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BioSense Critical Prototype Evaluation (CPE)

Planning and analysis considerations

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Technical Memorandum
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Canada

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Abstract

Defence Research and Development Canada has recently undertaken the development of a stand-off bioaerosol sensing, mapping, tracking and classifying system (BioSense) technology demonstrator. BioSense is a sensor based on lidar and laser induced fluorescence spectrometric technologies, and built to detect bioaerosol clouds at distances up to 5 km. In November 2008, the core portion of the BioSense instrument has been subjected to an interim contractual performance evaluation, known as Critical Prototype Evaluation (CPE), to verify that it meets the projected minimum sensitivity requirements of a bio-cloud of Bacillus Globigii (BG) having 3 μm in diameter and concentration of 20 Agent Content Particle per Litre of Air (ACPLA) at a range of 1 km. Also, this Test and Evaluation will perform the evaluation of contract Rated Technical parameters associated with the radiometric capacity of the instrument that will largely dictate the sensitivity of the developed prototype and its day time operational capability. This document details the theoretical models that were followed to evaluate these characteristics and associated errors, as well as the general experimental procedure to acquire the parameters required by these models. Note that a test plan produced by DRDC Suffield details the experimental plan and schedule of the CPE.

Résumé

Recherche et développement pour la défense Canada a récemment entrepris un projet de démonstration technologique visant le développement d'un système de détection, de cartographie, de poursuite et de classification des bioaérosols en retrait (BioSense). BioSense est un capteur basé sur les technologies lidar et la spectrométrie de la fluorescence induite par laser. Il est conçu pour détecter les nuages de bioaérosols à une distance pouvant aller jusqu'à 5 km. En novembre 2008, la composante principale de l'instrument BioSense a été soumise à une évaluation contractuelle intermédiaire de la performance, définie comme l'Évaluation Critique du Prototype (ECP), afin de s'assurer qu'il satisfait aux exigences minimales de sensibilité pour un bio-nuage de Bacillus Globigii (BG) ayant un diamètre de 3 μm et une concentration de 20 'Agent Content Particle per Litre of Air' (ACPLA) à une distance de 1 km. De plus, ce test a permis une évaluation contractuelle nominale des paramètres techniques associés à la capacité radiométrique de l'instrument qui dictera largement la sensibilité du prototype développé et sa capacité opérationnelle diurne. Ce document détaille les modèles théoriques afin d'évaluer ces caractéristiques et leurs erreurs associées, de même que la procédure expérimentale générale qui devrait être suivie afin d'acquérir les paramètres requis par ces modèles. Il est à noter qu'un plan de test produit à RDDC Suffield détaille le plan expérimental et le calendrier de l'ECP.

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Executive summary

BioSense Critical Prototype Evaluation (CPE): Planning and analysis considerations

J-R Simard; P. Lahaie; S. Buteau; G. Roy; P. Mathieu; J. McFee; S. Rowsell; Jim Ho; P. Lacasse; DRDC Valcartier TM 2008-301; Defence R&D Canada – Valcartier; March 2009.

Introduction or background: Defence Research and Development Canada has recently undertaken the development and construction of a stand-off bioaerosol sensing, mapping, tracking and classifying system (BioSense) technology demonstrator. BioSense is a sensor based on lidar and laser induced fluorescence (LIF) technologies and built to detect bioaerosol clouds at distances up to 5 km. In November 2008, the core portion of the BioSense instrument has been subjected to a Critical Prototype Evaluation (CPE), an interim contractual performance evaluation, to verify that it meets the minimum sensitivity requirements.

Results: This document addresses the modeling concepts that dictate the experimental method to evaluate BioSense capability to detect aerosolized Bacillus Globigii (BG) having an average diameter of 3 µm and forming a 10-meter thick cloud of average concentration of 20 ACPLA at a range of 1 km. It also establishes, in detail, the experimental considerations and methodology used to perform the evaluation and the rating of BioSense contractual technical parameters.

Significance: The CPE constitutes a contractual go / no go gate in the Technology Demonstration Project and the development contract of the BioSense sensor. The proposed approach combines lidar and LIF fundamentals, bioaerosol challenging clouds and referee point sensor measurements to derive the sensor's day and night time sensitivity performance and associated errors. It also demonstrates its ability to detect a bio-cloud of BG 10 meters thick having an averaged concentration of 20 ACPLA at a range of 1 km.

Future plans: A detailed CPE test plan has been produced based on the considerations reported in this document. Considering a satisfactory achievement in the CPE, the development of BioSense will be allowed to continue with a final delivery expected in May 2009. The BioSense full capabilities will be evaluated during field trials in summer/fall 2009.

Sommaire

BioSense Critical Prototype Evaluation (CPE): Planning and analysis considerations

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Introduction ou contexte: Recherches et développement pour la défense Canada a récemment entrepris le développement et la construction d'un Projet de Démonstration Technologique (PDT) visant le développement et la construction d'un système de détection, de cartographie, de poursuite et de classification à distance des bioaérosols (BioSense). BioSense est un capteur basé sur les technologies lidar et de Fluorescence Induite par Laser (FIL) et est conçu pour détecter les nuages de bioaérosols à une portée de 5 km ou plus. En novembre 2008, la partie centrale de l'instrument BioSense a été soumise à une Évaluation Critique du Prototype (ECP), une évaluation contractuelle intermédiaire des performances, afin de vérifier s'il satisfaisait aux exigences minimum de sensibilité.

Résultats: Ce document s'attaque aux concepts de modélisation qui dictent la méthode expérimentale utilisée afin d'évaluer les capacités de BioSense à détecter le Bacillus Globigii (BG) sous forme d'aérosols ayant 3 μm et formant un nuage de 10 mètres d'épaisseur à une concentration moyenne de 20 ACPLA à une portée de 1 km. Il établit aussi, en détail, les conditions expérimentales ainsi que la méthodologie utilisées afin d'exécuter l'évaluation et la qualification des paramètres techniques contractuels de BioSense.

Importance: L'ECP constitue un jalon contractuel tout-ou-rien du PDT et du contrat de développement du capteur BioSense. L'approche proposée combine les notions fondamentales lidar et FIL, des défis sous forme de nuages de bioaerosols et des mesures faites à partir de capteurs locaux de référence afin de mesurer les performances de sensibilité du capteur durant la nuit et le jour, des erreurs associées ainsi que démontrer sa capacité à détecter un bio-nuage de BG ayant une épaisseur de 10 mètres et une concentration moyenne de 20 ACPLA pour une portée de 1 km.

