogen Raman return. The system is a prototype housed in a 12-m trailer, however, it has the potential to be a much smaller system. The Norwegian system also measures high resolution spectra from biological material, exciting fluorescence with a pulsed 355 nm (frequency tripled) Nd:YAG laser (see Section 3.3). In contrast, the UK are investigating the discrimination capability of a spectrally resolving LIF LIDAR using pulsed 266 nm radiation from a frequency quadrupled Nd:YAG laser, using 10 broad spectral bands to collect low resolution spectra [9] (see Section 3.4). The latest development of this system utilises the elastic backscatter from 1064 nm IR radiation provided by the residual fundamental Nd:YAG light to detect and map clouds. The system is relatively small and is housed in a 5-m trailer.

Other research systems are also being developed within Europe, for example, the German CBRN centre are evaluating a multiple wavelength LIDAR using 1064 nm IR elastic scatter, 532 nm for depolarisation measurements and 266/355 nm to induce fluorescence from clouds (Section 3.2). A consortium of European

companies and research agencies are demonstrating a novel 280 nm and 355 nm based LIF LIDAR for shorter range civil applications under the Biological Optical Defence Experiment (BODE) for Preparatory Action for Security Research (PASR) [10].

3.1 Canadian System

The Canadian sensor called SINBAHD (Stand-Off Integrated Bioaerosol Active Hyperspectral Detection) characterizes spectrally the Laser Induced Fluorescence (LIF) of stand-off bioaerosols using intensified range-gated spectrometric detection technique. It is a LIDAR system, entirely integrated within a 12-m long modified towable trailer and, with a diesel-electric generator, constitutes a completely self-sufficient system. A schematized representation and a picture of the sensor are presented in Figure 2 and Figure 3 respectively.

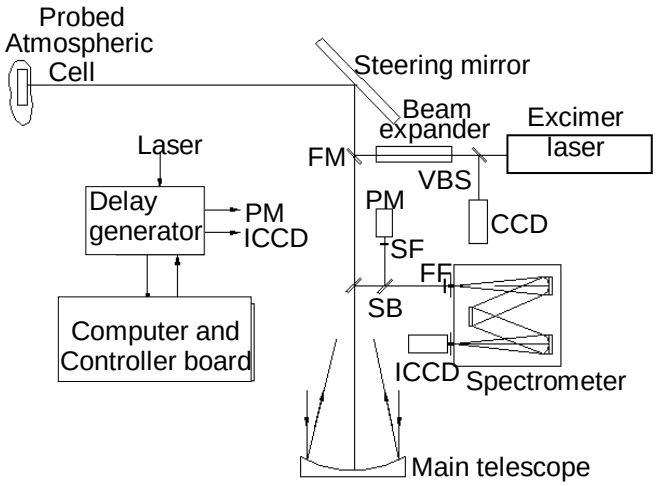

Figure 2: Schematic Representation of the Canadian SINBAHD Prototype.

Figure 3: Picture of the Canadian SINBAHD Sensor.

The laser source is a UV Xenon-Fluoride excimer laser emitting between 120 – 170 mJ per pulse at 351 nm and a pulse repetition frequency of 125 Hz. A visual channel, including a beam splitter (VBS), zoom lens and CCD inserted at the laser output, allows the precise pointing of the laser beam to the target of interest. After passing through a beam expander, the divergence is approximately 147 μrad (width) x 308 μrad (height). An adjustable 45-degree folding square mirror (FM) is placed at the center of the telescope-collecting aperture to obtain a co-axial beam with the collecting optical axis. A 50 cm by 33 cm elliptical steering mirror controlled by motorized gimbals is used to select the line of sight of the LIDAR. A 30 cm diameter Newtonian telescope of 127 cm focal length collects the returned radiation and focuses it at the entrance slit of the imaging spectrometer. A beam splitter (SBS) followed by a narrow band pass filter centered at 350 nm (SF) and a photo-multiplier tube (PM), allows sampling of the elastic scattering. This photo-multiplier is connected to a transient recorder and provides elastic scatter returns as a function of range. This information is used to configure the width and position of the intensified range-gate. This elastic scattered radiation is blocked by two UV high-pass filters (FF) before reaching the spectrometer. The 300 line/mm grating in combination with the 200 μm wide entrance slit of the spectrometer confers a spectral resolution of 4.8 nm and a span of 230 nm, optimized between 300 and 600 nm. An intensified CCD (ICCD) camera from Andor™ Technology detects the dispersed radiation at the exit window of the spectrometer. The 128 × 1024-pixels CCD array is binned vertically and from the 1024 horizontal pixels, 675 are in the intensified region and define the 230 nm spectral span of the inelastic scattering collector. The intensifier gate is synchronized with each fired laser pulse with a delay defining the range of the probed atmospheric cell. Between each laser pulse, the natural radiant contribution present in that probed atmospheric cell is sampled. The intensifier sensitivity combined with the 16-bit dynamic range of the camera and the spectral distribution of the collected signal over the CCD columns permit the detection of very low signal levels while retaining the spectral information.

3.2 German System

For the purpose of research and development of a biological stand-off detector, the German CBRN centre at Munster (WIS) devised a concept of how to determine the needed capabilities of such a detector. As it seems not to be very likely to detect biological agents at distance by a passive system or relying only on one physical property, the detector should be able to look for elastic backscattering, fluorescence, the Raman-effect and depolarisation. To which extent and how many of those effects will be needed for the detection has to be determined by field experiments. The analysis will be done by PCA or similar methods. The measurement of the lifetime of excited states by probe pumping was neglected this time, because we expect the amount of data to be to huge to be processed in a sufficient amount of time.

Prior laboratory experiments with a tuneable laser showed, that it should be possible to detect living biological material by use of at least two different excitation frequencies and the resulting fluorescence (LIF). In our system we work with the third and forth harmonic of a Nd:YAG laser, hence 355 nm and 266 nm. It is very likely that other wavelengths will yield better results for the discrimination of living biological material from other aerosols, but this laser was chosen because a number of existing COTS products use this laser. This allowed faster and cheaper development the system and to achieve it in a rugged form.

The realisation of this concept was done by Jenoptik and was delivered as one system build in a car by end of 2007. First field trials have been conducted from spring to summer 2008 proving the elastic backscattering and fluorescence can be measured at a distance of 1000 m. This distance is considered as a starting point, due to the restrictions of our probing ground. It seems to be likely, that we will be able to test with 3000 m and 6000 m next year as well, which might be the reasonable maximum distances for LIF due to the attenuation of the atmosphere. The measurement of the elastic backscattering was specified to be possible up to 12 km. During Fall 2008 Jenoptik has realized some improvements to the experimental set-up.

Figure 4: German Biological Agent LIDAR (BALI).

3.3 Norwegian System

The Norwegian sensor detects bioaerosols utilizing the laser induced fluorescence technique. The LIDAR is a breadboard based system where only commercial-off-the-shelf (COTS) components were used. A sketch and a picture of the LIDAR geometry are found in Figure 5 and Figure 6, respectively. The breadboard system is 30 cm x 120 cm wide and long, weighs ~70 kg, and is mounted on a tripod. In addition to the tripod mounted system, a laser power supply and a small control unit comprise the LIDAR system.

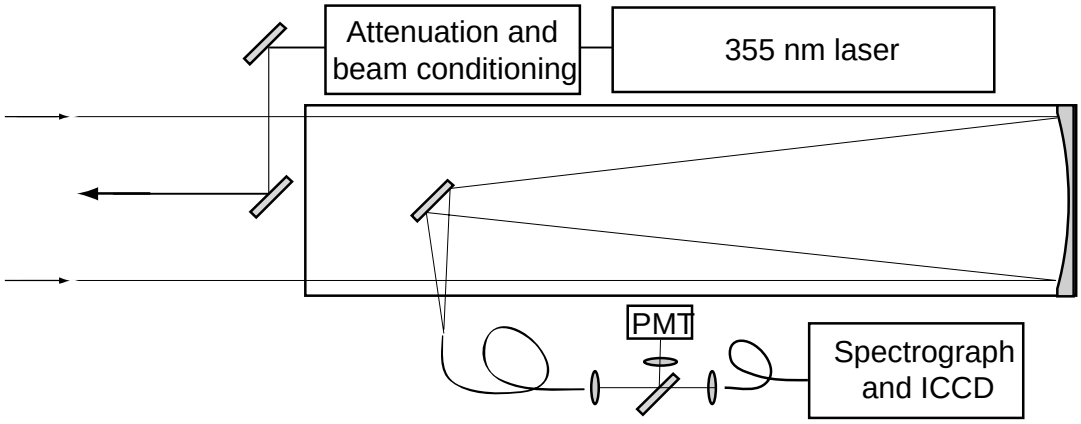

Figure 5: Sketch of the Norwegian LIDAR System.

Figure 6: Picture of the Norwegian LIDAR System.

The laser source is the 355 nm output from a tripled flashlamp pumped Nd:YAG laser (Quantel Brilliant B). The laser operates at 10 Hz pulse repetition rate with up to 150 mJ pulse energy per pulse and approximately 5 ns pulse length. An attenuation stage in front of the laser provides the opportunity to adjust the transmitted laser energy from 0 – 150 mJ. The laser beam is expanded and collimated by a two-lens telescope to a divergence that matches the field of view of the detection channel, about 0.3 mrad, and is transmitted on-axis with the detection system. The return light is collected by a 250-mm diameter, 1200-mm focal length Newtonian telescope which focuses the light into a 365 µm core diameter optical fiber. The collected light is split in two channels by a dichroic mirror. The elastic backscatter at 355 nm is coupled onto a photo-multiplier tube (PMT) and the inelastic scatter which contains both fluorescence and Raman scattering, is coupled to a grating based spectrograph which spectrally resolves the light onto an intensified CCD (ICCD) camera.

The light detected by the PMT provides information about the presence of aerosols and their distance from the LIDAR. The ICCD camera (Andor DH720) can be gated, and can thus, if adjusted properly, avoid fluorescence signals from, e.g. vegetation behind the scene. The signal from the PMT is used to set the correct gating for the ICCD camera. Gating of the camera is performed by turning on and off a high voltage across the multi-channel plate in the camera which provides the amplification of light. The level of amplification can be adjusted with 8 bit resolution from 1 to a maximum of ~500. Combined with the ~20% quantum efficiency of the photocathode, the average maximum amplification factor is ~100.

The spectral resolution of the detection system is about 7 nm, with the 365 µm diameter optical fiber and the 300 lines/mm grating in the spectrograph, and the spectrum between 340 nm and 680 nm is monitored by the camera. This corresponds to about 50 spectral channels. The spectrograph grating has a 500 nm blaze angle (i.e. peak diffraction efficiency) and high diffraction efficiency in the 350 – 600 nm range. To eliminate background light, in particular during day-time operation, a background recording with identical camera settings is performed between each laser shot, and subtracted from the LIDAR return in software.

The amplified area of the ICCD camera is 690 x 256 pixels. As there is no spectral information in the vertical direction, full vertical binning of the pixels of the ICCD is used. In the horizontal direction, the number of pixels (or, in reality, columns) that can be binned are adjustable. The ~7 nm spectral resolution of the detection system corresponds to ~12 pixel horizontal binning.

The system's field of view (FOV) increases linearly with size of the optical fiber while the spectral resolution is inversely proportional to this size. With a 365 µm diameter fiber, the FOV is 0.3 mrad. If a larger FOV is desired this can be obtained by a larger diameter optical fiber at the sacrifice of spectral resolution.

The measured return signals are currently analysed using two algorithms. The first is by use of anomaly detection, in which the algorithm is trained on relevant backgrounds to establish a statistical multi-variate model of a normal situation (without release), calculating the probability that each measured spectrum is normal. This method is fast and can quite reliably detect a release without classifying its content.

The second method is the spectral angle mapper method in which each spectrum with N channels represents a vector in a N-dimensional space, and where the angle between a measured spectrum and known key spectra are calculated, and the measured spectrum can be classified if this angle is low enough. This method has shown potential to classify the release when the measured signal from the release is sufficiently high enough.

3.4 United Kingdom Systems

In the UK, between 2003 and 2008, Dstl constructed a series of 3 prototype UV LIF LIDARs. The first (Mk1) investigated the utility of collecting bulk fluorescence [11] from aerosols illuminated by 266 nm UV light from a frequency-quadrupled Nd:YAG laser (Quantel Brilliant). The second system (Mk2) included spectral resolution of the collected fluorescent light to increase its discrimination potential. It is shown schematically in Figure 7 and was constructed using readily available commercial components wherever possible. Pulsed UV illumination is generated by a Big Sky Laser Inc CFR 400 Nd:YAG pulsed laser, operating at a wavelength of 266 nm, with pulse energies of up to 40 mJ. The elastically scattered radiation and any fluorescence emission from the aerosol are collected by a 250-mm diameter cassegrain telescope. This focuses the radiation into a system of detectors via an aperture that defines the field of view. The aperture has a diameter of 1 mm and produces a field of view of 0.69 mr. The outgoing laser beam and incoming light are co-linear, but do not share any optical components which minimises potential interference. The main fluorescence signal enters the spectrometer via a converging lens and a 1-mm slit aperture. The light is dispersed via a diffraction grating onto a linear photo-multiplier array. The array consists of 16 elements, 0.8 mm wide, with 1 mm pitch. Although there are 16 elements available, only 10 elements in the spectral region of interest (300 – 500 nm) are measured. Signals from these active elements are amplified by 10 identical high bandwidth pre-amplifiers and are subsequently digitised by oscilloscopes prior to storage, display and analysis.

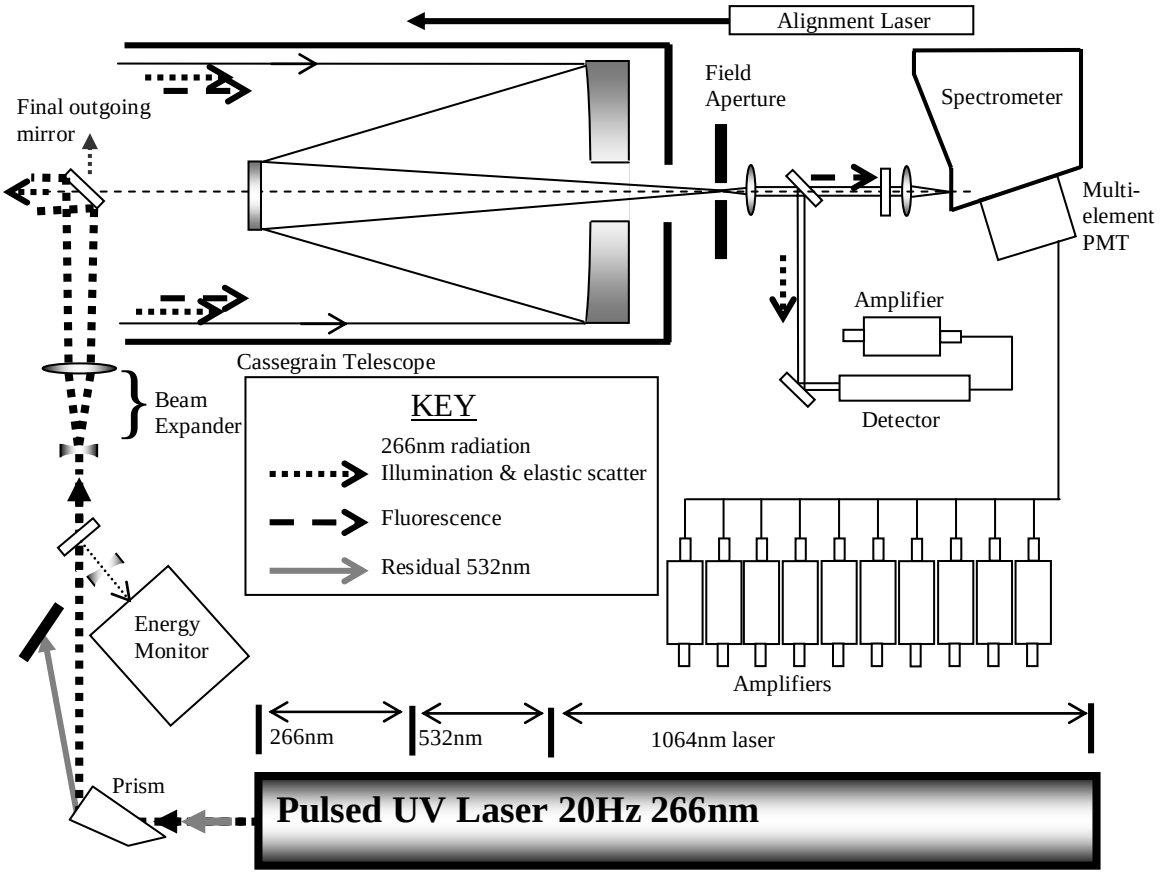

Figure 7: Schematic of the System Optical Layout.

The entire system is mounted on a stellar telescope mount, which allows aiming to a very high degree of accuracy. The system software controls the scanning angle, speed and elevation and allows the system to follow a complex vertical and azimuthal scan path to follow the terrain. Support vector machine (SVM) and Bayesian algorithms were incorporated into the instrument software as tools for evaluating the system's discrimination capability. For trials purposes the whole system was installed into a small trailer so that it could be transported.

Most of the results described below were obtained using this Mk2 system and they show that fluorescence spectra have promising utility for discriminating biosimulant clouds from fluorescent interferents. The UV backscatter approach used to map clouds and hard targets in the system's field of view has some limitations, because returns are influenced to a large extent by the atmospheric small particle aerosol content and ozone concentration, causing variations in the backscatter sensitivity.

To improve the system's cloud mapping performance, the most recent system design (Mk3) uses the fundamental infrared (IR) 1064 nm radiation from the Nd:YAG laser as the illumination source for backscatter measurements, due to the lower atmospheric absorption at this wavelength. An Avalanche Photodiode (APD) has been used as the IR backscatter detector. In addition to the inclusion of the IR cloud-mapping wavelength, the system has undergone improvements to the digitisation hardware, software and has been fitted into a new trailer with improved infrastructure. A schematic of the re-designed optical layout is shown in Figure 8.