Perspectives: Un plan de test détaillé de l'ECP a été produit à la suite des considérations rapportées dans ce document. En supposant une réussite satisfaisante de l'ECP, le développement de BioSense pourra continuer avec une livraison finale anticipée en mai 2009. Les pleines capacités de BioSense seront évaluées durant des essais sur le terrain à l'été/automne 2009.

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1 Introduction

1.1 Background

In May 2007, Defence Research and Development Canada Valcartier awarded a competitive contract to MacDonald Dettwiler and Associates (MDA) Ltd to develop a stand-off bioaerosol sensing, mapping, tracking and classifying system, BioSense. BioSense is a technology demonstrator project which aims at demonstrating to the Canadian Forces (CF) an efficient means to detect bioaerosol clouds at distances up to 5 km using lidar and Laser Induced Fluorescence (LIF) technologies. The Critical Prototype Evaluation (CPE) aims at providing an interim evaluation of the BioSense Core instrument capabilities to detect an aerosol cloud of simulants of biological agents of 20 ACPLA at 1 km. This is a requirement embedded in the BioSense project's prime contract with MDA 18 months after contract award. It also constitutes a Go/Nogo gate for continuation of the contract. Upon satisfactory completion of the CPE, the contractor will be allowed to complete the BioSense development. If the contractor fails the CPE, he will be allowed a maximum of 3 months to resolve the issue and retest. If unsuccessful, the contract will be stopped and the way ahead reassessed. Note that this document does not address the BioSense testing after final system delivery.

The CPE was held in November 2008 at DRDC Suffield where facilities were deployed to generate well controlled and well characterized clouds of simulants of biological agents challenging the sensitivity of the BioSense Core instrument.

In order to mitigate possible non-cooperative weather conditions at the execution of the CPE, the BioSense Core instrument was also challenged with well calibrated scattering targets.

1.2 Objectives

The data collected with the BioSense Core instrument with calibration targets pursues two objectives:

- Confirm the capability of the prototype to detect aerosolized Bacillus Globigii (BG) having an average diameter of 3 μm and forming a cloud 10-meter thick of average concentration 20 ACPLA at a range of 1 km. The detection threshold is deemed to be 4 times the standard deviation of the collected signal before the dissemination based on the correlation with referee detectors. This is the primary objective of the CPE;
- Evaluate experimentally the Rated Technical Objectives defined in the technical specifications of the contract W7701-061936 using calibrated scattering hard targets based on the general lidar equation and compare the experimental results with those projected by the contractor in his awarded proposal (#01-4518). This is a contract evaluation requirement and a risk mitigation to the primary objective of the CPE.

The acquisition of the elastic and inelastic lidar data to achieve the primary objective implies aiming the BioSense Core at volume having a cross section of 1 to 2 meters in diameter at a range of 1 km where the bioaerosol concentration will be monitored. The evaluation of the BioSense Core Rated Technical Objectives implies acquisitions of the elastic and inelastic lidar data while aiming calibrated hard targets having about 30 cm in diameter at range varying from 200 m to 1 km.

An additional goal is the comparison of the noise floors between day and night times of the three lidar channels of the BioSense core to assess the day time capabilities of the prototype.

The results of the CPE has been analyzed within a month after the execution of the trial and the results will be presented at the BioSense Senior Review Board (SRB) meeting held early in 2009. Decisions on the continuation of the project and contract will be taken by the SRB at that occasion.

1.3 Document overview

This document establishes:

- The modelling concepts dictating the experimental method to evaluate the primary objective and the Rated Technical parameters of the BioSense Core and the associated experimental errors (Chapters 3 and 4);
- The experimental considerations and methodology deployed during the CPE to acquire the parameters that allows the evaluation of the primary objective and the Rated Technical parameters (Chapter 5);

The contractor is invited to comment on the CPE testing design and propose new approaches to improve the goals of the CPE. However, the final decision about any aspects of the CPE design is under the responsibility of the Scientific Authority of the BioSense project/contract.

A test plan of the CPE has been produced based on the present document.

2 Trial preparation and methodology

2.1 Approach

The execution of the CPE will be performed at DRDC Suffield. Three main sets of measurements will be performed to evaluate the BioSense Core instrument. The most important measurements will be obtained by challenging the BioSense Core with well characterized aerosol clouds of simulants of bio-agents. These clouds may be produced within the lidar adapted bioaerosol chamber or directly in open air at the Colin Watson Aerosol Layout. The second measurements in importance will involve challenging the BioSense Core with calibrated hard targets and atmospheric nitrogen. This second set of measurements has two objectives. First, it is a risk mitigation to the main objective, which requires bioaerosol generation that may be problematic if weather during the CPE does not cooperate. Second, it provides the evaluation of the Rated Technical parameters of the BioSense Core defined in the Technical Specifications associated with the contract award process. Most of these measurements will be performed at a range of 1 km. However, some of these measurements may be made at shorter ranges (approximately 200 or 500 meters) for higher Signal-To-Noise (S/N) acquisitions. The third set of measurements will involve background clutter acquisitions during day and night times. These latter acquisitions will be used to evaluate the degradations of the BioSense Core sensitivity between day and night times due to the natural radiance.

2.2 Organization and responsibilities

The BioSense Core is the responsibility of the main contractor. They also have the responsibility of transporting, deploying and operating the BioSense Core at DRDC Suffield during the CPE. Therefore, the contractor should choose a deployment platform that will protect the prototype against all environmental aspects during the transportation to DRDC Suffield and during the execution of the CPE. During the CPE, the platform and its prototype will be located in an area controlled by DRDC Suffield. However, it is expected that personnel will be on site only during the test and evaluation hours. Therefore, it is important that the platform of the BioSense Core can be closed (ideally rapidly), protecting the instrument against bad weather. Such bad weather is expected considering the time period (around November 2008) of the execution of the CPE. Electrical power will be provided by DRDC Suffield on a 24 hrs/day basis. Other trial support requirements may be requested from DRDC by the contractor well in advance of the CPE.

Before and during the CPE, several parameters will be gathered for the analysis of the performance of the BioSense Core. The gathering of most parameters directly related to the BioSense Core will be the responsibility of the contractor. The gathering of most parameters related to environmental conditions and the challenges presented to the BioSense Core will be the responsibility of DRDC. Some exceptions exist. Therefore, Tables 1 to 9 list the different parameters to collect before and during the CPE and the organization in charge of their acquisition.