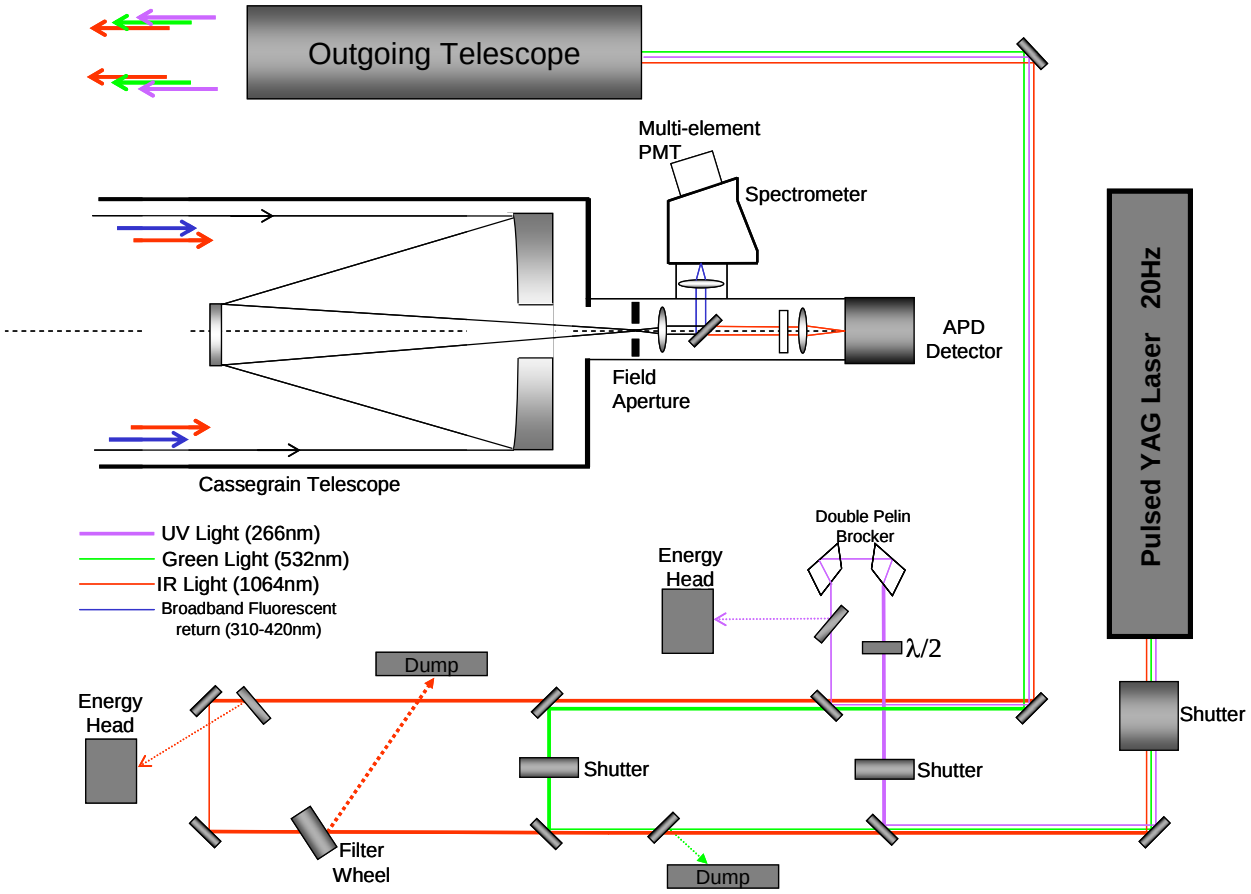

Figure 8: Schematic of the Multi-Wavelength LIDAR System.

The three wavelengths are separated into unique beam paths in order to allow independent control of the energy at each wavelength. The different wavelengths can also be independently blocked if required. The energy of the IR beam can be selected with dielectric attenuators up to a maximum of 70 mJ. The system is used with full UV power at all times, while a small percentage of the energy of 532 nm green beam can be projected when the initial alignment of the system is performed. In normal operation this green beam is blocked. Figure 9 shows the Mk3 multi-wavelength LIDAR head on the scanning mount, *in situ* in the trailer.

Figure 9: The Multi-Wavelength LIDAR System.

4.0 LONG-WAVE INFRARED DIFFERENTIAL SCATTERING

While Long-Wave Infrared (LWIR) LIDAR technology has been available for over a decade for stand-off chemical detection it lacked the sensitivity and advanced algorithms needed to be applied to stand-off biological aerosol detection. Recent improvements in technology and algorithms, however, have made this approach feasible. The US Army's Frequency Agile LIDAR (FAL) (Figure 10) was utilized as a test-bed of the LWIR DISC technology. In addition, advanced state-of-the-art algorithms were developed for LWIR detection and discrimination of biological aerosols using Differential Scattering (DISC). These improvements have enabled the FAL to successfully discriminate biological materials from common battlefield interferents at operationally significant ranges and concentrations during testing at Dugway Proving Ground, UT.

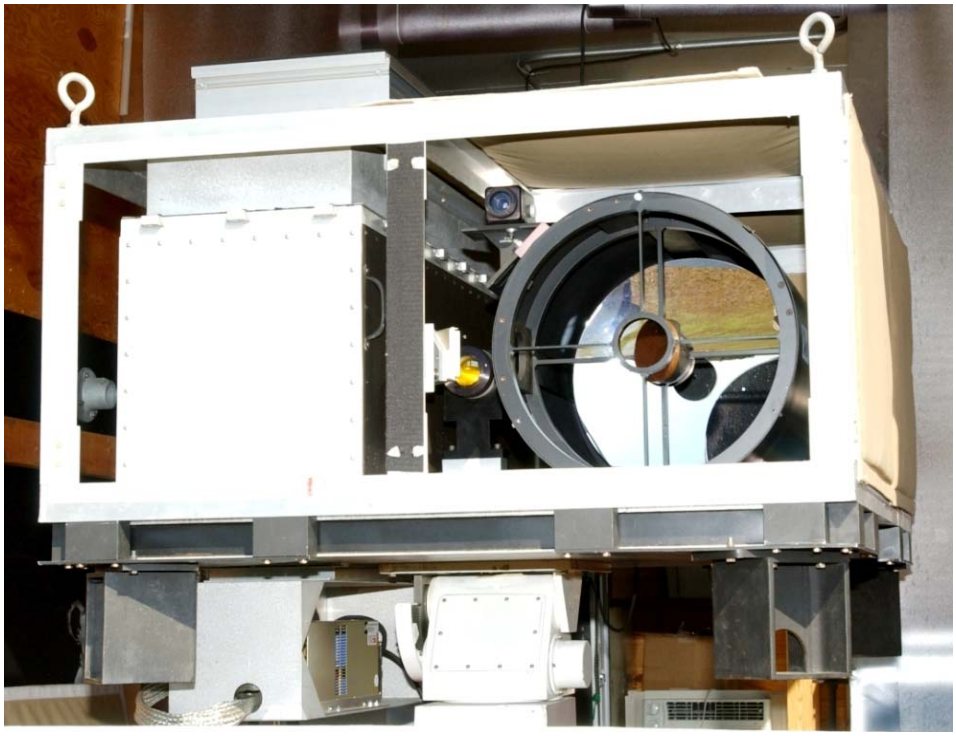

Figure 10: LWIR DISC LIDAR.

The US Army's Frequency Agile LIDAR (FAL) that was used as a test-bed of the LWIR DISC technology uses a sealed CO_2 Transversely Excited Atmospheric (TEA) laser capable of automated tuning at the laser repetition rate of 200 Hz. It can access up to 60 discrete wavelengths between 9.2 microns – 10.8 microns at an output power that ranges from 120 mJ at a low gain line to 220 mJ at a high gain line. The receiver consists of a 14 inch Cassegrainian telescope and a 1 mm liquid nitrogen cooled HgCdTe detector. The field of view is 1.5 mrad and the transmit divergence is about 1 mrad. The transmitter and receiver are mounted on a gimble that allows for scanning in both azimuth and elevation.

5.0 INFRARED DEPOLARIZATION

Wavelength Normalized Depolarization Ratio (WANDER) and differential backscatter (DISC) have been combined in a stand-off detection system to provide advanced warning discrimination capabilities for bioaerosols (anthrax, plague, ricin, etc.) and interferents (dust, smoke, pollen, etc.). The sensor, developed by Lockheed Martin Coherent Detection (LMCT) [12], is shown in Figure 11. The discrimination technique uses the aerosol optical signatures at key wavelengths to simultaneous probe the shape, size, and refractive index of the aerosol. This technique uses backscatter measurements, which form a good basis for robust and sensitive detection suitable for field operation during day and night conditions.

Figure 11: LMCT WANDER LIDAR.

Combined measurements of multi-wavelength depolarization ratios and differential backscatter parameters assembled in an appropriate discrimination algorithm have demonstrated the ability of real-time day and night discrimination of biological simulants. The current WANDER system has been operated in an eye-safe mode and has demonstrated the appropriate sensitivity for an early warning system.

6.0 TEST CAMPAIGNS

6.1 Montreal Trial: CIFAUE 06

The CIFAUE trial, standing for Characterization of Induced Fluorescence of Aerosol in Urban Environment was conducted at the Montreal garrison Longue-Pointe, located in the East part of Montreal, Quebec, Canada, the last week of September 2006. The pursued objective was to obtain the basic characteristics of induced fluorescence from aerosols present in an urban environment and its evolution with time. This field trial was organized by DRDC Valcartier and the British and Canadian stand-off systems were present. The CIFAUE trial included four phases, each one dedicated to the characterization of a particular area of interest (AOI):

1) Traffic interchange;
2) Harbor facilities;
3) Freight classification yard and industrial/commercial quarters; and
4) The Olympic stadium area (Figure 12).

The aerosols present in these specific urban AOI were characterized during an entire night for each one of them, from about 8 PM to 5 AM.

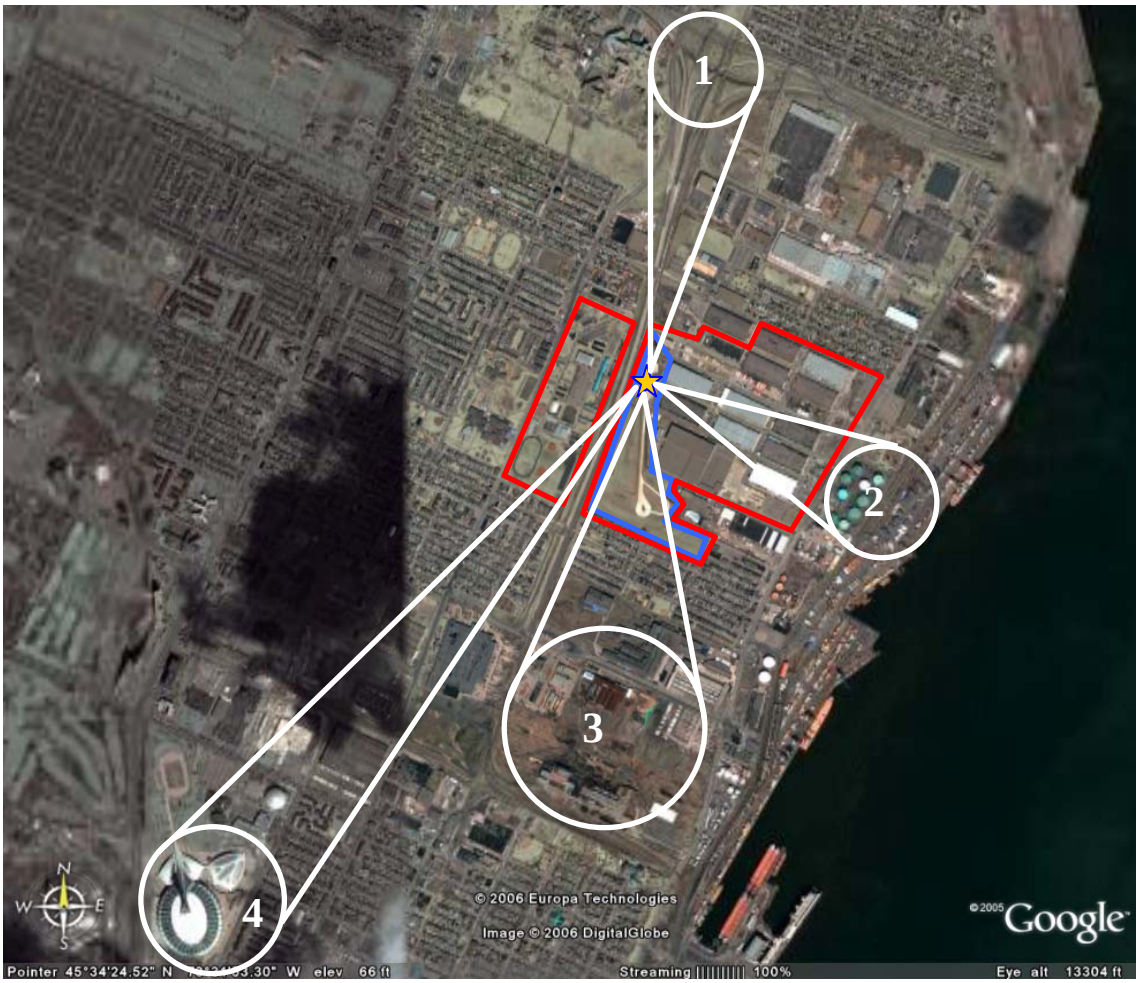

Figure 12: The Four Areas of Interest (White Circle) Selected for CIFAUE Trial Relatively to the System Position (Yellow Star) in the Test Track (Blue) of Garrison Montreal (Red).

6.2 Suffield 2007 Trial: SBT07

The Suffield BioSense Trial 2007 (SBT07) was held at the Colin Watson Aerosol Layout (CWAL), Experimental Proving Grounds (EPG), DRDC Suffield, Alberta, Canada, from July 17th until September 2nd 2007. This Field trial was orchestrated by DRDC Suffield and the specific objective was to correlate stand-off measurements with Agent Containing Particle per Liter of Air (ACPLA) point measurement for different agent simulants. The Canadian stand-off system, SINBAHD, and some short-range British sensors participated to this trial.

The trial included a total of 58 open-air releases of different agent simulant (old and new BG, EH), growth media nutrient broth) and interferents (sea mist, smokes). All releases, with the exception of the smoke interferents were wet releases produced by an agricultural sprayer (model AU8110, MICRONAIR). The sprayer was mounted on a mobile platform circulating on the circumference of 100-metre radius circle centered on the aerosol grid. This platform was moved as a function of wind direction in order to position the aerosol cloud on the grid where the reference equipment was located (Figure 13).

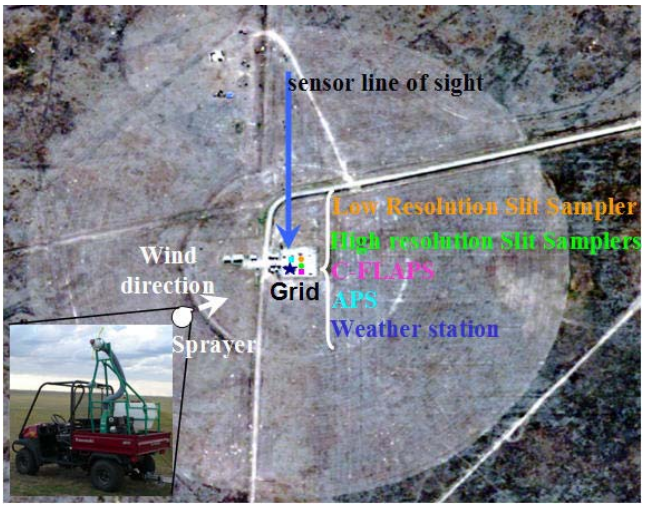

Figure 13: Suffield 2007 Trial Set-up, Inset: Picture of the Sprayer Apparatus Used to Disseminate Simulants.

Three types of reference equipment were deployed on site for reference and correlation purpose: Aerodynamic Particle Sizer® (APS), Fluorescent Aerosol Particle Sensor (C-FLAPS) and high resolution slit sampler array (SSA) (Figure 14). This later point sensor allows the evaluation of the threat level contained within the cloud, saying the Agent Containing Particles per Liter of Air (ACPLA). The slit samplers are drawing ambient air through a slit orifice before impacting onto a rotating plate containing growth media. The high resolution slit sampler array (HF Research, custom build) consisted of 10 serially connected samplers, each with a 0.5 or 1 revolution/min, which operated as a continuous 20 or 10 minutes collector, respectively. Biological particles, if present in the aerosol, are impacted onto the surface of the nutrient agar plate and after an incubation period, live particles can be counted as bacterial colonies by means of a flat bed scanner driven by custom software developed jointly by DRES, Dugway Proving Ground (DPG) and Spiral Biotech. The ACPLA bioaerosol concentration can hence be calculated as a function of time based on the slit rotation speed and airflow intake rate.

Figure 14: Reference Point Sensors Used during Suffield 07 Trial: Aerodynamic Particle Sizer (APS), C-FLAPS and Slit Samplers (SSA Unit).

The second reference point detector is a Fluorescent Aerosol Particle Sensor (C-FLAPS). The C-FLAPS contains a FLAPS Model 3317 (from TSI) and an aerosol concentrator (model XMX/2A, SCP Engineering, St. Paul, MN), used as a front end to the FLAPS intake. The FLAPS simultaneously measures for each drawn individual airborne particle, the scattered-light intensity and the fluorescence emissions. It uses side scatter to provide particle sizing information and fluorescence emission to evaluate biological content. The C-FLAPS operated at 400 L/min concentrating to 1 L/min delivered to the FLAPS intake. This particle throughput facilitated rapid data acquisition. During real time sampling, the C-FLAPS presents size and fluorescence intensity information for each particle. Data derived from a given sampling period can be reduced to a fractional number (gated % fluorescence) representing the percent of particles that exhibited fluorescent signal above a preset size and intensity threshold. The last reference point sensor used is the commonly APS provides high-resolution, real-time aerodynamic measurements of particles from 0.5 to 20 µm in diameter. This sensor allows evaluating the particle per liter of air concentration (ppl) and the aerodynamic particle size distribution employing the time of flight measurement.

6.3 Umeå Trial, September 2008

The Umeå field trial was hosted by the Swedish Defence Research Establishment at the test site of the NBC School in Umeå in northern Sweden (63°53'N, 20°16'E, ~50 m elevation) during 15-26 September 2008. Both semi-closed chamber tests and open-air releases were performed. The distance from the detectors to the aerosol cloud was 250 – 400 m. Reference equipment included Slit-samplers, C-FLAPS, MAB and Aerodynamical particle sizer (APS).

The semi-closed chamber is made up of two 20' containers docked together and equipped with air-curtains over a 1 m x 1 m window at each end. The total path inside the chamber was about 10 m and the distance to the test chamber was about 250 m. During the open-air releases, the release was done from a mobile platform that could move along a 100-m radius or a 200-m radius circumference of the center of the test grid as function of the wind direction for the released aerosols to hit the center of the grid where the reference equipment was placed.

Both wet and dry releases and day- and night-releases were performed, with a total of 50 releases of which about half was open-air releases. A list of releases is given in Table 2. An overview photo of the test range is shown in Figure 15 and close-up pictures of the test chamber are shown in Figure 16.

Table 2: List of Release Substances During Umeå08 Field Trials. *Formerly known as Bacillus Globii **Formerly known as Erwinia Herbicola, EH

Release Substance	Simulant for	Wet/Dry
BT (Bacillus Thuringensis, Turex)	Spores	Both
BG (Bacillus Atropeus)*	Spores	Both (DPG and Novozymes)
OA (Ovalbumin)	Toxins	Dry
PA (Pantoea Agglomerans)**	Live bacteria	Wet
MS2	Virus	Wet
Diesel exhaust	Interferent	NA
Fog oil	Interferent	NA
Pollen (Pinus sylvestris)	Interferent/Background	Dry
Signal smoke	Interferent	NA

Figure 15: Overview of the Test Range (At the left is the semi-closed chamber).

Figure 16: Left: Test Chamber; Right: Close View of Air Curtain.

6.4 Dugway Proving Ground, Utah, USA

The Joint Biological Stand-off Detection System (JBSDS) Increment II Technology Demonstration III was conducted at Dugway Proving Ground (DPG), UT. This technology demonstration was designed to determine the optical signatures for simulants (*Bg, Ba-killed, Eh, Ft, Yp-killed, ricin, OV, MS2, etc*.), interferents (smoke, dust, pollen, fungus, etc.) and to assess the natural variability of these materials due to environmental factors, preparation procedures, and dissemination conditions. Signatures for natural interferents present at DPG were also collected. Various dissemination techniques were utilized to provide opportunities to characterize these techniques to further increase the confidence in predicted plume composition. In addition, experiments were designed to assess the detection and discrimination sensitivity of stand-off systems. Over 100 releases were conducted during this demonstration. Most of the releases were conducted at the Joint Ambient Breeze Tunnel (JABT) [13], which is shown in Figure 17, but there were also some open air releases as well.

Figure 17: Joint Ambient Breeze Tunnel at Dugway Proving Ground, UT, USA.

The systems under test were positioned at the JABT Staging Facility (Figure 18) oriented so that they were lasing west toward the JABT. The participating systems and the referee systems were positioned side by side and lased at the same time. The distance between the test systems and the east end of the JABT was approximately 1.2 km. Figure 19 shows a picture of the JABT taken from the staging facility. One stationary reference hard target was used for aligning the test systems.

Figure 18: Staging Facility at the JABT.

Figure 19: JABT Test Site and Test Participants.

Five Aerodynamic Particle Sizer (APS) instruments were used as referee systems to monitor the background aerosol concentration and simulant aerosol concentrations at different locations inside the JABT. The APS instruments were calibrated before the start of any record testing.

7.0 UV-LIF FIELD TEST RESULTS

7.1 Canadian Results

SINBAHD, the Canadian stand-off bioaerosol sensor was used to characterize spectrally the Laser Induced Fluorescence (LIF) of either specific background environment or materials related to bioaerosol threat detection during various field trials. A few results obtained with the stand-off Canadian sensor will be presented herein.

During the CIFAUE trial, held in Montreal, during the last week of September 2006 (Section 6.1), SINBAHD has been deployed to obtain data for characterizing the urban background, pursuing two objectives: the characterization of the statistics of the stationary aerosol background and the identification of spectral anomalies occurring in this environment. The detection of an anomaly is performed by comparing a newly incoming signal to the evolving mean and covariance of the past signals using the Mahalanobis distance as the mathematical operator. This operator is chosen because it reacts to both a change in spectral characteristics and amplitude of the signal. In Figure 20 and Figure 21 the same color code is used to associate a given result in terms of this Mahalanobis distance in Figure 20 and a spectral vector in Figure 21. Examples of amplitude variations are shown by green and pink vectors and spectrally anomalous vectors are the two black signals. This method shows a good sensitivity since small variations triggered a detection. To limit the amount of false alarms, a classification algorithm shall be used to identify to which class of aerosols an anomaly is belonging.

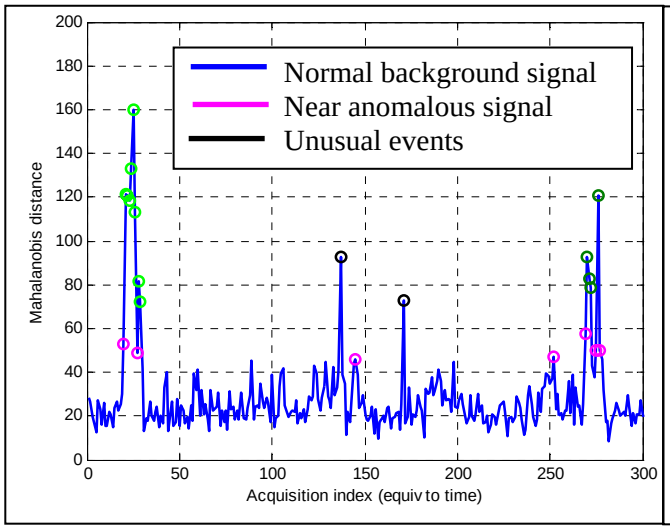

Figure 20: Mahalanobis Distance as Function of Time Equivalent Index from a SINBAHD Urban Background Acquisition during the CIFAUE Trial, Montréal, CAN, September 2006.

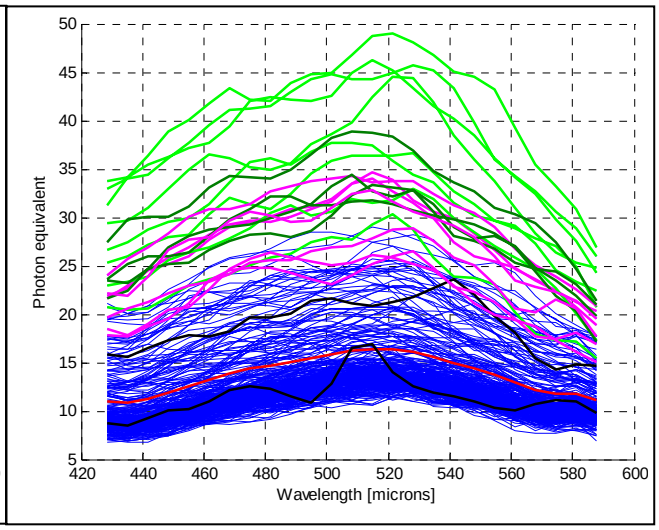

Figure 21: Urban Background Spectral Signals Acquired by SINBAHD during the CIFAUE Trial, Montréal, CAN, September 2006 (color code matching Figure 20).

A multi-variate analysis technique can be use to separate the different fluorescent signal contributions by representing the collected signal as a linear combination of normalized spectral signatures contained in a library. This multi-variate technique allows the extraction of energetic contributions, meaning the amplitude of a given signature, which one represents the detection signal for this particular material. Figure 22 presents this detection signal in the case of an open-air wet BG (*Bacillus subtilis* var. *niger*.) release performed during the Suffield 2007 (SBT07) trial (Section 6.2). This SINBAHD detection signal is also correlated with the slit sampler output on Figure 22. The reference sensor was at 990 m from the SINBAHD sensor position and the cloud was about 20 meters in depth. After optimization of the correlation between SINBAHD result and the ACPLA values, the detection limit defined as four times the standard deviation of the signal while the material is not present (off-signal) can be obtained. This process is limited in precision due mainly to the difference in the cloud probed volume by SINBAHD compared to the reference equipment, which is the main limitation for open-air releases. In spite of this, the obtained correlation between the Canadian stand-off system and the point reference system (Figure 22) is fairly good, especially considering the low signal to noise ratio obtained for the SINBAHD results. This obtained correlation allows expressing the 4-sigma detection limit of the stand-off system in ACPLA which is directly related to the threat level for that particular material, for a given range and cloud depth.

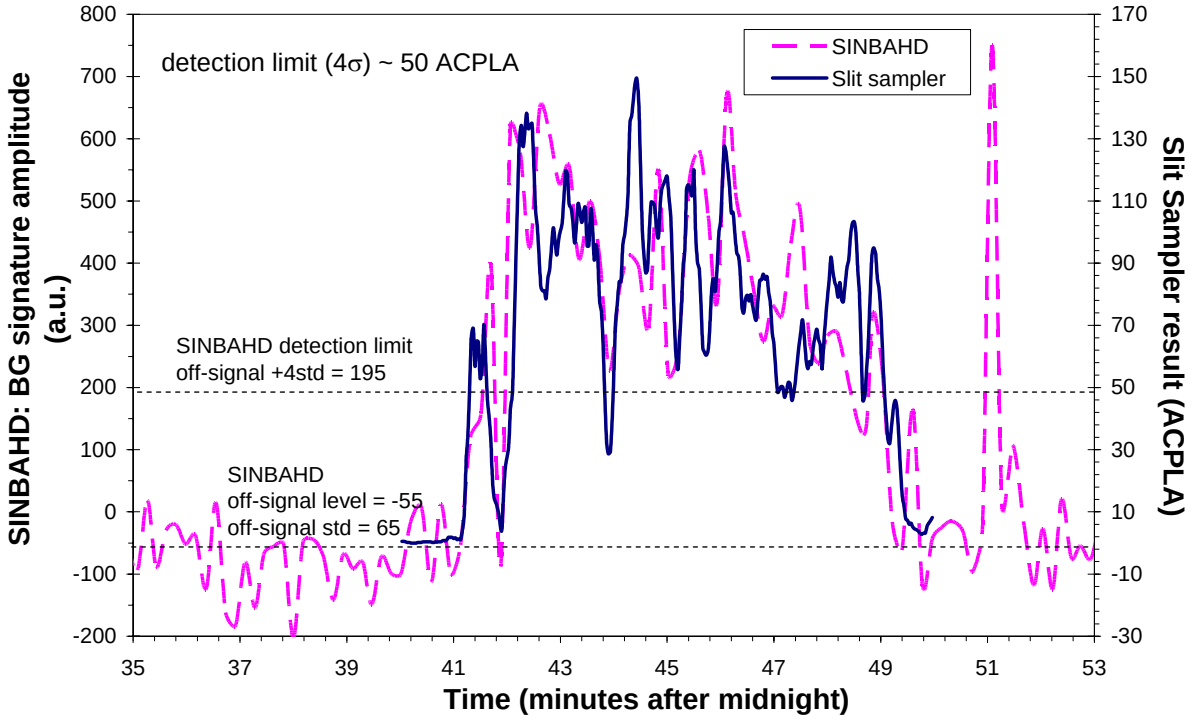

Figure 22: Slit Sampler and SINBAHD MA Results for a 20-m Cloud of Old BG at a Range of 990 m (T48) during Suffield 2007 Trial (SBT07), Alberta, Canada.

Figure 23 presents the spectral signature of various simulants acquired by SINBAHD during the Joint Biological Stand-off Detection System Increment II (JBSDS II) Tech Demo III trial (Section 6.4), held at Dugway Proving Ground (DPG), USA in August 2007. These sensor dependant signatures were obtained from releases performed in the Joint Ambient Breeze Tunnel (JABT) during which the generated cloud was characterized in particle per litter of air (ppl) by numerous Aerodynamic Particle Sizer (APS). SINBAHD stand-off sensor was located at a range of 1.26 km from these reference sensors and used a 20-m gate for all acquisitions. All materials show spectral feature in the 380 – 600 nm and specificity of material signature is observed in most cases, which are needed for detection and classification respectively. For every material type, significant signature robustness over time and between different releases was observed.

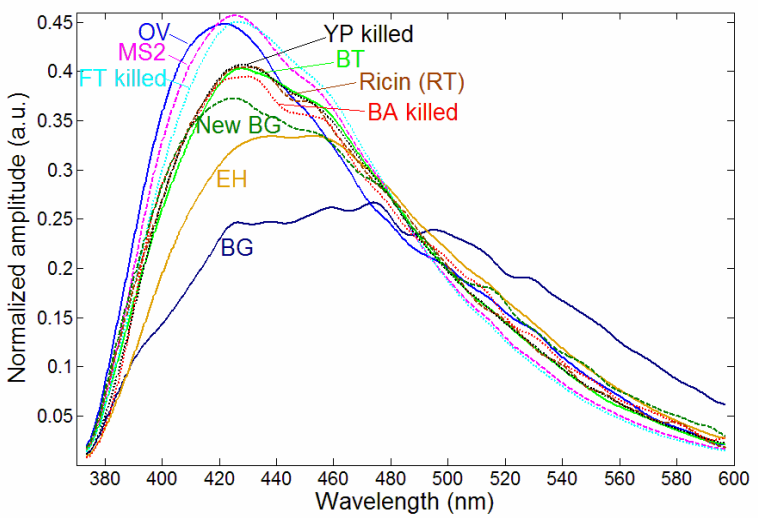

Figure 23: Normalized Fluorescence Signatures Acquired by SINBAHD during the JBSDS II Tech Demo III Trial, DPG, USA, August 2007.

Once the normalized spectral signatures of the different disseminated materials are extracted (Figure 23), multi-variate analysis is used to obtain the detection signal and the corresponding 4-sigma sensitivity limit. Figure 24 presents the correlation between the SINBAHD detection signal (dashed) and the reference ppl measurement (solid) during a BG release at sunrise. Following the high quality of the correlation obtained, the 4-sigma detection sensitivity was evaluated to be about 8 kppl for a 20-m thick cloud of BG at 1260 m while the sun was rising up (6:45).

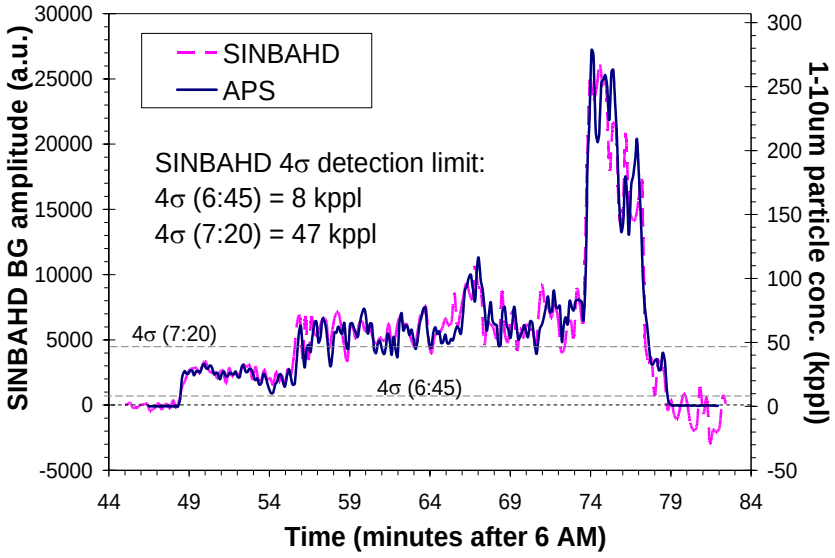

Figure 24: SINBAHD Detection Signal with a 20-m Gate at 1260 m and APS Reference Data for a Release of Live BG at Sunrise.

7.2 Norwegian Results

The releases in the semi-closed chamber were used to record key spectra for the simulants releases, as is shown in Figure 25.

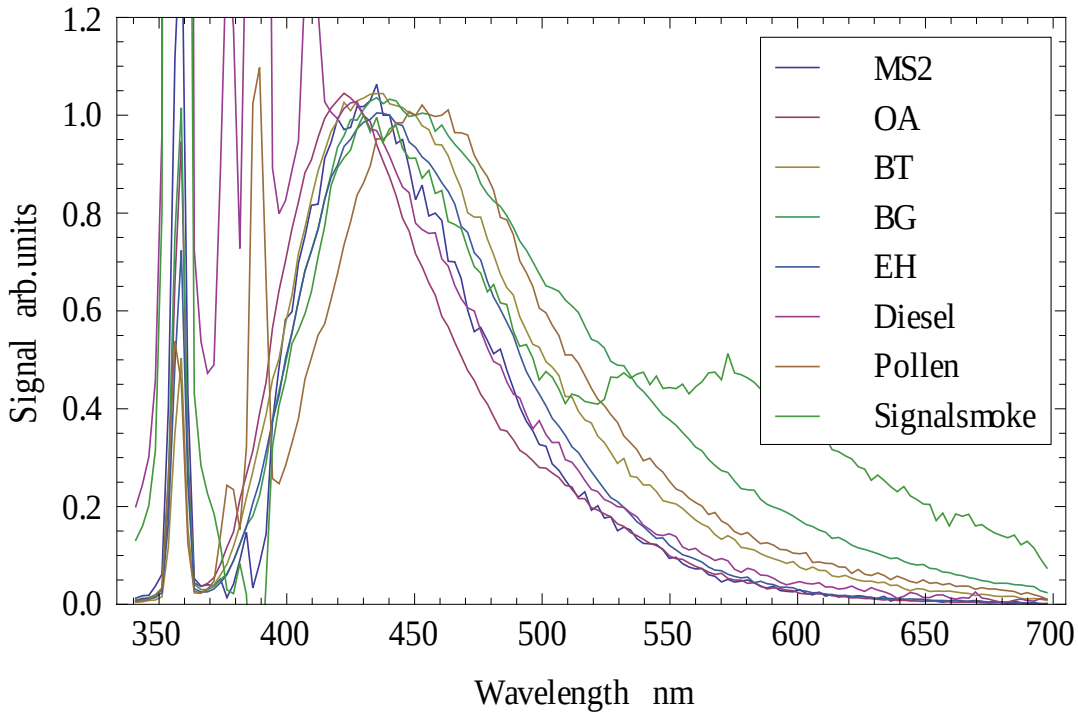

Figure 25: Measured Spectra during Semi-Closed Chamber Releases.