In order for DRDC to perform an adequate and timely analysis of the data acquired, it will be the responsibility of the contractor to provide DRDC, well in advance of the CPE, with examples of the data file format that will be produced by the BioSense Core during the CPE.

2.3 CPE schedule

A CPE test plan will be produced by DRDC well in advance of the CPE. This test plan will detail the different tasks to be performed at the CPE. As of the latest version of this document, it is expected that all CPE tasks will be performed within five working days (4 nights and 1 day). Night trials will be performed as soon as darkness occurs and may last up to 12 hours. The Day trial (dedicated to background clutter acquisitions) should be held under bright day light and should last up to 8 hours. Chapter 5 provides some details on the different tasks that should be performed during the CPE.

The contractor must be aware that little planned debugging time will be reserved during the CPE. Therefore, it is expected that the contractor will have verified that the BioSense Core performed adequately the expected CPE tasks before its transportation to DRDC Suffield. Furthermore, it is expected that the contractors will attend a security meeting at Suffield. This meeting, necessary to access the Suffield trial range, should be held the Thursday preceding the week of the CPE. Also, the period between the security meeting and the start of the CPE (including the weekend) may be requested by the contractor to finalize the preparation of the BioSense Core for the CPE within a service building located on the Suffield range.

2.4 Reporting

The parameters acquired during the CPE will be analyzed by DRDC personnel based on the model described in Chapters 3 and 4. The results of this analysis will be compared with the sensitivity performance criterion of the BioSense TDP (20 ACPLA at 4x the noise floor standard deviation for a cloud 10-meter thick of BG having 3 μm average diameter at a range of 1 km) and the contract Rated Technical Parameters (stated by the main contractor in their technical bid proposal #01-4518). If the TDP performance criterion is clearly achieved during the execution of the CPE, the contractor will be informed that the BioSense Core appears to have successfully passed the CPE. In any case, if the TDP performance criterion can be clearly observed during the execution of the CPE or not, the data acquired during the CPE will be analyzed and the results presented to the Senior Review Board who, based on the results presented, may authorize the continuation of the BioSense TDP (and contracted work), request a second CPE if results cannot clearly confirm the performance criterion (contractor will then work exclusively on tasks aimed at the success of this second CPE) or stop the BioSense TDP (and contracted work) if the BioSense Core clearly cannot achieve the TD performance criterion and has no chance to achieve it in the near future. In the meantime, the contractor will continue the contracted work based on the original schedule targeting the delivery of the BioSense system by May 2009 until the decision from the SRB has been officially stated.

In addition, the contract Rated Technical Parameters will be communicated to the contractor after the CPE data have been analyzed by DRDC personnel. These results will be discussed with the contractor and may generate design modifications depending on the sensitivity performances reported by these parameters in comparison with those stated by the contractor at contract award. The resulting parameters may also be presented at the SRB for complement of information.

3 BioSense Core evaluation with bioaerosol clouds

The use of bioaerosol clouds to challenge the BioSense Core instrument represents the primary objective of the CPE. This primary objective is associated with a requirement of the BioSense project. However, this trial objective may not be possible if the weather, at the execution of the CPE, does not cooperate. Intense wind, rain, snow or freezing temperatures are examples of bad weather conditions that may jeopardize the evaluation of the BioSense Core instrument with aerosol clouds of simulants of biological agents. Nevertheless, successful challenging of the prototype with well characterized bioaerosol clouds will provide very valuable insight into the anticipated capability of the final BioSense prototype to detect internationally recognized simulants of biological agents. This justifies the expenditure of effort even under the high risk associated with possible inclement weather conditions during the CPE.

The procedure to be deployed to evaluate the BioSense core with challenging bioaerosol clouds is detailed in Subsections 5.2.2.1 and 5.2.3.1. The location of the challenging bioaerosol cloud (direction, range and range interval), disseminated in open-air or in a lidar adapted bioaerosol chamber, will be provided by DRDC personnel. At that location, referee point sensors such as aerosol particle sizer(s) (APS), Slit Sampler Array(s) and Canadian Fluorescent Aerodynamic Particle Sizer (C-FLAPS) will be deployed to characterize the concentration of the cloud in particles per litre (ppl), Agent Contained Particle per Litre of Air (ACPLA) and percentage of fluorescing aerosols, respectively. The preferred range between the BioSense core and the cloud will be ~1 km but shorter range may be selected. Before the dissemination of the cloud, the parameters identified in Tables 3 and 6 will be recorded for each series of measurements made with a disseminated bioaerosol cloud. Steps 1 to 5 of Subsections 5.2.2.1 and 5.2.3.1 will be performed. The period where the BioSense core fires the laser at the pre-programmed ranged volume will begin about 5 minutes before the cloud is produced to measure the laser-induced background signal level before dissemination. Then, for about 10 minutes during which the bioaerosol cloud is disseminated and a last 5 minutes to measure the laser-induced background signal after the cloud dissemination for a total of about 20-minute continuous measurements with the BioSense Core instrument. For each acquisition, the contractor will design a method for evaluating the corresponding non-induced laser signal background contributions (background passive radiance and electronic contributions). These non-induced background contributions will be used during the analysis of the collected data to obtain the signal resulting only from the inducing laser pulses. This series of measurements will be repeated for the three channels of BioSense (the fluorescence and UV channels may be done simultaneously) at least twice to obtain two sets of valid results for each channel. It may be repeated for different simulants of biological agents if time permits. For these evaluations, the inelastic channel and the elastic channel at 355 nm will produce measurements resulting from the binning of about 10 seconds of laser firing. For the NIR elastic channel, each laser pulse fired will produce an acquisition. During the analysis, a number of NIR laser pulses will be binned and the sensitivity of the NIR elastic channel to detect the bio-cloud will be derived from the binned measurement. The number of binned laser pulses constituting each measurement will be driven by the anticipated number of binned laser pulses that will define the spatial sampling interval of the aerosol map produced by BioSense in representative operational scanning modes.

During the analysis of the acquired data, the amplitudes of the binned signal detected by the BioSense Core, corrected for non-induced background contributions (and process by multi-variable analysis for the spectral channel) will be time correlated with the data obtained with the referee sensors. From this correlation analysis, the linear relation between the signal detected by the BioSense core and the concentration of the disseminated bio-cloud will be established. Then,

this linear factor will be applied to the standard deviation of the BioSense signal during the laser-induced background measurements. The resulting standard deviation expressed in ppl and ACPLA will report the sensitivity of the BioSense core to detect the bio-cloud for the configuration of measurements.