The strong features between 350 and 410 nm are due to elastic backscatter (355 nm) and to Stokes-shifted Raman backscatter from oxygen (376 nm), nitrogen (386 nm), and water vapour (408 nm), and are disregarded when calculating the angle using SAM.

The angle between the measured spectrum and the key spectra during an open-air BG release is shown in Figure 26. The upper curve shows total fluorescence 410 – 670 nm and the calculated angles between the spectrum and the key spectra are shown in the lower graph using a 5 second (i.e. 50 pulses) running average to smooth the measured spectra. It is clear that the instrument is capable of classifying the release provided that the return signal is strong enough. The Aerodynamic Particle Sizer (APS) that was placed at center of the grid and close to the position of the laser beam during this release, reported a density of particles with diameter greater than 0.8 µm of approximately 10 – 20 kppl during most of this release.

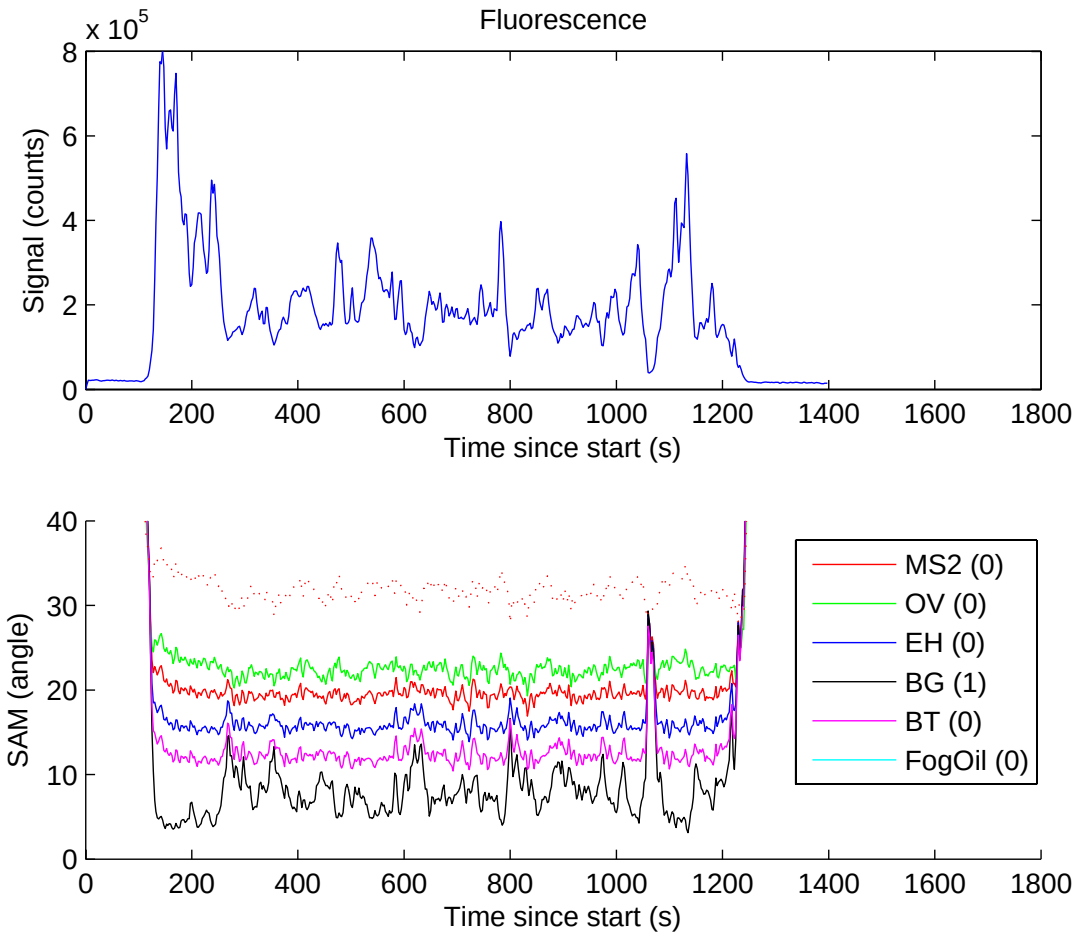

Figure 26: Top: Total Measured Fluorescence 410 – 670 nm during a BG Release; Bottom: Calculated Angle between Measured Spectrum and Key Spectra.

Anomaly detection was tested on datasets which were obtained in a trial with low laser pulse energy. A dataset for simultaneous release of a simulant and an interferent was created by superimposing the low signal from a BG-release on top of a strong pollen release. The pollen spectrum was in the background on which the anomaly algorithm was trained on. The weak BG release was easily detected as an anomaly although the fluorescence signal from pollen was a factor of 4 stronger that that from BG. This is shown in Figure 27 and Figure 28.

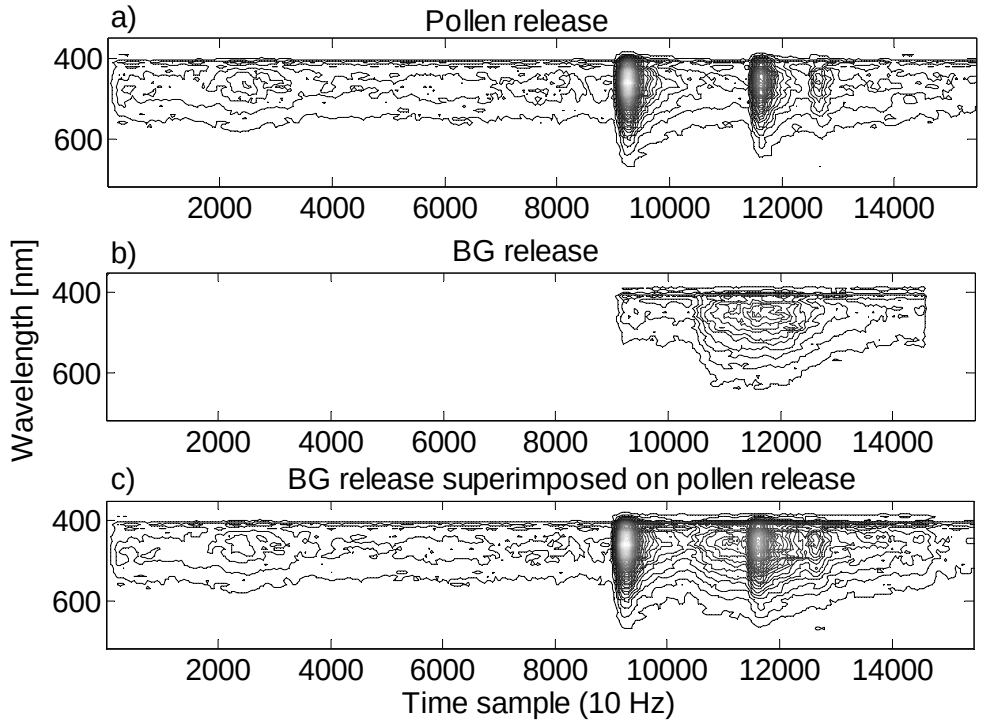

Figure 27: A BG Release was Superimposed on a Significantly Stronger Pollen Release to Test the Anomaly Detection Algorithm.

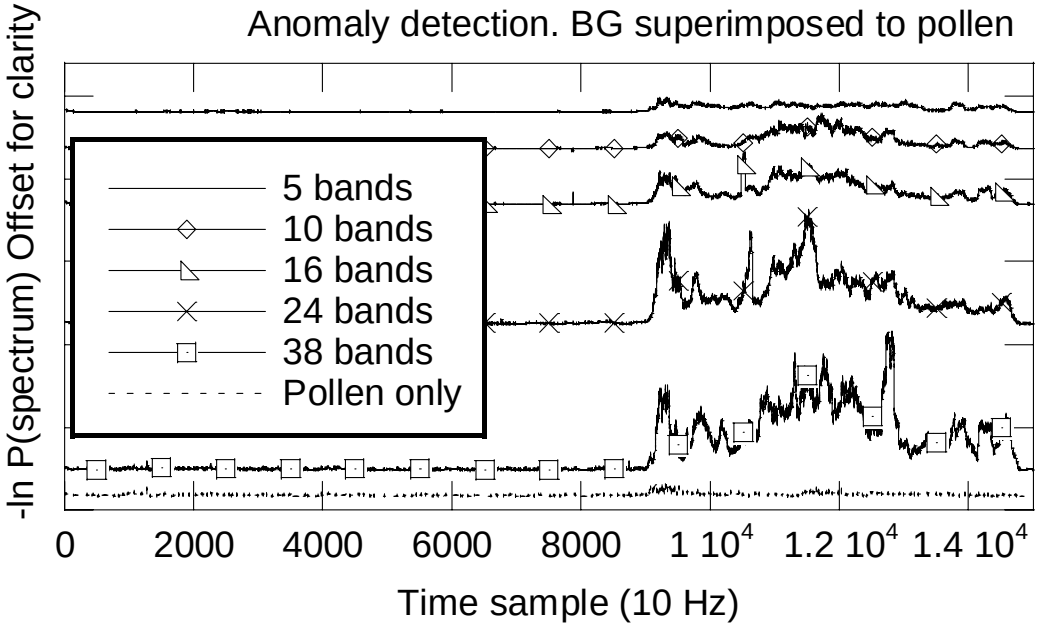

Figure 28: Anomaly Detection of the BG Release Described in Figure 27. The algorithm was tested with different spectral resolutions, and the BG release was detected with high S/N for spectral resolutions above 10 bands.

Also done in this study was to artificially reduce the spectral resolution to investigate the sensitivity of the detection algorithms to the spectral resolution of the LIDAR. It was found both for anomaly detection and for SAM that 10 – 20 spectral channels appear sufficient for these algorithms [14],[15]. This is shown in Figure 28 for anomaly detection and in Figure 29 for SAM. Here, the angles between the key spectra for BG, BT and Ovalbumin (OA) have been calculated for full spectral resolution, and by artificially reducing the resolution. It is seen that the angles are unchanged all the way down to ~10 channels.

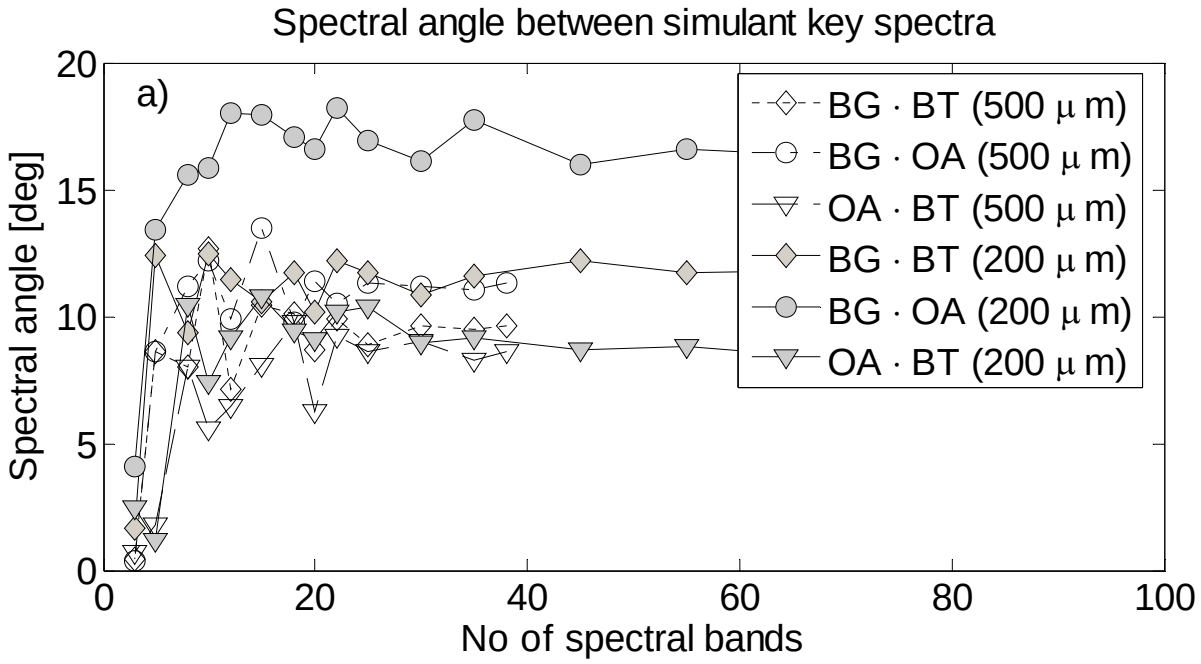

Figure 29: Calculated Angle between Three Different Key Spectra for Different Spectral Resolutions.

7.3 United Kingdom Results

Trials of the UK Mk2 system were completed at Dugway Proving Grounds (DPG), Utah, in 2005 and 2006. Some trials were conducted in the stand-off Joint Ambient Breeze Tunnel (JABT) which allows well contained clouds of test aerosols to be interrogated over a prolonged period of time. Reference Airborne Particle Sensors (APS TSI model 3321) were placed in the tunnel and used to quantify the test LIDAR system's sensitivity. The system measured a number of test aerosols including ovalbumin (OV, toxin simulant), killed vaccine strain *Yersinia pestis* (YP), MS2 (viral simulant) and smokes from burning vegetation and diesel exhaust (from both un-maintained and clean engines). These releases were used to assess the system's generic discrimination capability. Example spectra of an OV and an un-maintained diesel engine exhaust released in the JABT are shown in Figure 30 and Figure 31.

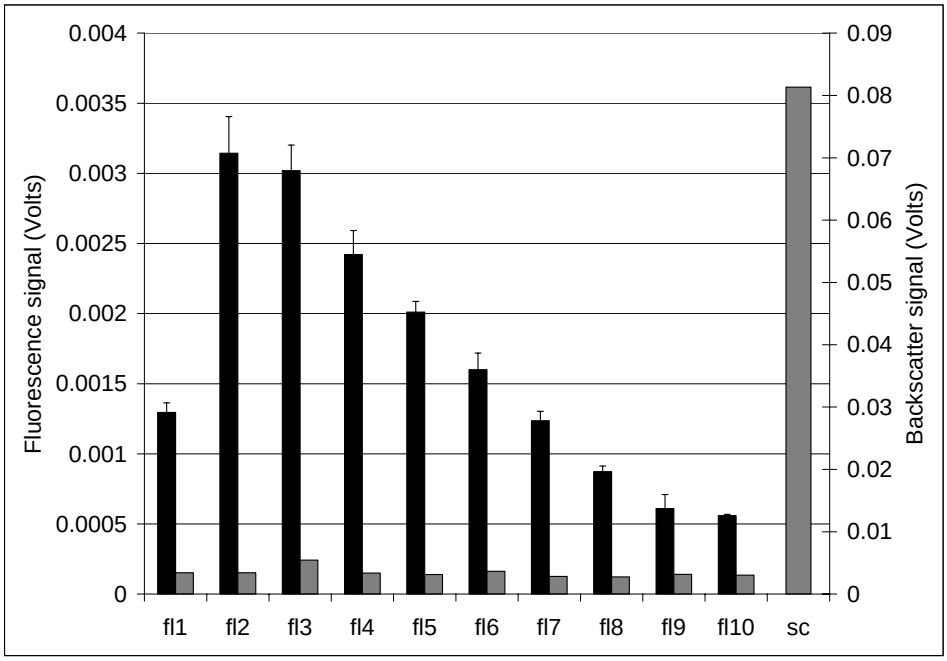

Figure 30: A 2-Minute Averaged Period of an OV Release in the JABT. Fluorescence signal shown for each of the 10 Fluorescence (fl) channels. Signal noise on channels shown on grey bars, variation in cloud signal shown on standard deviation bars. UV backscatter return shown on SC bar.

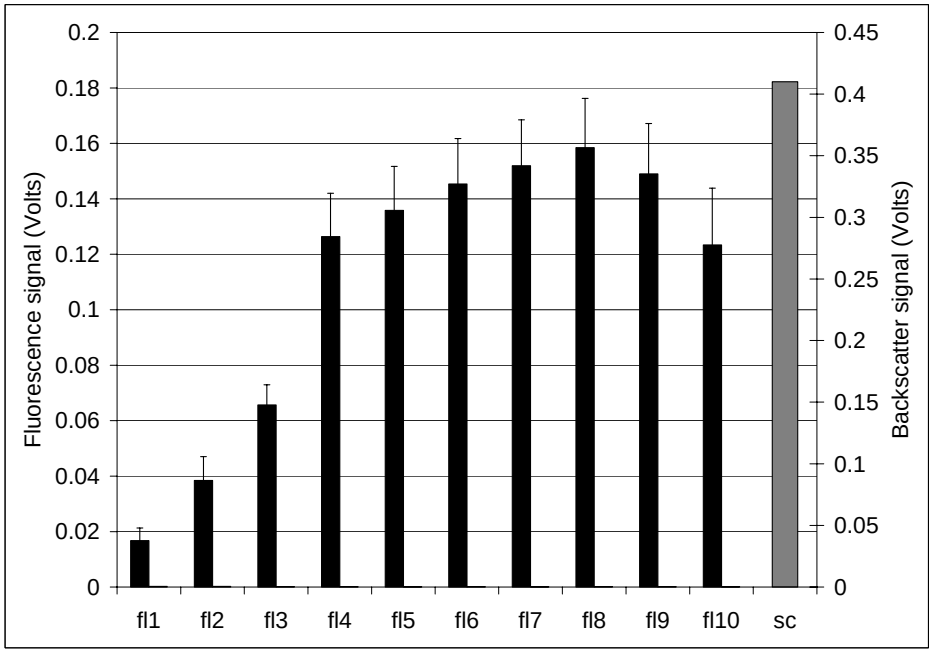

Figure 31: A 2-Minute Averaged Period of an Unmaintained Diesel Engine Exhaust Measured in the JABT. Fluorescence signal shown for each of the 10 Fluorescence (fl) channels. Signal noise on channels shown on grey bars, variation in cloud signal shown on standard deviation bars. UV backscatter return shown on SC bar.