The resulting standard deviation expressed in ppl and ACPLA will then be multiplied by 4 (the detection threshold is set at four times the standard deviation) and compared with the objective of detecting a bio-cloud of BG 10 meters thick having an averaged concentration of 20 ACPLA at a range of 1 km. This result will be presented and discussed with the members of the Senior Review Board of the Technology Program Demonstration (TDP) of DRDC.

4 BioSense core evaluation with calibrated targets

4.1 Fundamentals

At the fundamental level, the optical signal collected by all lidars can be defined as a differential equation relating the element of light collected and sent to a detector and the element of volume from where this element of light originated. This equation can be expressed as

$$dP_\lambda(\lambda_0,\vec{r},t) = J_\lambda(\lambda_0,\vec{r},t)\, p_\lambda(\vec{r})\, dV\,, \tag{1}$$

where dP_λ is the spectral element of light power detected at a time t resulting from elastic or inelastic scattered laser light with an excitation wavelength λ_0 and within a volume element dV located at position $\vec{r}$, $J_\lambda(\lambda_0,\vec{r},t)$ is the spectral radiance generated by the scattered laser light within that volume dV and responsible for the detected spectral element of light[1] and $p_\lambda(\vec{r})$, the geometric factor, is the fraction (or probability) of this spectral radiance reaching the lidar detector.

The spectral radiance J_λ is detailed by introducing the laser irradiance I incident at the volume dV as

$$J_\lambda(\lambda_0,\vec{r},t) = \beta_\lambda(\lambda_0,\vec{r})\, I(\lambda_0,\vec{r},t)\,, \tag{2}$$

where β_λ is defined as the volume spectral backscattering coefficient at position $\vec{r}$. In this last equation, we assumed β_λ sufficiently small to ignore the laser transmission lost in the volume element dV. This coefficient takes into account the physical characteristics of the scatterers and depends on the excitation wavelength. It can be defined as

$$\beta_\lambda(\lambda_0,\vec{r}) = \sum_i \mathrm{N}_i(\vec{r})\, \sigma_\lambda^i(\lambda_0)\,, \tag{3}$$

where $\mathrm{N}_i(\vec{r})$ is the volume density of scatterer i at position $\vec{r}$ and σ_λ^i is the spectrally distributed backscattering cross section of the scatterer species i for an excitation wavelength λ_0.

Finally, the geometric factor $p_\lambda(\vec{r})$ introduced in eq. 1 can be detailed further as

$$p_\lambda(\vec{r}) = \frac{\mathrm{A}_{AS}}{\left|\vec{r}\right|^2} \times t_\lambda^a(\vec{r}) \times t_\lambda^c(\vec{r}) \times \xi(\vec{r})\,, \tag{4}$$

[1] It is important to note the time delay that exists between the moment where the spectral radiance is generated within the volume element dV and the moment it is detected by the lidar. This delay depends on the time of flight between this volume element and the lidar instrument. This time variable will be introduced later in this document.

where A_{AS} is the total area of the aperture stop of the lidar collector including obscuring components, t_λ^a and t_λ^c are the atmospheric and lidar collector spectral transmission, respectively, for a collected photon originating from location $\vec{r}$. $\xi(\vec{r})$ is the overlap function describing the fraction of scattered photons emitted at location $\vec{r}$ and collected by the aperture stop that will reach the detector. This last parameter is regularly referred to as the geometrical form factor or obscuration factor and is one of the main optimizing criteria for an adequate optical design of a lidar transmitter.

Equations 1-4 form the fundamental model of most lidar designs. In the following, this basic model will be refined further for the specific case of the BioSense lidar design. To relate this fundamental model to the measurements made at the CPE, eq. 1 must be integrated over the probed volume, over the time interval associated with the returned signals of interest and, in the particular case of the inelastic scattering, over the spectral interval of interest of the BioSense instrument. Before transforming eq. 1 accordingly, a series of simplifications are applied. These are listed in the following subsection.

4.1.1 Simplifying approximations

In order to facilitate the CPE, the following T&E design considerations will be enforced to simplify the use of the fundamental model detailed in the previous subsection.

- **The maximum radial distance $|\vec{r}_r|$ from the optical axis in the probed volume is much smaller than its range *R*** ($\left|\vec{r}\right|^2 = \left|\vec{r}_r\right|^2 + R^2 \approx R^2$)**.** This is expected in most configurations. With this approximation, *R* is the range variable along the lidar optical axis[2].
- **The variability of the parameter $1/R^2$ over the probed range interval is negligible.** This is achieved by keeping the range interval of the probed volume much smaller than the range to the center of the probed volume R_0. In this case, the fractional error in the signal collected resulting exclusively from the distributed range interval ΔR corresponding to the probed volume[3] can be evaluated as $2\Delta R/R_0$.
- **Signal contributions from parasitic scatterers are negligible (no summation over multiple types of scatterers in eq. 3).** This will be achieved by making the signal returns from the targeted scatterers of interest much greater than all other parasitic scattering sources.
- **The concentration of targeted scatterers in the probed volume is considered as uniform.** This should be achieved by using well instrumented, confined aerosol chamber specially designed to provide highly uniform challenging aerosol cloud. If generated bio-cloud is not spatially uniform, an averaged aerosol concentration along the laser path will be derived. Such a chamber will use referee sensors providing the concentration of the challenging aerosol cloud in ppl and/or ACPLA.
- **The response time of the inelastic scatterers to return the signal following the laser irradiation is much smaller than the laser pulse duration or the lidar electronic time gate.** This allows ignoring the convolution of the return signal with the response time of the

[2] For single optical axis lidar, the optical axis is defined by the laser path. When the lidar transmitter optical alignment is optimized, the collector field-of-view should be centered on the laser path axis.

[3] For well confined aerosol clouds where the electronically created range gate is greater than the cloud thickness, ΔR is essentially determined by the cloud thickness.

inelastic scatterers which causes parts of the return signal to be lost because they lie outside the programmed electronic range gate. This loss can be evaluated as the ratio $\tau_i / \Delta t$ where τ_i is the inelastic scatterer relaxation time and Δt is the lidar electronic time gate[4].

- **The overlap function is taken as the area of the aperture stop minus the obscuration area.** This simplification is obtained when focusing the optics of the lidar at the (centered) plane of the probed volume and that the optical field depth of the lidar collector is much greater than the range interval of the probed volume. If these conditions cannot be achieved, an approximate value of the overlap function and associated error for the experimental configuration shall be provided by the contractor with justifying arguments.
- **The central flat region of the field of view of the lidar collector includes more than 90% of the laser power irradiated in the probed volume.** This is dictated by the optical design of the BioSense Core instrument as the focusing capability of the emitter at short ranges. The fraction of the laser power not included in the field of view will contribute to reducing the rated Detection Sensitivity Parameters (see definition of these parameters in Section 4.2). This reduction in the sensitivity parameters will be captured within $t^e_{\lambda_0}$, the optical transmission of the lidar emitter.
- **The fraction of the atmospheric attenuation within the probe volume is negligible.** This is achieved by keeping the range interval of the probe volume much smaller than the total range and by disseminating a sufficiently small concentration of the targeted scatterers.

4.1.2 Simplified model derivation

With the simplifications detailed in the previous section inserted in equations 1-4 and integrating over the volume *V* delimited by the collector field of view irradiated by the laser pulse for a given instant *t*, eq. 1 is reduced to

$$P_\lambda(\lambda_0, t) = \int_V dP_\lambda(\lambda_0, \vec{r}, t) = \int_V J_\lambda(\lambda_0, \vec{r}, t)\, p_\lambda(\lambda, \vec{r})\, dV \,, \tag{5}$$

$$P_\lambda(\lambda_0, t) \equiv P^i_\lambda(\lambda_0, t) = \frac{A_{AS}}{R_0^2}\; t^a_{\lambda_0}(R_0)\, t^a_\lambda(R_0)\, t^e_{\lambda_0} t^c_\lambda\; \xi_\infty\; \mathbf{N}_i(R_0)\, \sigma^i_\lambda(\lambda_0) \int_V I_L(\lambda_0, r, t)\, dV \,, \tag{6}$$

where the index *i* refers to the scatterer specie, R_0 is the distance between the exit of the lidar transmitter and the center of the probed volume, I_L is the laser pulse irradiance spatial distribution at the instant *t* and where the transmission of the lidar emitter $t^e_{\lambda_0}$ and of the atmosphere between the lidar and the probed volume $t^a_{\lambda_0}(R_0)$ at the laser wavelength have been reported outside the integral. Then, the photonic energy collected by the lidar within an electronic time gate Δt is given by

[4] This reduction of the return signal related to the inelastic scatterer relaxation time can be eliminated by setting the range gate significantly larger than the targeted cloud.

$$E_\lambda^i(\lambda_0,t,\Delta t) = \int_t^{t+\Delta t} P_\lambda^i(\lambda_0,t)\,dt$$

$$= \int_t^{t+\Delta t} \frac{A_{AS}}{R_0^2}\, t_{\lambda_0}^a(R_0)\, t_\lambda^a(R_0)\; t_{\lambda_0}^e t_\lambda^c\; \xi_\infty\, \mathbf{N}_i(R_0)\sigma_\lambda^i(\lambda_0) \int_{\mathbf{V}} I_L(\lambda_0,r,t)\,dV\,dt\,, \tag{7}$$

To further simplify eq. 7, it is necessary to insert the relation between the time where a signal resulting from firing the laser is being detected and the range from where this detected signal originates. Taking the instant that the laser pulse leaves the lidar transmitter as the time origin ($t = 0$) and noting that the light pulse has to travel to and from the element of volume where the laser light has been scattered, it is straightforward to establish that

$$t = \frac{2R}{c} \qquad \text{and} \qquad dt = \frac{2dR}{c}\,. \tag{8}$$

Furthermore, by introducing the definition of I_L which is the element of laser energy dE_L incident on an element of area dA perpendicular to the laser axis per time interval dt and substituting eq. 8 in the volume integral of eq. 7, this volume integral is reduced to

$$\int_{\mathrm{V}} I_L(\lambda_0,r,t)\,dV = \int_V \frac{dE_L}{dt\,dA}\,dA\,dr = \frac{c}{2}\int_V dE_L = \frac{c\,E_L}{2}\,, \tag{9}$$

where E_L is the total laser pulse energy and where we used the equivalence $dr \equiv dR$. Inserting the last result in eq. 7 and integrating over time, the collected photonic energy is derived as

$$E_\lambda^i(\lambda_0,R_0,\Delta r) = E_L\; \xi_\infty \frac{A_{AS}}{R_0^2}\; t_{\lambda_0}^a(R_0)\, t_\lambda^a(R_0)\;\; t_{\lambda_0}^e t_\lambda^c\;\; \Delta R\, \mathbf{N}_i\;\; \sigma_\lambda^i(\lambda_0)\;. \tag{10}$$

Finally, by introducing the quantum yield Ψ_λ describing the efficiency of the detector to convert the collected photons into electrons, the electronic conversion factor κ defining the number of electronic counts produced for each photon detected[5] and the number of laser pulses n_p fired to produce the detected signal in eq. 10, the spectral signal $S_\lambda^i(\lambda_0,R_0,\Delta R)$ resulting solely from multiple laser pulses (or corrected for non-laser induced background contribution) is derived as[6]

$$S_\lambda^i(\lambda_0,R_0,\Delta R) = \kappa\,\Psi_\lambda\; n_p\; E_\lambda^i(\lambda_0,R_0,\Delta R)$$

[5] These electronic counts may be those produced by a CCD camera or any other electronic transducer components. It should be derived from the sum of counts resulting from the detected photon and distributed over several (spectral) columns of the CCD. It is also important to note that if the electronic transducer is performing photon counting detection, κ is equal to 1.

[6] Here, the spectral convolution of the collected signal that determined the spectral resolution is not introduced. This spectral characteristic of the BioSense core instrument will be monitored during the CPE but is not a necessary quantity to evaluate the rated Detection Sensitivity Parameters.

$$= \kappa \Psi_\lambda \quad n_p E_L \quad \xi_\infty \frac{A_{AS}}{R_0^2} \quad t^a_{\lambda_0}(R_0) t^a_\lambda(R_0) \quad t^e_{\lambda_0} t^c_\lambda \quad \Delta R \mathbf{N}_i \quad \sigma^i_\lambda(\lambda_0) \; . \tag{11}$$

electronic conversion	laser energy	geometry	atmospherics	optics	cloud column	scatterers

Equation 11 expresses the spectrally distributed signal detected by a lidar as a function of its electronic conversion efficiency, the total laser energy sent to the probed volume located at a range R_0, the geometric parameters, the atmosphere and the lidar optics transmission characteristics, the targeted cloud column[7] and the spectral cross section of the scatterers *i* disseminated in the probed volume. This equation forms the basic model dictating the design of the T&E of the (CPE) that aims at measuring the rated Detection Sensitivity Parameters associated with the BioSense instrument. Only the convolution with the spectrometer spectral response has not been introduced in the previous modelling. However, since the CPE targets spectrally integrated quantities, the effect of the spectrometer convolution will not affect the evaluation of the Detection Sensitivity Parameters.