Open range trials were also conducted with test aerosols released as both crosswind and downwind challenges to evaluate the scanning capability of the system. One night of trials included dawn trials and Figure 32 below shows the fluorescence return from a cloud of killed vaccine strain YP at the beginning of the sunrise (5500 lux). The system could still detect measurable fluorescence from a BG cloud with light levels equivalent to a cloudy day (approx 25000 lux). However, this single trial needs to be repeated to quantify the fluorescent signal reduction in rising ambient light levels.

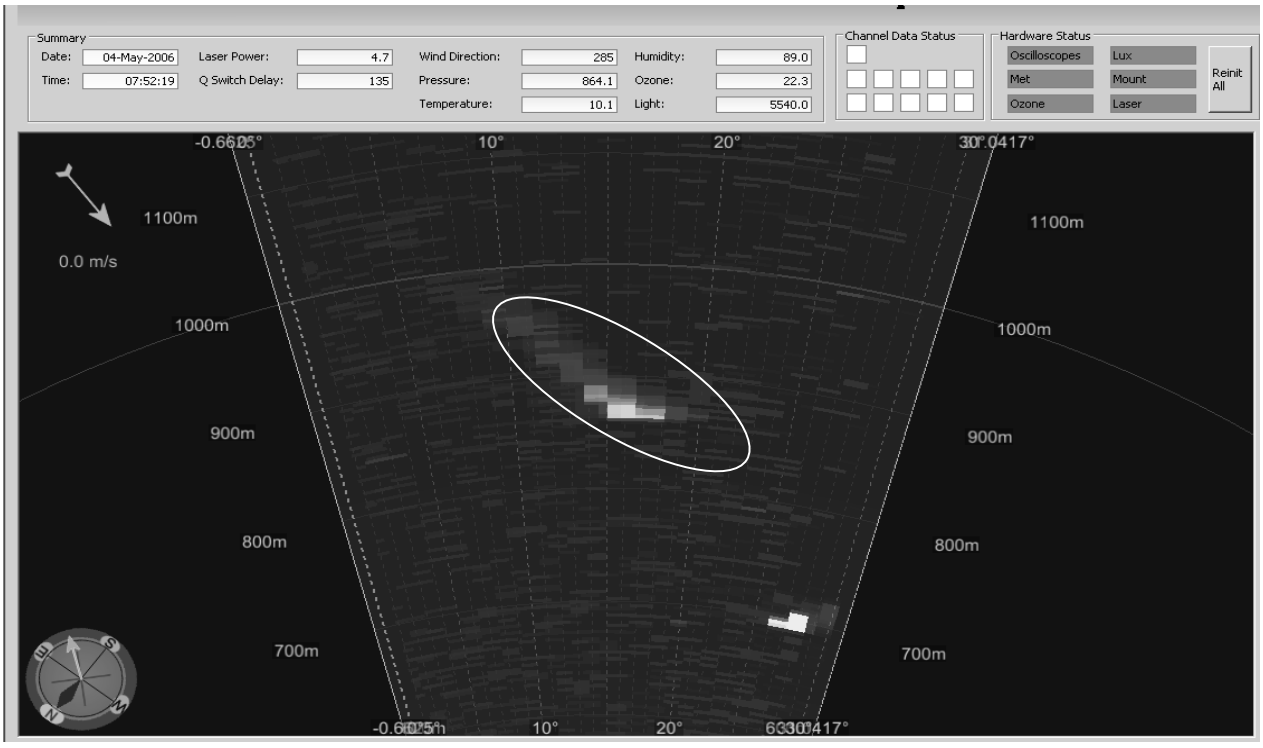

Figure 32: A Screen Shot of the System Software Showing the Fluorescence Intensity from a Cloud of Killed Vaccine Strain *Yersinia Pestis* with 5500 Lux Light Intensity.

Figure 32 above shows an example of the real-time display software that has been created to display the scanning LIDAR data (the highlight around the cloud pixels has been added later). A Support Vector Machine (SVM) algorithm was trained on previous trials data to give a generic 2-class 'biological' or 'non-biological' classification for selected aerosol clouds. This has been interfaced with the control software to give an automated detection and classification of potential agent clouds whilst the system is in operation. A Bayesian classifier has also been developed and implemented on the LIDAR software to allow comparison of both classifiers on the system. Initial results in the field trials were promising. For a full quantitative assessment data would be required from a range of different environmental conditions where background aerosols could contribute to the measured signals.

Spectral angle mapping (SAM) has been employed to assess the separability of different material spectra. The technique converts the 10 channels of fluorescence information into a 10-dimensional vector. The angular separation between the vectors of different materials can be used to measure the separability of the two materials' spectra. Figure 33 and Table 3 shows the percentage overlap for a variety of biosimulants and interferents. It is unlikely that the system would be able to reliably discriminate between materials with an

overlap greater than 5%. The caveat must be added that the data used for this analysis were collected in ideal conditions with very low background and a controlled, high-density cloud maintained in a breeze tunnel. The same performance may not be replicated in more realistic circumstances, where interferents may mix with biosimulants and background aerosol.

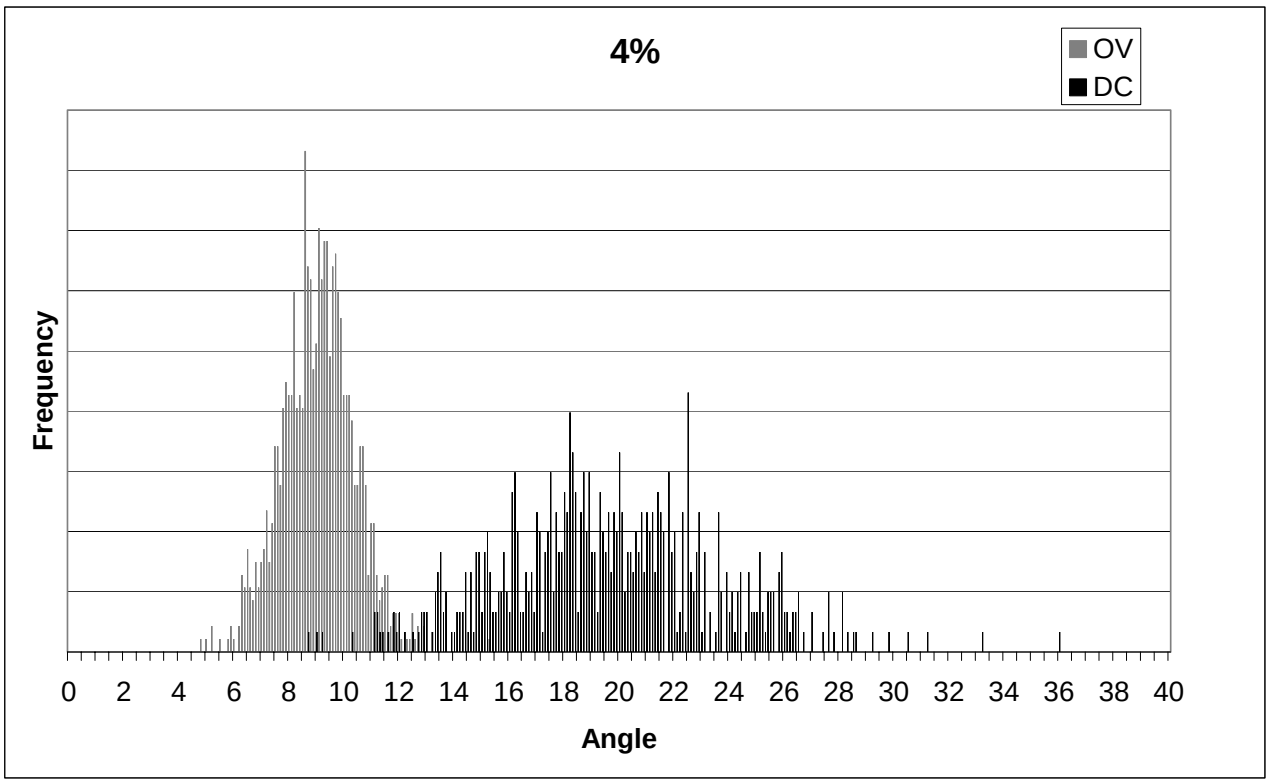

Figure 33: Graph Showing the SAM of Clean Diesel Exhaust (DC) and Ovalbumin (OV) with a 4% Overlap.

Table 3: Percentage Overlap of Spectra from SAM Analysis. Black blocks have close to zero overlap and therefore should be possible to discriminate on clean data.

Clean Diesel Exhaust (DC)	**DC**		
Dirty Diesel Exhaust (DOS)		**DOS**	
MS2	14.8		**MS2**
OV	4		

As the SAM table indicates the system could separate some materials based on their spectra; a multiple class SVM was then incorporated into the LIDAR software as a research tool to allow investigation of any additional discrimination capability that could be gained from the spectral approach. It is possible that if the multiple-class

output is subsequently recombined into a two-class biological/non-biological output (anticipated to be required in any operational generic detection system), it may result in less confusion between bio-simulants and fluorescent interferents.

Figure 34 shows result of the 2-class SVM algorithm applied to a fluorescent cloud detection during a scanning trial. The sensitivity of the fluorescence detection is such that the discrimination has been achieved on clouds at ranges of up to 2 km, in real time, without the need for staring, at scan speeds up to $2°s^{-1}$.

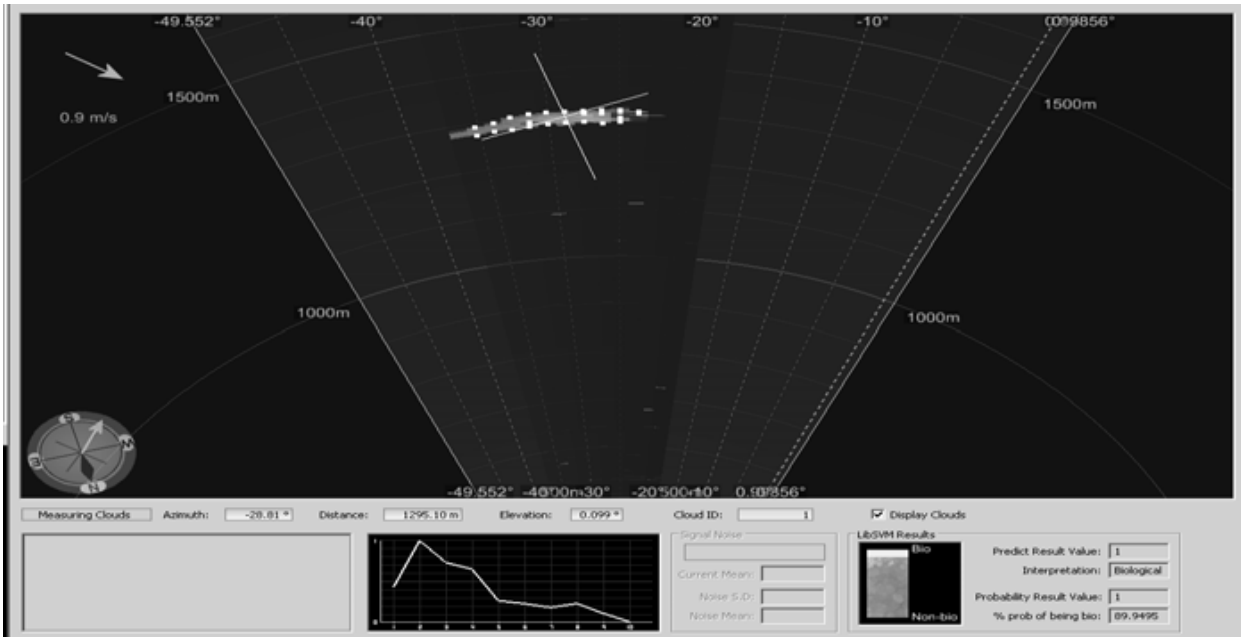

Figure 34: Display Screenshot with Cloud Detection.

8.0 LWIR FIELD TEST RESULTS

The traditional algorithmic approach to estimating the concentration of an aerosol cloud from LIDAR backscatter measurements requires prior knowledge of the wavelength dependent backscatter coefficients. In applications were those parameters are well characterized *a priori* the traditional approach is well suited. In the present application of detecting a biological threat cloud that was produced by an unknown source, using an unknown process, in the presence of a complex background, the traditional approach is not feasible. For these reasons it is necessary to estimate the spectral structure and concentration from the same data. The algorithm that has been developed in collaboration with Russell Warren of EO-Stat estimates the aerosol backscatter wavelength dependence and concentration range dependence in parallel [16]. It operates sequentially using a combination of Kalman filtering for the concentration and maximum likelihood for the backscatter. The backscatter and concentration estimates are used to construct a generalized likelihood ratio test statistic for the presence of aerosol whose distribution under the null hypothesis is well characterized. Once the presence of a material is detected and the spectrum (Figure 35) is estimated the discrimination algorithm is applied. Several discrimination algorithms were evaluated. These included the Linear Fisher Discriminant (LFD), Multi-Layer Perceptrons, and Support Vector Classifier (SVC). The SVC significantly outperformed the other approaches and the results are shown in Figure 36.

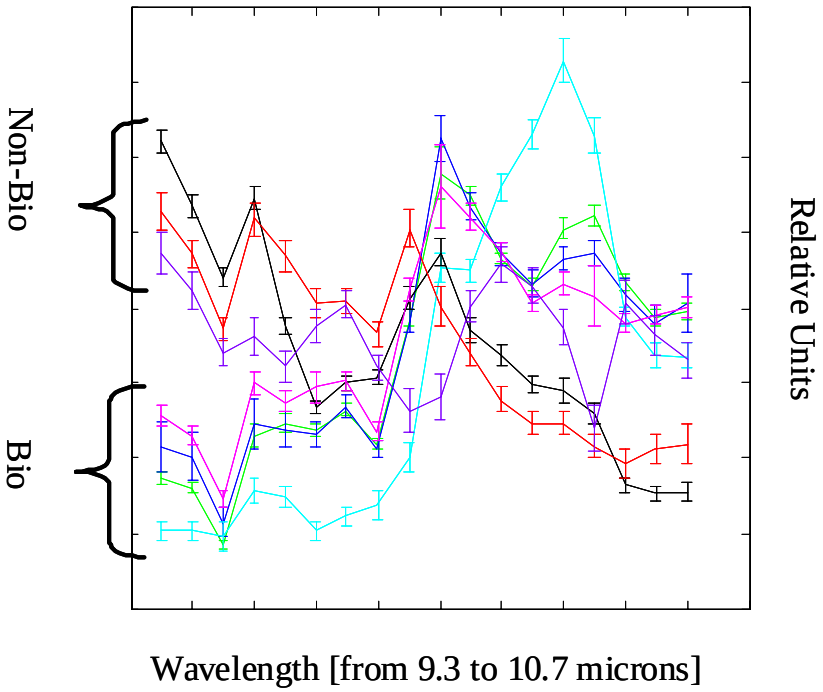

Figure 35: Sample Backscatter Spectra of Some Biological Simulants and Interferents in the LWIR Region. The single shot measurement standard deviation is shown.

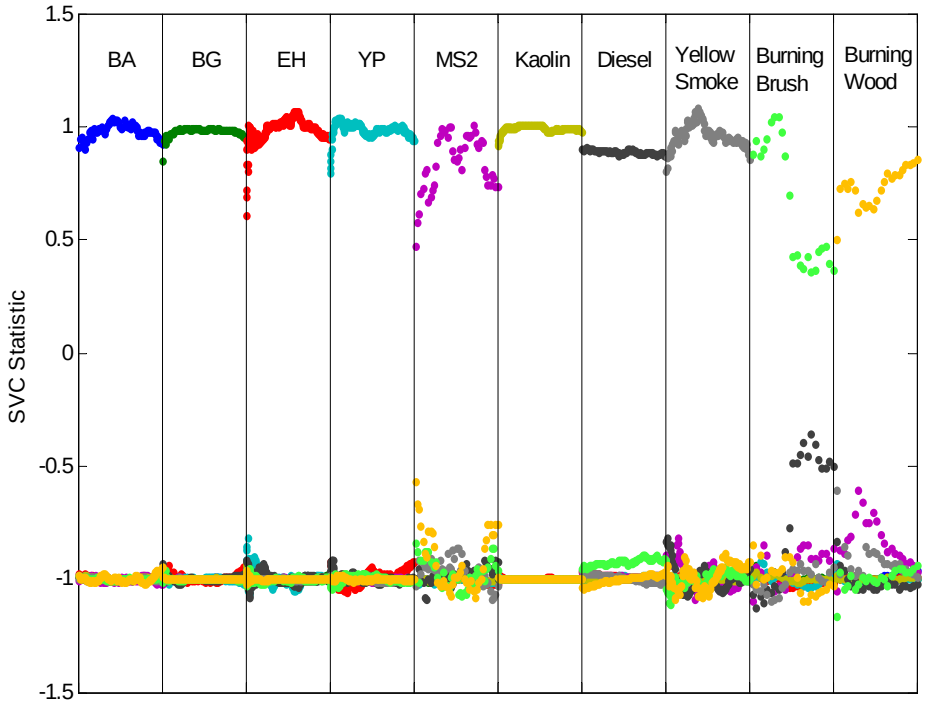

Figure 36: LWIR Demonstrated Discrimination Results.