In the following sections, this equation will be further developed and adapted as a function of the BioSense sensitivity parameters to be characterized.

4.2 Evaluation methodology of the Detection Sensitivity Parameters

The Detection Sensitivity parameters *Se* have been defined in the BioSense main contract technical specifications as follows[8]:

$$Se^i_{355} = \left[P^L_{355} \times A_{AS} \times \tilde{t}_o \times \tilde{\Psi} \times \xi_\infty\right]^{-1} \text{ [W m}^2\text{]}^{-1}; \tag{12}$$

$$Se^e_{355} = \left[P^L_{355} \times A_{AS} \times t_{355} \times \Psi_{355} \times \xi_\infty\right]^{-1} \text{ [W m}^2\text{]}^{-1}; \text{ and} \tag{13}$$

$$Se^e_{NIR} = \left[P^L_{NIR} \times A_{AS} \times t_{NIR} \times \Psi_{NIR} \times \xi_\infty\right]^{-1} \text{ [W m}^2\text{]}^{-1}; \tag{14}$$

where:

P^L_{355}: Averaged power of the laser source at 355 nm.

P^L_{NIR}: Averaged power of the laser source at the NIR wavelength.

A_{AS}: Area of the aperture stop of the lidar transmitter.

[7] The scatterer concentration in cloud column is averaged over the whole range interval defined by the lidar range gate or the cloud thickness itself. If the lidar range gate is greater than the region where the targeted cloud is located, the lidar range gate is determined by the cloud column to reflect that a fixed number of scatterers contribute to the return signal.

[8] In these definitions, the names of the different variables have been slightly changed from those used in the BioSense technical specifications document to avoid confusion with the names of the variables introduced in the present document.

$\tilde{t}_o$: Averaged transmission of the lidar transmitter between 375 and 700 nm. Results from the product of the collection optics transmission averaged over the spectral interval of collection times that of the lidar emitter optics at 355 nm.

t_{355}: Transmission of the lidar transmitter at 355 nm. Results from the product of the lidar collection optics transmission times that of the lidar emission optics at 355 nm.

t_{NIR}: Transmission of the lidar transmitter at the NIR wavelength. Results from the product of the lidar collection optics transmission times that of the lidar emission optics at the NIR wavelength.

$\tilde{\Psi}$: Averaged quantum efficiency of the inelastic detection hardware between 375 nm and 700 nm.

Ψ_{355}: Quantum efficiency of the elastic detection hardware at 355 nm.

Ψ_{NIR}: Quantum efficiency of the elastic detection hardware at the NIR wavelength.

ξ_∞: The lidar obscuration factor at an infinite range.

One of the objectives of the CPE is to measure the values associated with these Detection Sensitivity Parameters from specific T&E performed at that occasion. The different sensitivity parameters evaluated experimentally will be compared with those identified in the Technical Bid made by the main contractor on May 2007 (Proposal # 01-4518). This comparison and the results obtained with challenging bioaerosol clouds will be presented at the Senior Review Board of the DRDC Technology Demonstration Program and decision to progress forward with the BioSense main contract (and project), to repeat the CPE in order to improve the outcomes or to stop this effort, will be taken depending on the bio-cloud sensitivity demonstrated and the agreement between these experimental results with those identified by the contractor in his proposal.

The following 2 subsections detail the specific modeling methodology that will dictate the T&E procedures deployed at the CPE to quantify the bio-cloud sensitivity and these Detection Sensitivity Parameters. The next subsection establishes the modeling equation for the inelastic channel while the following subsection derives similar modeling equations based on the same principle but for the elastic channels. The main principles that will dictate T&E procedures are detailed in chapter 5.

4.2.1 The inelastic channel

One of the key principles in evaluating the bio-cloud sensitivity and the rated sensitivity parameters of the BioSense Core will be to operate the instrument within its linear dynamic ranges. To help in achieving this goal, especially when using hard surfaces as the calibrated targets, well calibrated attenuation optics (or other components achieving the same goal) will be mounted within the lidar collector to reduce its optical transmission by a known amount. The insertion of this optical attenuation on the BioSense collector will introduce a new factor χ representing the artificial reduction of the collecting power of the BioSense Core lidar transmitter. With the addition of this parameter, the inelastic Detection Sensitivity Parameter Se^i_{355} derived from the model represented by eq. 11 can be re-ordered by grouping the scalar and spectral parameters as follows

$$\frac{S^i_\lambda(\lambda_0, R_0, \Delta R)}{t_{mea}} = P^L_{355}\, A_{AS}\, t^o_\lambda\, \Psi_\lambda\, \xi_\infty \quad \kappa\chi \frac{t^a_{\lambda_0}(R_0)\, t^a_\lambda(R_0)}{R_0^2} \quad \mathbf{N}_i\, \Delta R\, \sigma^i_\lambda(\lambda_0)\,, \qquad (15)$$

where t_λ^o is the spectral transmission of the combined lidar emitter and collector[9], and the total laser firing time period t_{mea} is the period corresponding to the time interval between the first and the last laser pulses fired to build the lidar signal S_λ^i from scatterers *i*. This variable has been introduced so that the lidar equation can be expressed as a function of the averaged laser power P_{355}^L at 355 nm.

The methods described below will be deployed to characterize some of parameters on the right side of eq. 15.

- κ**, the instrument electronic conversion factor in analog mode,** will be derived as the averaged number of CCD counts integrated over the spectra corresponding to a single detected photon. To obtain at least 50 occurrences of single detected photons, sufficient gated spectra will be acquired with the spectrometer entrance slit closed. The gate duration will have to be sufficiently long to have a high probability of having single self-emitted electron by the photocathode within a resolved spectral interval but sufficiently short to make the probability of having two self-emitted electrons interfering within the same resolved spectral interval negligible. This measurement of κ will be repeated for all intensification levels that will be used during the CPE. To obtain this quantity, the correction for the electronic background spectral contribution will be derived from the averaged CCD counts aside from the spectral interval where the self-emitted electron events occur. The instrument electronic conversion factor when operated in photon counting mode is equal to 1 by definition.
- ΔR**, the effective range-gate width,** is defined by the aerosol cloud column. This approach is acceptable as long as the lidar range-gate defined as $c(\Delta t + \Delta t_L + \Delta t_i)/2$, where c is the speed of light, Δt is the lidar electronic time-gate, Δt_L is the laser pulse duration and Δt_i is the inelastic scatterer relaxation time, is greater than the range interval occupied by the challenging cloud.
- R_0**, the range to the probed atmospheric volume**, will be measured with a commercial range-meter from the position of the aperture stop of the BioSense lidar collector up to a large hard surface placed at the center range of the targeted volume. For measurements with calibrated hard targets, R_0 is the range to the positions of these hard targets.
- $t_\lambda^a(R_0)$ **and** $t_{\lambda_0}^a(R_0)$**, the spectral transmission of the atmosphere between 375 nm and 700 nm, and at 355 nm for the range** R_0, will be derived using the MODTRAN software for the aerosol atmospheric model that is the most appropriate for the geographic location of the CPE and the visibility distance given by a visibility-meter and/or a transmission-meter deployed at the site of the CPE[10]. To limit the errors introduced by these quantities when derived with the MODTRAN model, R_0 should be minimized, when ever possible, for these measurements.
- χ, **the artificial reduction of the lidar transmitter efficiency,** will be determined by the calibrated attenuation factor associated with the optical components inserted in the lidar

[9] Once averaged between 375-700 nm, this quantity will provide the quantity $\tilde{t}_o$, the averaged transmission of the lidar transmitter between 375 nm and 700 nm identified as one of the parameters defining the inelastic sensitivity parameters Se_{355}^i.

[10] If neither a transmission-meter nor visibility-meter is deployed at the CPE trial site, atmospheric visibility will be estimated from public weather station data.

collector. This factor of attenuation should be known spectrally, or better, be neutral for the spectral interval of interest (355 nm, 375-700 nm and NIR).

- Ψ_λ, **the spectral quantum efficiency of the BioSense detector converting collected photons into electronic signals**, will be based on the specifications provided by the manufacturer of the ICCD. This quantity will not be used directly to derive the rated technical parameters but should be useful for more in-depth analyses.

In order to minimize the error in the characterization of the inelastic Detection Sensitivity parameter Se^i_{355}, the parameters defining this quantity are grouped together. This dictates re-writing eq. 15 as follows

$$\Phi_\lambda = P^L_{355}\, A_{AS}\, t^o_\lambda\, \Psi_\lambda\, \xi_\infty = \mathrm{K}\frac{S^i_\lambda(\lambda_0, R_0, \Delta R)}{t^a_\lambda(R_0)\mathbf{N}_i\, \Delta R\, \sigma^i_\lambda(\lambda_0)}, \tag{16}$$

where

$$\mathrm{K} = \frac{R_0^2}{t_{mea}\kappa\chi\, t^a_{\lambda_0}(R_0)}. \tag{17}$$

With these definitions, the inelastic Detection Sensitivity Parameter Se^i_{355} will be derived as

$$Se^i_{355} = \left[\tilde{\Phi}\right]^{-1}, \tag{18}$$

where $\tilde{\Phi}$ is obtained by averaging Φ_λ between 375-700 nm[11].

During the CPE, all measurements aiming at quantifying Se^i_{355} will involve the measurement of Φ_λ with two different techniques. One will involve the use of the fluorescent spectral calibration target developed by INO (contract #W7701-061901), the second will involve the use of the inelastic Raman signal from atmospheric nitrogen. The second technique measuring Φ_{N2}, Φ_λ at the specific Raman signal from atmospheric nitrogen, will be used to support the results obtained with the fluorescent spectral calibration target. These two techniques are detailed in the following two subsections.

[11] The CPE will focus on a measurement based on the product quantity $t^o_\lambda \Psi_\lambda$ averaged over the BioSense spectral interval instead of the spectral averaging of the individual quantities. If the spectral averaging of the individual quantities is required, the quantum efficiency Ψ_λ as provided by the manufacturer specifications will be introduced to derive the specific quantity $\tilde{t}_o$.

4.2.1.1 Evaluation of the inelastic Detection Sensitivity Parameter Se^{i}_{355} using the fluorescent spectral calibration target

An evaluation of Φ_λ, identified here as Φ^{cal}_λ, will be made by firing the BioSense lidar at the fluorescence calibration target developed by INO under contract with DRDC. At least two properties associated with these calibration targets should be produced by the Biosense main contractor (or its subcontractor) in collaboration with DRDC personnel before making measurements with these targets. The evaluation of these properties should be based on the instructions of use produced during the development of these calibrated fluorescence targets. These properties of the calibrated fluorescence targets are:

- The quantum yield $\Lambda(\lambda_0)$ representing the probability that a fluorescent photon is produced within the spectral interval of acquisition of the BioSense instrument when an excitation photon is incident on the fluorescent material as well as the error $\Delta\Lambda(\lambda_0)$ associated with this quantity, and;
- The spectral probability distribution $\rho_\lambda(\lambda_0)$ describing the probability that a fluorescent photon is emitted between λ and $\lambda+\Delta\lambda$ within the spectral interval of acquisition as well as the spectral error $\Delta\rho_\lambda(\lambda_0)$ on this quantity.

The quantities $\Lambda(\lambda_0)$, $\Delta\Lambda(\lambda_0)$, $\rho_\lambda(\lambda_0)$ and $\Delta\rho_\lambda(\lambda_0)$ should be provided, with supporting arguments, by the BioSense main contractor in collaboration with DRDC personnel shortly before making measurements with the fluorescent calibration targets[12]. Furthermore, it is important to obtain these properties based on the principle that the fluorescence radiance is expected to follow the Lambertian law where one of the key characteristics is a 2π steradian hemispheric uniform induced radiance (at least for radiometric measurements made in the direction perpendicular to the surface of the fluorescent target).

Based on the two properties associated with the calibration target, Φ^{cal}_λ can be derived using eq. 16 by replacing the product $\mathbf{N}_i \Delta R\, \sigma^i_\lambda(\lambda_0)$ by $\gamma\, \Lambda(\lambda_0)\, \rho_\lambda(\lambda_0)/2\pi$ where γ is the fraction of the total laser power incident on the fluorescent calibration target during an acquisition. In this expression, the factor 2π is introduced based on the methodology used to obtain the properties of the calibrated fluorescing target where the Lambertian law was assumed. With this substitution, Φ^{cal}_λ can be expressed as

$$\Phi^{cal}_\lambda = \mathrm{K}\,\frac{2\pi\, S^{cal}_\lambda(\lambda_0, R_0, \Delta R)}{t^{a}_\lambda(R_0)\, \gamma\, \Lambda(\lambda_0)\, \rho_\lambda(\lambda_0)}. \tag{19}$$

For the acquisition made with the calibrated fluorescence target, the laser beam will be centered on the calibration target and the fraction of the laser power incident on the calibration target will be derived by comparing the laser power spatial distribution at that range to the exposed effective area of the calibration target.