The SVC maximizes the separation between data points, the so-called maximum margin hyperplane. The margin is by definition the distance from the hyperplane to the nearest data point. The primary difference of the SVM approach as compared to traditional classifiers is that only the data points actually lying on the boundary of the margin determine the classifier structure. This difference leads to several key advantages. The SVC directly finds the optimal solution without needing to estimate the underlying probability distribution of the data. This is a key advantage over other approaches because it is rarely possible in practice to obtain the underlying distribution. In addition, while the LFD is optimal if the data is independent and multi-variate normal, this is rarely the case and clearly not true in this application. These advantages lead to a more robust classifier with better resulting separation.

9.0 INFRARED DEPOLARIZATION FIELD TEST RESULTS

The architecture of the data analysis and discrimination algorithm is appropriate for real-time implementation. An operation software prototype was used to evaluate developed algorithms. Figure 37 provides example results of LMCTs discrimination algorithm implementation and optional outputs for non-scanning operation. Figure 37 highlights two depolarizing materials emphasizing the multi-wavelength dependence of the depolarization ratio for classification. Plume maps and discrimination results as a function of time and distance for dust and *Bg* are shown in the left and right columns, respectively. Data from these releases were not included in the development of the discrimination algorithm. Both of these releases were properly identified and interferent and simulant, respectively, indicating an important step in the validation of compatible hardware and software for an early warning stand-off detection system utilizing WANDER and DISC. Discrimination of simulated threats from interferents based on categories related to optical signatures is critical for the development of a multi-variable classifier with appropriate balance and representation of each class. To date the operational system has demonstrated the capability to discriminate simulants (e.g. *Bg*, *Eh*) from interferents with the sensitivity necessary for early warning.

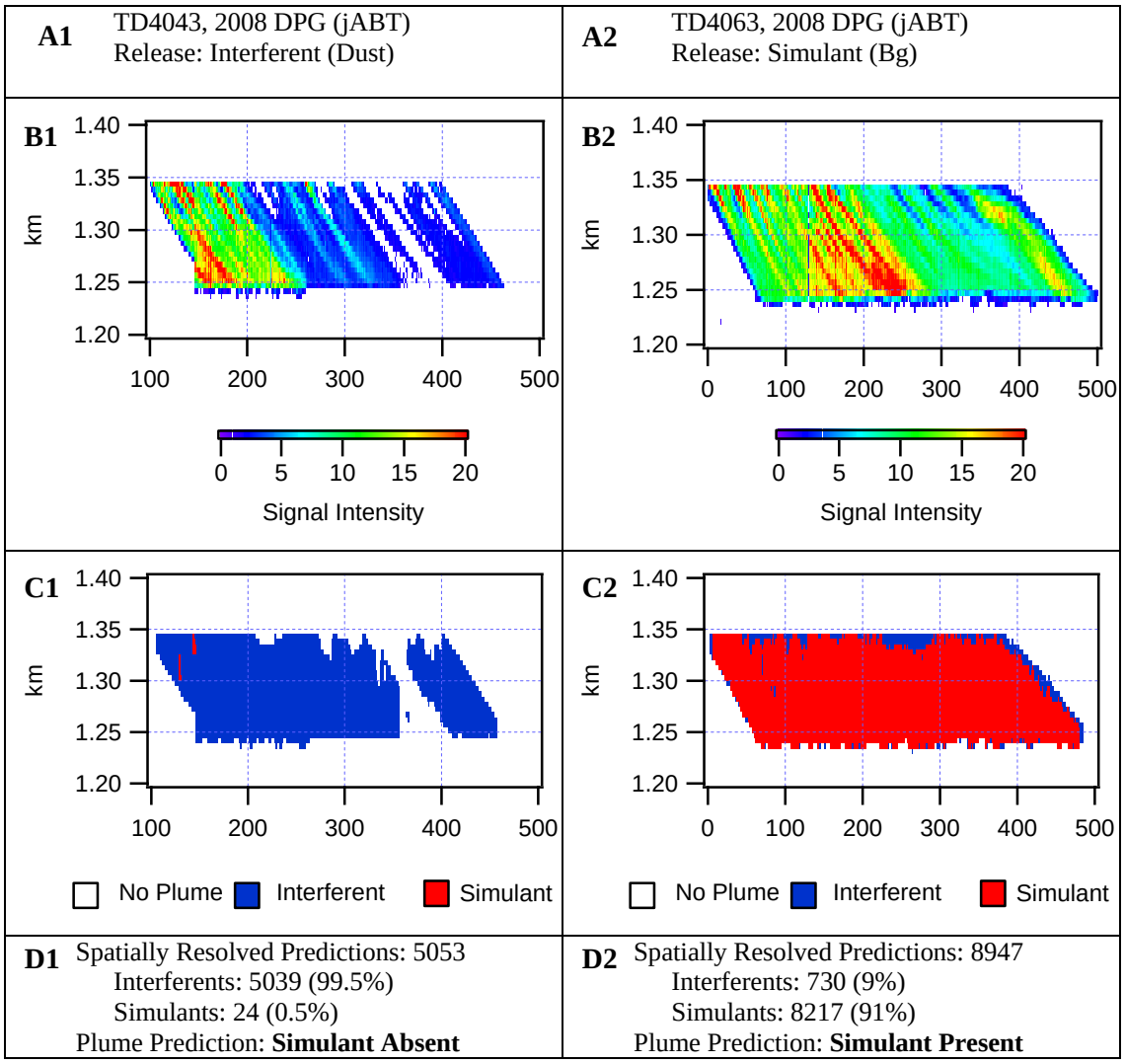

Figure 37: Examples of Spatially Resolved Discrimination Results (the left and right columns are for release TD4043 and TD4063 (*Bg*), respectively) – A) includes the release details; B) indicates the plume map as a function of time and distance; C) indicates the spatially resolve discrimination results; D) summarizes the discrimination results. In both cases the plumes have been properly discriminated.

The results utilize the spatial resolution capability of the WANDER system. With appropriate plume mapping and boundary selection the signal intensities can be integrated to enhance the system sensitivities while maintaining the ability to filter out hard targets or other artifacts. During full system operation the dynamic boundary selection ability extends the systems sensitivity to lower concentrations and more challenging environments.

10.0 SPECTROSCOPIC MEASUREMENTS

Unlike chemical warfare agents, biological warfare agent cross-sections, as well as simulants, are either entirely unknown or there is a paucity of information available. The problem is the complexity of bio-aerosol

characterization. The high diversity of chemical composition, size distribution, and shape are examples of this complexity. The situation required a fundamental and adaptable approach to cross section determination.

An approach was developed to derive the required cross-sections of simulants from thin film measurements and other inputs, and then compare these results to cross-sections obtained from recent outdoor aerosol field tests and laboratory aerosol chamber measurements [[17] – [20]] (Figure 38). These cross-sections can then be used to predict the performance of stand-off detection systems versus actual BW agents as well as be used in developing the design of an optimal biological detection system that exploits known signatures, in optimal spectral regions, to enhance detection and discrimination of hazardous biological materials.

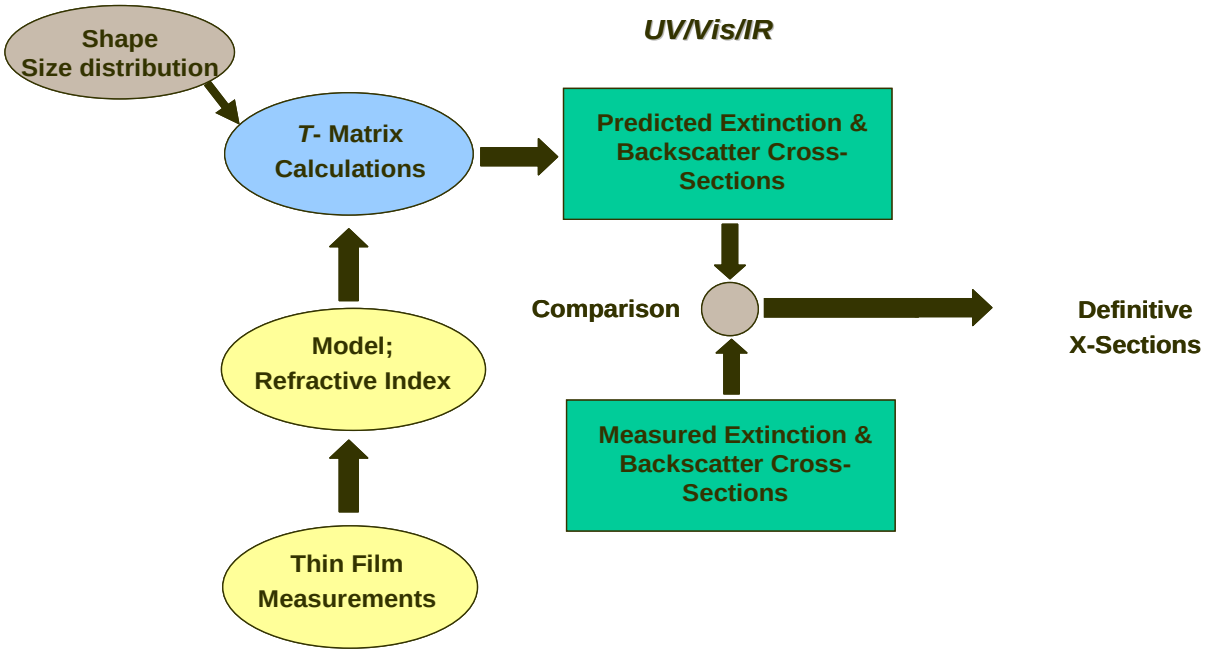

Figure 38: Block Diagram Depicting the Methodology for Developing Validated Cross-Sections.

The basis for the determination of optical cross-sections is thin film measurements of the biological material of interest. Optical cross-section measurements were performed using a Fourier transform infrared spectrometer (FTIR) combined with UV/visible measurements to span the electromagnetic (EM) spectrum from the UV through the far-IR region. Comprehensive coverage of the EM spectrum is required to determine the optimal spectral region(s), and specific signatures, for detection/discrimination of biological species. This is true for any present or future optical-based technology that may be used for either point or stand-off detection.

Once the indices of refraction have been determined these become inputs to *T*-matrix calculations. The values of n and k were combined with structural information along with a particular size distribution of the biological material of interest to determine the extinction and backscatter cross-sections. The *T*-matrix calculations were also used to investigate the effects on these optical cross-sections that might result from a release with a different particle size distribution. Additionally, since these *T*-matrix calculations provide the full Müller matrix, polarization effects were also investigated.

11.0 COMPARISON OF TECHNOLOGIES

All the National UV LIF LIDAR systems have demonstrated discrimination of bio-simulant material from potential interferents in field trials using spectrally resolved returns. The systems are mature and supported by a large underpinning knowledge base of fundamental fluorescence spectroscopy. However, their performance in increasing ambient light levels decreases as rising background light cannot be optically filtered out of the fluorescent return, reducing signal to noise levels. Some reduced capability in daylight conditions has been demonstrated for both the 266 nm and 351 nm wavelength based systems.

In contrast, the depolarisation LIDAR and LWIR differential scatter LIDAR both detect well defined wavelengths allowing the background to be decreased *pro rata*, and so these maintain a daytime capability. However, these systems are less mature and less is currently known about the underpinning spectroscopy of the measurements being made. For example, depolarisation signals appear to depend upon humidity, as water may be adsorbed onto particles.

IR elastic backscatter is suggested as a way of increasing cloud mapping and tracking range for UV LIF systems, and multi-wavelength depolarisation could also be combined within a fluorescence system to increase its daytime capability.

All these techniques discussed can be incorporated into robust systems which can be operated in field trial conditions similar to some potential deployment postures. While the research systems are still large and heavy, there is potential to engineer vehicle-mounted, scanning systems.

Table 4: Comparison of the Relative Performance of Each Technology

Parameter	Elastic Scatter Depolarization	Laser Induced Fluorescence	Differential Scattering
Probability of Detection	G	G	G
Probability of Discrimination	Y/G	G	Y/G
Weight	R/Y	R/Y	R/Y
Deployment Posture	Y/G	Y/G	Y/G
Daytime Capability	Y/G	R/Y	Y/G
Scan Capability	G	G	G
False Alarm Rate	Y	Y/G	Y

Table 5: Comparison of the Advantages and Risk Areas for Each Technology

Technologies	Pros	Cons	Organisations
Fluorescence	Demonstrated discrimination Large knowledge base System maturity	Reduced daytime capability	Canada, Norway, UK, USA
Multi-Wavelength Depolarisation	Daytime capability Potential to combine with fluorescence	Dependence on humidity System maturity Small knowledge base	USA
Long-Wave IR Differential Scattering	Daytime capability Chemical Detection Eye safety?	System maturity Small knowledge base	USA

12.0 RECOMMENDATIONS

Based upon the results of the LIDAR systems tested and discussed above, the Task Group recommends that the best option for the near-term (2008 – 2010) application of stand-off detection systems is UV LIF. The choice of 266 nm or 355 nm excitation wavelength depends upon the range requirement, discrimination potential, and day-time performance considerations. Spectrally-resolved fluorescence improves the discrimination potential and useable results can be obtained with as few as 10 spectral bands. Near-IR depolarization may be added to enhance the discrimination potential and improve daytime discrimination. Long-term options include infrared depolarization and LWIR differential scattering (DISC). These technologies have better daytime performance and LWIR DISC has the potential for combined CB detection. Finally, the use of advanced algorithms, such as Support Vector Machines and Spectral Angle Mapping, is recommended to assess the discrimination capability of the systems.

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Annex A – LASERS FOR BIODETECTION

A.1 LASERS FOR BIODETECTION

Active techniques for detection of biological warfare agents may use infrared or ultraviolet lasers, or both.

A.2 UV LASERS

For laser induced fluorescence, wavelengths in the ultraviolet are required. The most desired wavelengths are 260 – 300 nm for tryptophan excitation and ~350 nm for NADH excitation. Also excitation of different flavins, primarily riboflavin, is possible. A common excitation wavelength for riboflavin is ~450 nm.

To obtain good signal to noise ratio, the laser pulses need to be very intense – preferably in pulses of tens of nanoseconds duration with several millijoule pulse energies. As averaging over many pulses often is required, high pulse repetition rates (hundreds of Hz) is also desirable.

At present, high pulse energies in the ultraviolet is best achieved by:

- Third (355 nm) and fourth (266 nm) harmonic generation of a flash-lamp pumped Nd:YAG laser. This is a well-proven concept, with limitations with respect to lifetime of laser (30 million shots) and pulse rate (<100 Hz), but 5 – 50 ns pulses of several hundred millijoules is possible. The wall-plug efficiencies of the systems are lowered by inefficient transfer of energy from the flash-lamps to the laser medium, and are typically in the range of 1%.
- An excimer laser. This is a gas laser whose output wavelengths depend on the mix of gases used. Xenon and Chloride gives 308 nm while Xenon and Fluoride gives 351 nm. Both high output energy and high pulse rates are possible, but the laser is bulky (>100 kg) and inefficient, and is not well suited for operation in the battlefield.

Alternative approaches include:

- Third and fourth harmonic generation of a laser diode pumped Nd:YAG laser. Such systems can be small, have high efficiency and long lifetime. However, they are at present more suited for high pulse repetition rates at moderate pulse energies than vice versa. This is a basic property of most diode-pumped systems. It is still possible to design a high pulse energy system, but at relatively high cost. The driving forces in the market seem to be most interested in high average power, and not high pulse energies.
- To reach wavelengths other than 266 nm and 355 nm, other optical non-linear processes can be applied. For instance, the optimal excitation wavelength for tryptophan is 280 – 290 nm. This can be obtained using sum-frequency generation of 532 nm and 589 nm or by pumping an optical parametric oscillator with 266 nm. Such schemes increase the complexity of the system, and it is challenging to obtain high pulse energies.

UV LIF may also use high pulse repetition rate lasers with less energy, and instead average over a larger number of pulses. This will make the requirements for the laser easier to meet, but will increase the requirements on the detection technology. Most systems use photo-multipliers to increase the sensitivity of the detector. These devices are not shot-noise limited, so this approach will not necessarily increase detector noise. Integrating over more pulses will, however, increase the background signal which may reduce the sensitivity of the system.

A.3 IR LASERS

The primary wavelength regions of interest are determined by the 3 – 5 µm and 8 – 12 µm atmospheric transmission windows. Detection in these windows is based on elastic (Mie-) scatter, and several wavelengths (or a tunable source) are needed to resolve the spectral features of the bioaerosols.

The CO_2-laser can deliver tunable laser radiation between 9.2 µm and 10.8 µm at high pulse energies and average output powers. The CO_2-laser is well developed and can be made relatively small and lightweight.

A chemical laser based on DF has emission lines in the 3-5 µm band. This can be made very powerful (weapon-class), but it seems less suited for fielded operations.

Frequency down conversion of high power pump lasers through for example optical parametric oscillators (OPOs) is an alternative path to tunable radiation with high pulse energies in the infrared bands. Efficiencies can be made relatively high, and wide tuning ranges are available. High pulse energies are possible, but require more complex designs than for low pulse energies. Frequency conversion systems can be based on commercially available pump lasers.

A driving application for laser systems in this wavelength range is military electro-optical countermeasures. Here, both high average power and high pulse energies are desired. Typically, the bandwidth required in such systems is less narrow than needed in detection of bioaerosols. However, narrowing the bandwidth is likely a minor task.

A.4 SUMMARY

In conclusion, further development of laser sources is needed both for sources in the infrared and in the UV.

For the UV, commercial sources can at present be used, but future systems may require dedicated development to combine high pulse energies with high output power, perhaps also at wavelengths other than the 3^{rd} and 4^{th} harmonics of Nd:YAG.

In the infrared, the CO_2-laser covers a wavelength region around 10 µm, but for other wavelengths, dedicated development is required. There are several fields that drive the development of this technology, among them military electro-optical countermeasures and remote sensing. Therefore, it seems reasonable to conclude that even if there are no off-the-shelf systems for the infrared, the technology for adequate sources is available.

Annex B – PATENT INFORMATION SEARCH FOR "SHORT-RANGE BIO SPECTRA"

Enclosed: Information extracted from:

Pilot-Project for the evaluation of the market and the scientific validity of the technology know as 'Short-range Bio Spectra'

Final Report

December 2004

Canadian Institute for Scientific and technical Information

Authors: Jean Archambeault
Patrice Dupont

Conseil national de recherches Canada | National Research Council Canada

Canada

Highlights (p.2)

- The patent information search focused on the target technology, "Short-range Bio Spectra," and competing technologies, in databases of patents and patent applications in the United States (US), Europe (EP), Japan (JP) and the PCT (WO).
- Patent information and the past two years of scientific and technical publications in this area of research were retrieved along with relevant market studies.
- In the context of this report, 239 patents granted and patent applications were retained. Of these, a sub-set of 45 documents deal with technologies that are more or less similar to the technology targeted for this project.
- The amount of technological activity seen in this field since 1998 has been growing at an average rate of 75% annually.
- Few patent holders have more than one patent to their name, particularly in the group holding the 45 patents for technology similar to the target technology.
- A more marked increase in IP protection is seen in the case of technologies based on the use of antibodies and nucleic acids, enzymes, immunological methods, chemical analysis and methods of measuring environmental conditions (e.g., colony counters).
- Data from a study by Frost & Sullivan forecast an annual growth in the market for biodetection instruments of 12% over the next four years.
- A Business Communications Co. study emphasizes a need for this type of instrument for the protection of law enforcement services and first responders. The same study also confirms a higher regionalization of demand in Asia and a markedly higher rate of growth in the Middle East.

Objective (p.3)

To serve the Canadian Armed Forces, DRDC Valcartier offers business opportunities to private and public sectors within the scope of its scientific program, in its three main areas of expertise: combat systems, information systems and optronic systems. Before collaborating with the private and/or public sectors, DRDC Valcartier must ensure that its expertise and knowledge are transferable and usable without restrictions. In this regard, DRDC Valcartier must be able to evaluate its inventions and technologies, despite the fact that access to the internal services and databases required for evaluation and validation of the technologies and inventions is not always fully available.

The Canada Institute for Scientific and Technical Information (CISTI) is one of the main sources of information in all areas of science, technology, engineering and medicine. CISTI's scientific expertise in retrieving scientific and technical information completes and enhances the information picture that DRDC Valcartier will rely on in the decision-making process concerning the future of technologies and inventions created internally or through a collaborative effort.

With this objective in mind, this pilot project was initiated to assess the potential of a possible collaboration between the two organizations. CISTI was asked to produce a preliminary technology analysis report that will be used as a basis for the work of the participants in the pilot project. The report will be evaluated by DRDC Valcartier and will be used to produce a set of recommendations and adjustments designed to optimize collaborative efforts and enhance the positive outcomes for DRDC Valcartier. After receiving DRDC Valcartier's recommendations, CISTI will submit a final, amended report.

Activities Planned for CISTI

- Identification of scientific articles (English, French) published in the field over the past two years;
- Identification of market possibilities and trends;
- Identification and profiling of major players in the field.

Anticipated Results

a) Evaluate possibilities for protecting the target technology in the following countries in particular: Canada, the United States, England, France, Italy, Australia, New Zealand.

b) Identify similarities between the technologies identified and the DRDC Valcartier technology.

1. BACKGROUND (P.4)

1.1 Context

Improving technologies for detecting and identifying pathogenic biological agents (bioagents) in aerosol form (bioaerosols), whether anthropogenic in nature or not, is essential to military and civilian security.

Bioaerosols are effective at low concentrations; they are difficult to detect among other, inactive particulates and they vary widely. They also make it necessary for devices to be capable of rapid reaction times in order to avert a potential threat and counter the spread of a pathogenic agent. Hence, certain factors are key in the evaluation of the effectiveness of a detection technology:[1]

- **High sensitivity**: detection of very low doses of bioagents on an aerosol substrate in the presence of other suspended particulates.
- **High selectivity**: a high level of discrimination between bioagents and other, non-pathogenic particulates (false positives could cause panic among stakeholders and within the population).
- **High reactivity**: fast response time offered by the detection device.

Current technology development efforts are directed toward reducing the cost of detection instruments, reducing reaction times and improving portability,[2] specifically with regard to non-military uses.[3] Certain groups are particularly at risk and require detection instruments of a form adapted to ensure their security; e.g., first responders to a threatened or potential biological crisis, who must act immediately, without being able to use/access complex and costly equipment. The best bioaerosol detection equipment for such first responders would be portable, provide real-time warning of the presence of pathogens in the air and require limited training to use.

[1] "An Introduction to Biological Agent Detection Equipment for Emergency First Responders," U.S. Department of Justice, December 2001. p. 13 et seq.

[2] "Biological Detection System Technologies: Technology and Industrial Base Study," NATIBO, TRW Systems and Information Technology Group, February 2001. pp. 8-2 et seq.

[3] "Chem-Bio Detector Market Reaches $400M." National Defense Magazine, March 2002. URL: http://www.nationaldefensemagazine.org/article.cfm?Id=741.

1.2 Technology Overview (p.5)

Various technologies attempt to respond to the many expectations in terms of detection of biological agents. These expectations vary with the type of user, the material analyzed and the specific functions of the detection instruments.

The specific functions of detection instruments can be divided among four main elements:

- Collector
- Trigger/Cue
- Detector
- Identifiers

The following table[4] provides an overview of the various specific functions and the related generic technologies.

Table B-1: Specific Functions of Detectors and Related Technologies

<table>
<tr><th>Collector</th><th>Trigger</th><th>Detector</th><th>Identifier</th></tr>
<tr><td rowspan="2">• Cyclones
• Virtual Impactors
• Bubblers/Impingers</td><td>• Particle Size
– Aerodynamic Particle Sizing (APS)
• Particle Counting</td><td>• Bio-luminescence
• Fluorescence</td><td rowspan="2">• Mass Spectrometry
• Antibody-based
– Capillary Electrophoresis
– Ion Channel Switch Tissue Based Bio-sensor
– HHA/SMART® tickets
– Fiber Optic Waveguide
– Surface Plasmon Resonance
– Resonant Mirror
– Up-Converting Phosphor Technology
– Electrochemical Luminescence
– Threshold
– Molecular Polymeric Imprints
• DNA-based
– Polymerase Chain Reaction
– Combinatorial Peptides
• Raman Scattering</td></tr>
<tr><td colspan="2">Combined Trigger/Detector
• Fluorescence and Particle Sizing
• Size and Shape Analysis
• Pyrolysis/Gas Chromatography/Ion Mobility Spectrometry
• Chemical Luminescence
• Flame Photometry/Gas Chromatography
• Flow Cytometry</td></tr>
</table>

[4] From "Biological Detection System Technologies: Technology and Industrial Base Study," NATIBO, TRW Systems and Information Technology Group, February 2001. p. 3-3.

1.3 Target Technology (p.6)

In the context of this project, the area of application of the target technology is the following:

Substance analyzed:	Biological pathogen, aerosolized, i.e. carried by an aerosol substrate or airborne (bioaerosols)
Type of user:	First responders (emergency response teams, law enforcement services)
Specific function:	Cueing and detection to warn of the presence of bioagents, and characterization or identification of any bioagents detected

Short-range standoff detector category

2.1.4 Final Results (Patents) (p. 9)

The complete set of patents identified and sorted consists of **239** documents, including all the types of bioagent detection technologies that match the search and sort criteria set out above.

IMPORTANT: Note that the set consists of both patents that have been granted AND patent applications, i.e., requests for patents that have not yet been granted.[6] As will be demonstrated in the patent analysis, the inclusion of patent applications in the set was necessary in order to clearly reflect the activity being generated in the field by the current boom in detection technologies.

The breakdown of the set of patents by country[7] is as follows:

- US = 220
- WO = 13
- EP = 8
- JP = 6
- DE = 4
- FR = 1

** It is important to bear in mind that, when the duplicates were removed, priority was given to keeping the US patents, and hence there is a certain predominance of US patents in the set.

[6] The patent number can be used to distinguish between the two types of documents: the number for a patent that has been granted is in the format "USXXXXXXX," while a patent application is identified by a number in the format "US2001XXXXXXX," which represents, for example, a 2001 application.

[7] The main codes used to identify the countries associated with the patents can be found in Annex II.

3. OVERVIEW OF THE MARKET – INDUSTRY (P. 28-29)

Market data on detection of bioagents do not distinguish to any significant degree among the various competing technologies, particularly in the case of developing technologies that have not yet reached maturity. However, several interesting data were identified and extracted separately from complete reports. These extracted data and tables can be found in Annex III of this report.

3.1 Summary

According to the September 2003 report by Frost & Sullivan entitled "World Chemical and Biological Agent Detector Markets:"

- The market, totalling US$662M (combined military and civilian sales), continues to develop and is forecast to grow at an average of 12% annually over a period of 6 years (2003-2009).
- The level of competition and technological adaptation is high.
- The replacement rate is estimated at 5 – 10 years and the average product development time is 3 –5 years.
- Product satisfaction at present is considered fair.

While the relative dissatisfaction with current products could be an incentive to bring new players into the market (product improvement), the relatively low replacement rate and the high cost of the technologies involved[8] could deter the introduction of new companies[9] in the sector.

The October 2003 market study by the Business Communications Co. (BCC), entitled "Surveillance and monitoring of Explosive, Chemical, Biological and Nuclear Hazards," forecasts an increasing demand in the area of bioagent detection for the period until 2008.

- Demand for biological detection is highest in Asia (Annex III, Figure 6, tables 31 and 33).
- The greatest increase in the demand over the next five years will be seen in the Middle East (Annex III, Figure 6, tables 31 and 33).
- Demand for such products is markedly higher among civilian users (law enforcement services and first responders) than in the military (Annex III, tables 32 and 52), hence the call for portable, adapted technology, as identified in this market study (Annex III, Table 54).

Market studies inventoried

The data cited were obtained from the following two studies:

A – World Chemical and Biological Agent Detector Markets
October 2003
Frost & Sullivan
http://www.marketresearch.com/product/print/default.asp?SID=26940398-295642875-268711189&productid=1043754

[8] "Biological Detection System Technologies: Technology and Industrial Base Study," NATIBO, TRW Systems and Information Technology Group, February 2001. pp. 6-3 et seq.

[9] "Chem-Bio Detector Market Reaches $400M." *National Defense Magazine*, March 2002. URL: http://www.nationaldefensemagazine.org/article.cfm?Id=741

B – Surveillance and Monitoring of Explosive, Chemical, Biological and Nuclear Hazards
October 2003
Business Communications Co.
http://www.mindbranch.com/catalog/print_product_page.jsp?code=R2-736

In addition to the two studies listed above, the following may also be of interest. When the table of contents can be purchased separately, it will be provided. It will be possible for DRDC to ask CISTI to proceed with the purchase, at DRDC's expense, of tables or data considered relevant but not provided.

C – Security Technologies Part 2: Chemical and Biological Detection
December 2002
Frost & Sullivan
(Not used because not as recent, but parts could be of interest)
http://www.mindbranch.com/catalog/print_product_page.jsp?code=R152-085

D – Security Technologies–Advances in Chemical and Biological Detection Technologies (Technical insights)
October 2003
Frost & Sullivan
http://www.mindbranch.com/catalog/print_product_page.jsp?code=R152-103

E – The Biodefense Market for Chemical, Biological, Radiation, and Nuclear (CBRN) Warfare Detection
August 1, 2004
The Market and Press Agency
http://www.marketresearch.com/product/print/default.asp?SID=26940398-295642875-268711189&productid=1032388

F – Market Opportunities in Biodefense Research
July 1, 2004
BioInformatics, LLC
http://www.mindbranch.com/catalog/print_product_page.jsp?code=R158-068

G – Market Opportunities in Homeland Security
July 1, 2003
Richard K. Miller & Associates
http://www.mindbranch.com/catalog/print_product_page.jsp?code=R80-032

H – Biological Standoff Detection System (BSDS)
June 1, 2004
FORECAST INTERNATIONAL

Annex C – FINAL PRESENTATION FROM TASK GROUP 55

SET-098/RTG55/OT

Laser Based Stand-Off Detection of Biological Agents

May 2008

Gunnar Rustad
FFI - Norwegian Defence Research Establishment

Virginia Foot
CO-CHAIR, RTG55
Richard Vanderbeek
CO-CHAIR, RTG55

SET-098/RTG55/OT

Overview

- Background
- TG Objectives
- Progress
- Recommendations

2

SET-098/RTG55/OT

Background

- Biological weapons are a threat to NATO operations
- Early warning of the use of biological weapons in combat is essential
  - To establish a timely defense
  - To sustain operational tempo and freedom of action
- Mapping of biological weapon cloud is needed to obtain intelligence on affected areas

3

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Top Ten RTO DAT Priorities

- Database Access, Search & Networking
- **Standoff Biodetection**
- Database on Terrorist Activity/Characteristics
- Adapting Military Command & Control to Terrorism Response
- Differentiate Terrorists & Civilians / Biometrics
- Standoff Explosive Detection
- Info Architecture / CT Models / Modeling & Simulation
- Real-time Scenario Construction
- Mobile Ad-hoc Networks
- Training First Responders and Higher Echelons

4

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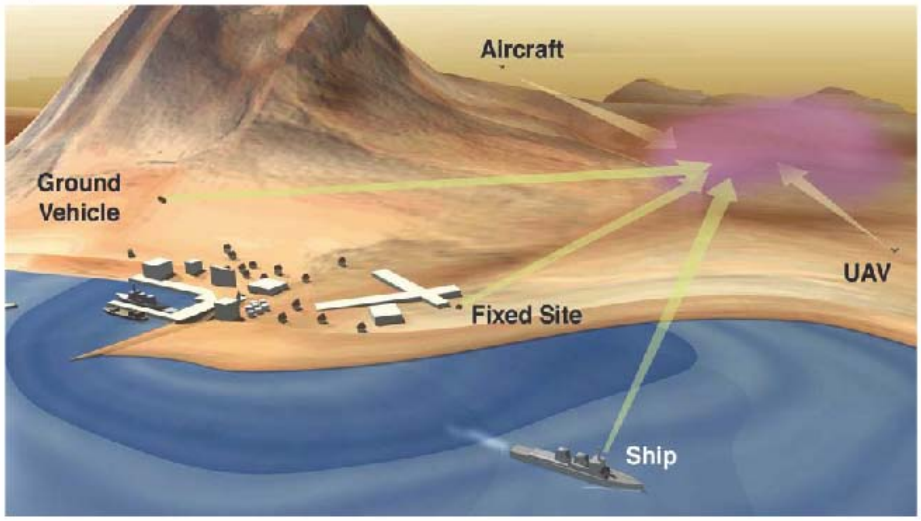
Standoff Detection



5

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Standoff Biological Detection Challenges

- Sensitivity
- Selectivity (bio/non-bio)
- Range of detection
- False alarm rate
- Daytime performance

6

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TG Objective

Study and improve performance of laser based standoff detection of biological agents.

Ultra-Violet Laser Induced Fluorescence (UV-LIF), Long-Wave InfraRed (LWIR) DIfferential SCattering (DISC) and Mid-Wave Depolarization will be studied.

7

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Participating Nations

- Canada
- Norway
- United Kingdom
- United States

8

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Progress

- Meetings Mar 2003, Nov 2003, Jun 2004, Oct 2004, Oct 2005, May 2006, Nov 2006, May 2007, Oct 2007
- Workshop Nov 2006 in Valcartier, Quebec, CA
- Field Trials
  - Montreal, CA in Sept 2006
  - Suffield, CA in July 2007
  - Umeå, Sweden in November 2006
  - Dugway Proving Ground, Utah in Apr 2006, Aug 2007

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Workshop

November 2006 - Valcartier, Quebec, CA

Standoff Measurement of Bioaerosols Size
Remote sensing of chem.-bio agents based upon intense femtosecond laser filamentation
LIDAR and bio-fluorescence detection activities at INO
Fluorescent *in situ* hybridization of bacillus spores
Spectroscopic characterization of fluorescent aerosols in a closed chamber
Overview of fluorimeter technologies at TELOPS
Spectral processing algorithms
IR Technologies (Differential Scattering & Depolarization)
A 10 channel spectrally resolved scanning UV LiF LiDAR for standoff BW detection
Norwegian UV LIF biolidar 10

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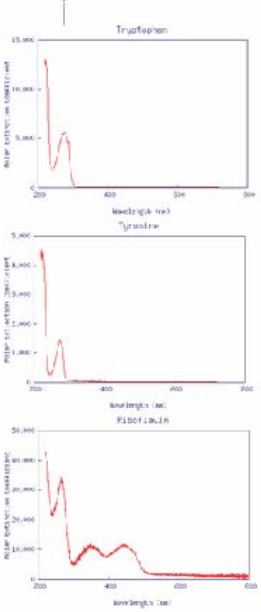
Ultraviolet Laser Induced Fluorescence



266nm excitation (UK)

351nm excitation (Canada)

- Exploit bulk fluorescence and/or spectral shape of fluorescent returns to discriminate between biological and non-biological aerosol particles
- Transmission wavelengths: 266nm and/or 351/355nm.
- Observed return photon wavelengths: (1) Elastic return at transmission wavelength(s) (2) Fluorescent return in bands 300nm-500nm and/or 400nm-650nm

355nm excitation (Norway) 11

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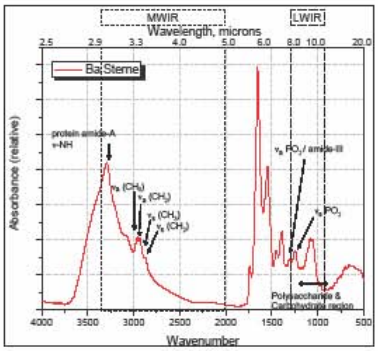
Infrared Lidar Systems



Depolarization Lidar (USA)

LWIR DISC Lidar (USA)

Depolarization

- Exploit ratio of returned photons with different polarizations to discriminate between threat and non-threat aerosol particles; potentially exploit polarization ratios measured at multiple wavelengths
- Potential transmission wavelengths: 532, 1064, 1500, & 3400nm likely candidates, other wavelengths 266-5000nm possible, and if combined with LIF, its excitation wavelength (266-355nm)
- Returns at transmission wavelength(s)

Longwave Infrared Differential Scattering (LWIR DISC)

- Exploit spectral shapes that arise from differential scattering in the longwave infrared to discriminate between threat and non-threat aerosol particles
- Transmission wavelengths: ~9-11 microns
- Observed return photon wavelengths: identical to transmission wavelengths

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SET-098/RTG55/OT

Testing: Dugway Proving Ground, UT

- **19 simulants, 14 interferents, 20 mixtures**
- **96 Tunnel releases and 11 open air releases**
- **Three versions of Bti grown with three different growth media preparations**

More than 30 materials and 20 mixtures released to validate the robustness of the discrimination.

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Testing: Urban background, Montreal, CAN

- 1-week trial (25-29 Sept. 2006, 5 nights)
- CAN and UK systems were present (two UV-LIF systems)
- Deployment site is about 3 km from downtown
- 4 areas of interest targeted

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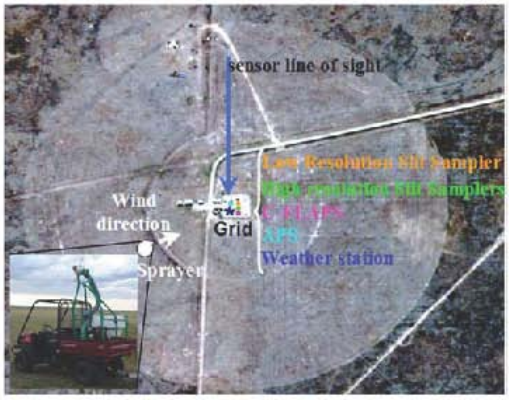
Testing: Suffield 2007, CAN

- 2-weeks trial (July 17th – August 2nd 2007, 10 trial nights)
- CAN (UV LIF standoff) and UK (short range + point) systems
- 58 cross wind open-air releases (simulants, interferents, mixtures)
- Cloud characterized in ppl (APS) and in ACPLA (slit sampler)



Viable bioaerosol concentration:
Agent Containing Particle per Litter of Air (ACPLA)

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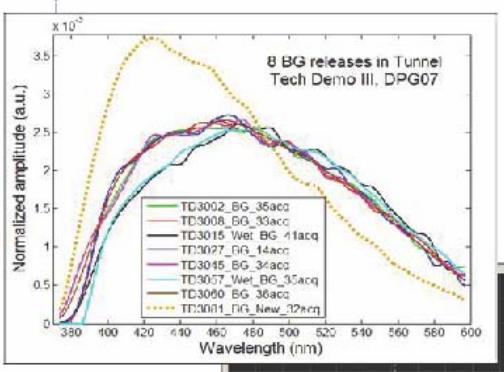
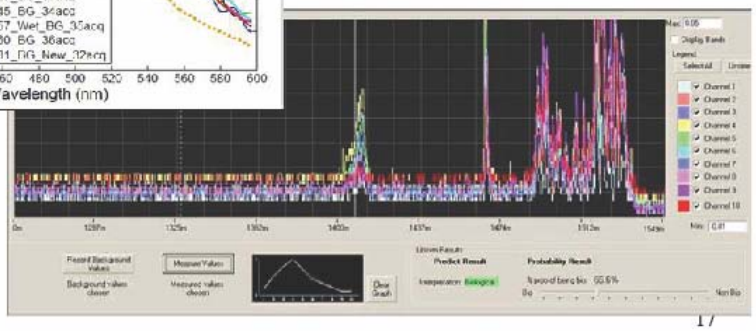
Spectral resolution of Fluorescence



- To discriminate between biological and non-biological aerosol particles
- Investigating both high resolution and fewer, broader resolution spectral systems



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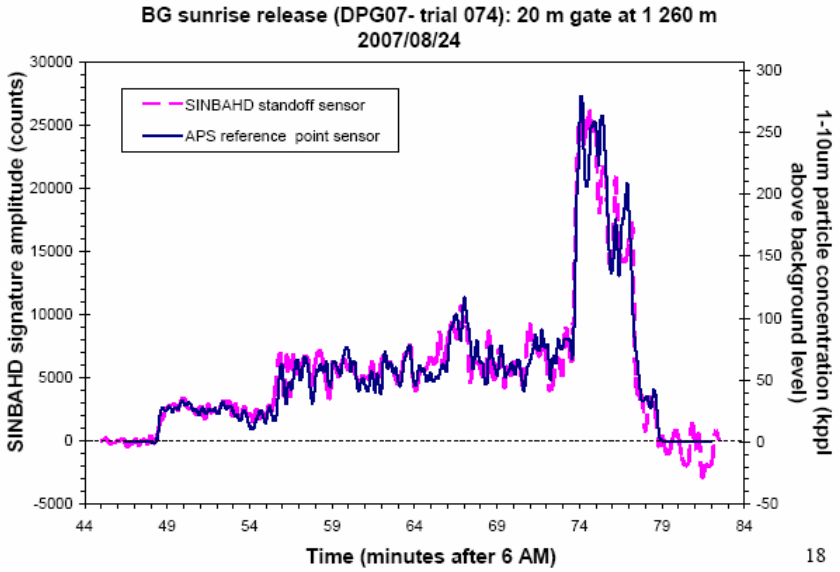
Stand-off and point detection correlation



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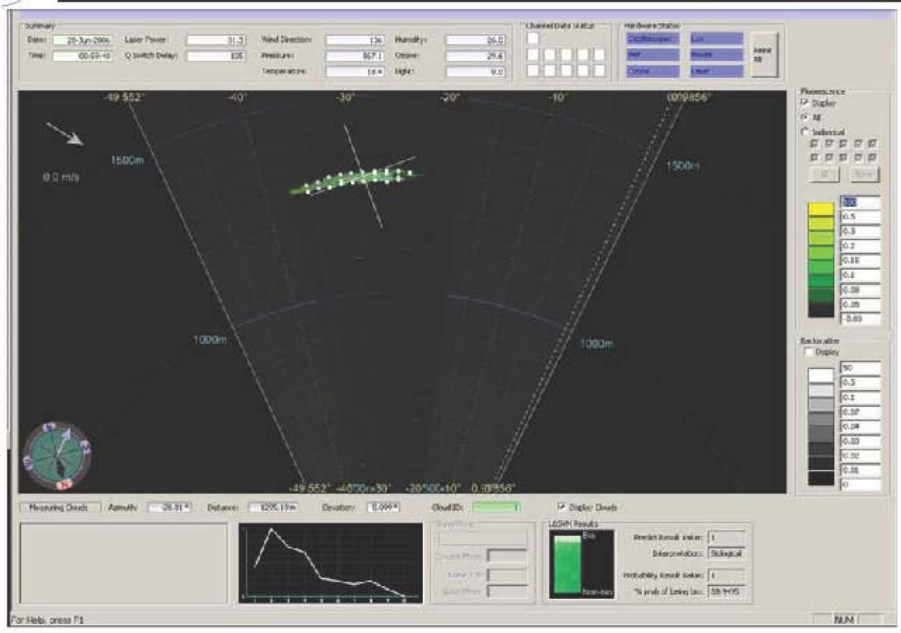
Data display & classification algorithms



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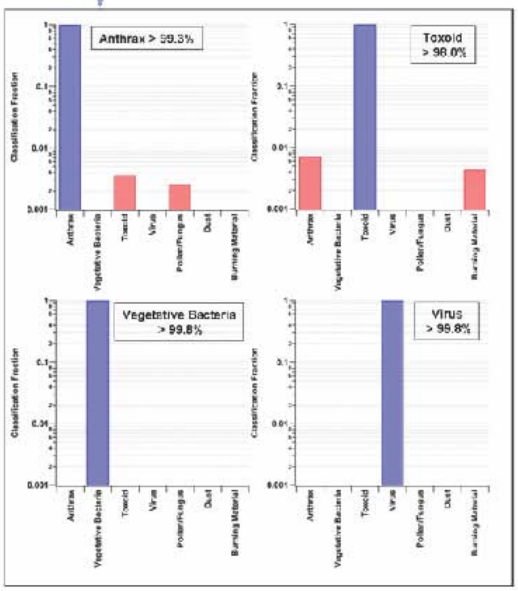
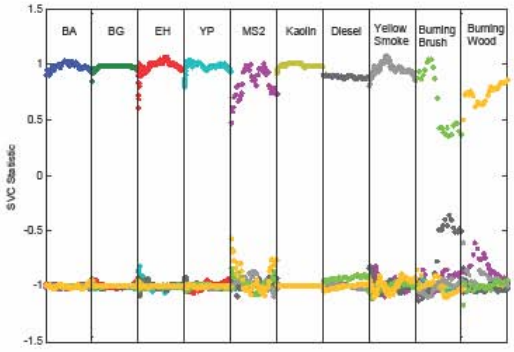
Data classification algorithms



Multi-wavelength infrared depolarization (left) and long-wave infrared differential scatter (bottom) technologies able to discriminate biological materials using support vector machine algorithm.



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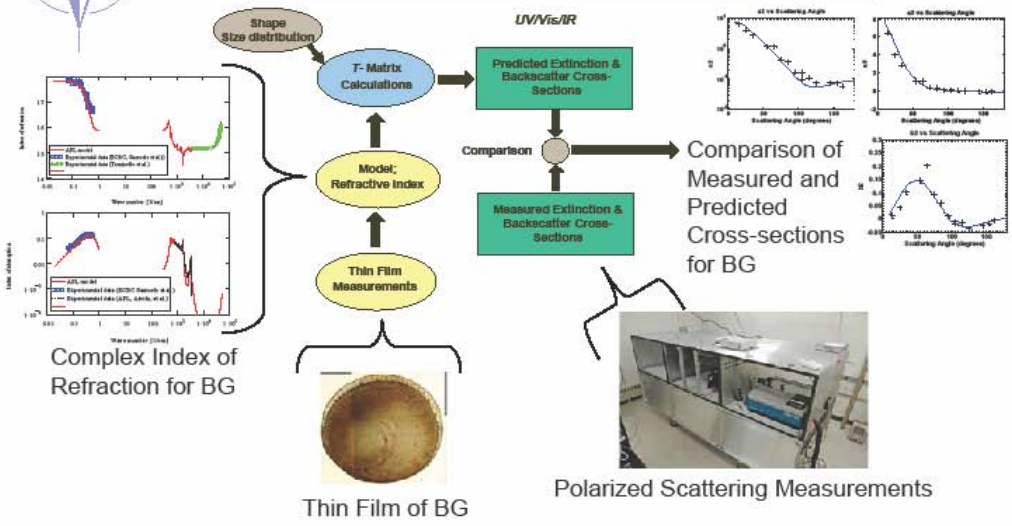
Spectroscopic Measurements



Validated cross-sections of simulants, interferents, and agents for use in modeling and performance prediction.

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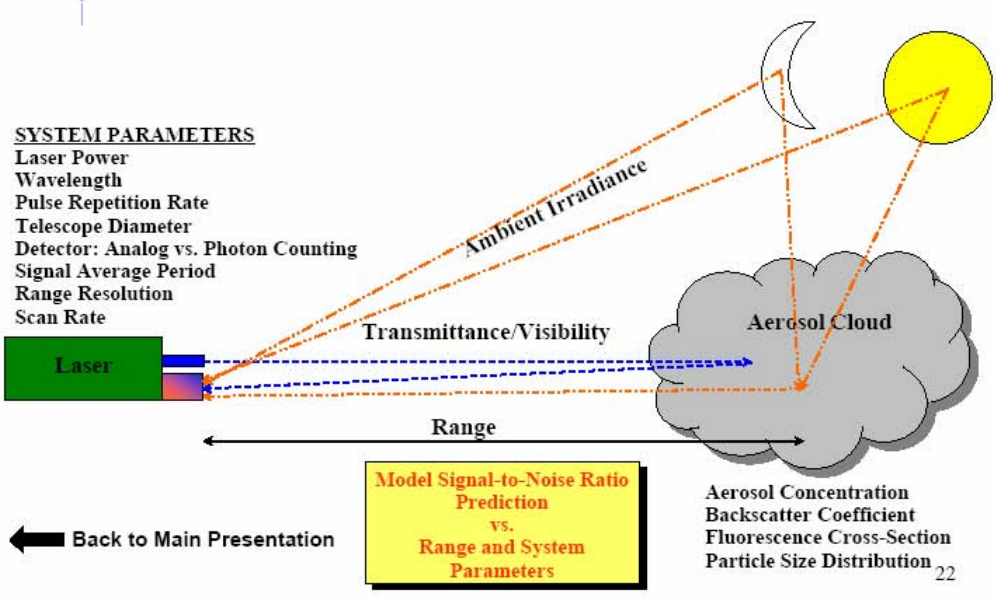
End-to-End Lidar Model



Back to Main Presentation

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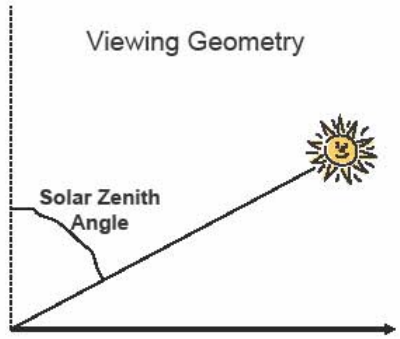
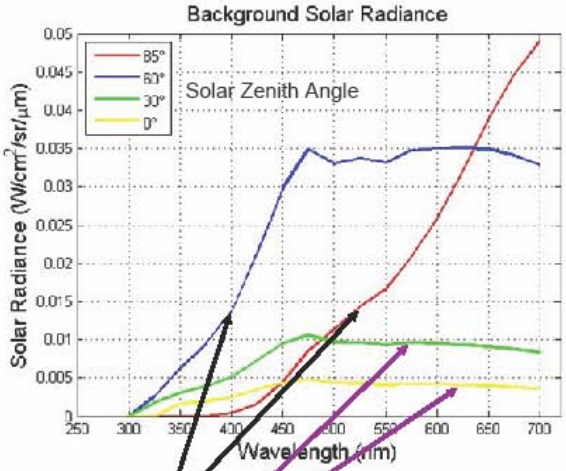
Daytime Background Radiance Levels





- A lower Sun means light is attenuated through much longer atmospheric path
  - Smaller intensities at smaller wavelengths
- A higher Sun makes it more difficult to scatter into LOS
  - Smaller intensities at larger wavelengths

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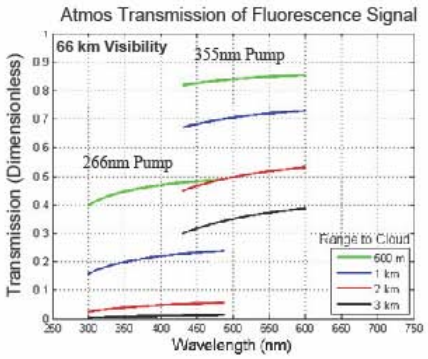
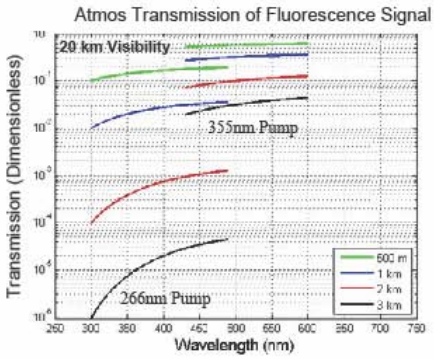
Atmospheric Transmission



At 66km visibility, signal loss for 266 pump from 500m cloud is as bad as for a 2km cloud with 355 pump.



At 23km visibility, signal loss for 266 pump from 1km cloud is almost as bad as for a 3km cloud with 355 pump.

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Comparison of Technologies

Parameter	Elastic Scatter Depolarization	Laser Induced Fluorescence	Differential Scattering
Probability of Detection	G	G	G
Probability of Discrimination	R/Y	G	Y/G
Weight	R/Y	R/Y	R/Y
Deployment Posture	Y/G	Y/G	Y/G
Daytime Capability	Y/G	R/Y	Y/G
Scan Capability	G	G	G
False Alarm Rate	Y	Y/G	Y

Technologies	Pros	Cons	Organizations
Fluorescence	Demonstrated Discrimination Large Knowledge Base System Maturity	Reduced Daytime Capability	Canada, Norway, UK, USA
Multi-Wavelength Depolarization	Daytime Capability Potentially Combined with Fluorescence	Dependence on Humidity System Maturity/Complexity Small Knowledge Base	USA
Long-wave IR Differential Scattering	Daytime Capability Chemical Detection Eye Safety	System Maturity Small Knowledge Base	USA

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Recommendations

- Best option for near-term (2008-2010) application is Ultraviolet Laser Induced Fluorescence (UV-LIF)
  - Choice of 266nm or 355nm excitation wavelength dependent upon range requirement, discrimination potential and day-time performance considerations
  - Spectrally resolved fluorescence improves discrimination potential, interesting results with as few as 10 bands
  - Consider adding near infrared depolarization to enhance discrimination and improve day-time discrimination
- Long-term Options
  - If day-time performance is important consider infrared depolarization or long-wave infrared differential scattering (LWIR DISC)
  - Consider LWIR DISC for potential combined CB detection/discrimination
- Advanced algorithms such as Support Vector Machines can improve discrimination performance

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REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's References	3. Further Reference	4. Security Classification of Document
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6. Title

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7. Presented at/Sponsored by

Final Report of Task Group SET-098/RTG-55.

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Multiple	82

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13. Keywords/Descriptors

Biological agents
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Differential scattering
Infra-red
Laser induced fluorescence
Laser technology
LIDAR
Standoff detection
Surveillance
Ultra-violet

14. Abstract

Several stand-off biological detection technologies covering a broad region of the electromagnetic spectrum have been investigated under RTG-055. In order to compare the relative merits of each technology several field trials have been conducted. Based upon the results of these activities the Task Group has made both near-term and long-term recommendations.

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