[12] The spectrally distributed probability and quantum yield of the produced fluorescence should be a measurement made over the whole incident surface of the calibration target and the variability of this spectral probability over that surface should be minimal. Furthermore, it is important to make sure that the fluorescence induced from surfaces other than the one that has been calibrated is negligible.

4.2.1.2 Error estimation associated with the measurement of the inelastic Detection Sensitivity Parameter using the fluorescence calibration target

To adequately assess the rated inelastic Detection Sensitivity Parameters derived from the experimental measurements made with the fluorescent spectral calibration targets, the error associated with this measurement, ΔSe^{i}_{355}, is derived from eq. 18 as follows,

$$\Delta Se^{i}_{355} = \frac{\Delta\tilde{\Phi}}{\tilde{\Phi}^{2}} \ , \tag{20}$$

or, when expressed as a relative error, as

$$\frac{\Delta Se^{i}_{355}}{Se^{i}_{355}} = \frac{\Delta\tilde{\Phi}}{\tilde{\Phi}} . \tag{21}$$

From the assumption that the error contributions from each spectral element are statistically independent, the relative error in $\tilde{\Phi}$ is derived as

$$\frac{\Delta\tilde{\Phi}}{\tilde{\Phi}} = \frac{1}{N}\sqrt{\sum_{i=1}^{i=N}\left(\frac{\Delta\Phi_{\lambda_i}}{\Phi_{\lambda_i}}\right)^{2}} \ , \tag{22}$$

where indices λ_i refers to the ith spectral interval, such spectral interval covering 375-700 nm with *N* being the total spectral interval considered in the calculation.

Using the property that the square of the relative error of a quantity is given by the addition of squares of the relative errors of all multiplicative components defining this quantity, the statistical independence of each noise contribution, and eq. 19, the relative error in $\Phi_{\lambda}{}^{cal}$, defined as $\Delta\Phi^{cal}_{\lambda} / \Phi^{cal}_{\lambda}$, for the measurement made with the fluorescent calibration target, is derived as

$$\frac{\Delta\Phi^{cal}_{\lambda}}{\Phi^{cal}_{\lambda}} =$$

$$\sqrt{\left(\frac{\Delta K_{\lambda}}{K}\right)^{2} + \left(\frac{\Delta t^{a}_{\lambda}(R_0)}{t^{a}_{\lambda}(R_0)}\right)^{2} + \left(\frac{\Delta\gamma}{\gamma}\right)^{2} + \left(\frac{\Delta\Lambda(\lambda_0)}{\Lambda(\lambda_0)}\right)^{2} + \left(\frac{\Delta\rho_{\lambda}(\lambda_0)}{\rho_{\lambda}(\lambda_0)}\right)^{2} + \left(\frac{\Delta S^{cal}_{\lambda}(\lambda_0, R_0, \Delta R)}{S^{cal}_{\lambda}(\lambda_0, R_0, \Delta R)}\right)^{2}} \ , \tag{23}$$

where

$$\frac{\Delta K_{\lambda}}{K} = \sqrt{\left(\frac{\Delta t_{mea}}{t_{mea}}\right)^{2} + \left(\frac{\Delta\tilde{\kappa}_{\lambda}}{\kappa}\right)^{2} + \left(\frac{2\Delta R_0}{R_0}\right)^{2} + \left(\frac{\Delta\chi}{\chi}\right)^{2} + \left(\frac{\Delta t^{a}_{\lambda_0}(R_0)}{t^{a}_{\lambda_0}(R_0)}\right)^{2}} \ . \tag{24}$$

It is important to observe that some of the error contributions are spectrally dependent while the corresponding parameters are not. In eq. 24, these spectral dependency characteristics as well as the description of the different error contributions are defined as follows:

- $\Delta t_{mea}/t_{mea}$ is the relative error in the time interval when the laser was fired. As a first approach, this quantity can be derived as 1 divided by the total number of laser pulses fired to obtain the measurement;
- $\Delta\tilde{\kappa}_\lambda/\kappa$ are the relative errors in number of counts per detected photon converted by the electronic transducer averaged over all the detected photons for this specific spectral acquisition. Since each detected photon carries the same statistically independent noise contribution, this quantity is given by the ratio of the standard deviation in counts for a single detected photon divided by the square root of the total number of photons detected in the spectral bin divided by the mean number of counts per detected photon. The absolute error in number of counts per detected photons will vary as a function of the number of photons detected. This results from the multiple detected photons averaging process. However, the mean number of counts per photon is not affected by this averaging process. Therefore, the absolute error will depend on the number of photons detected within a spectral bin, which justifies the spectral dependency of this quantity. Note that this source of error disappears if photon counting process is applied;
- $2\Delta R_0/R_0$ is the relative error in the range to the probed volume. In this expression, ΔR_0 is the error associated with the range meter when measuring the distance between the aperture stop of the lidar transmitter and the fluorescent calibration target;
- $\Delta\chi/\chi$ is the relative error of the attenuation factor introduced with the inserted optical component to reduce the collection power of the BioSense lidar collector. This error will be derived from the specification of the manufacturer and should be verified by the main contractor (or subcontractor). The main contractor shall provide the manufacturer specifications and, ideally, in-house calibration results characterizing the inserted optical components with supportive arguments. The attenuation factor is expected to be wavelength independent (property of neutral filters). However, it this is not the case, this parameter will be spectrally dependent; and
- $\Delta t^a_{\lambda_0}(R_0)/t^a_{\lambda_0}(R_0)$ is the relative error in the atmospheric transmission at the laser wavelength. This quantity can be derived from the atmospheric transmission defined as

$$t^a_{\lambda_0}(R_0) = \mathbf{e}^{-\alpha_{\lambda_0} R_0}, \text{ and allows the following definition,} \tag{25}$$

$$\frac{\Delta t^a_{\lambda_0}(R_0)}{t^a_{\lambda_0}(R_0)} = \sqrt{\left(R_0 \Delta\alpha_{\lambda_0}\right)^2 + \left(\alpha_{\lambda_0} \Delta R_0\right)^2}\,, \tag{26}$$

  where ΔR_0 is the error obtained from the range meter used to measure the distance between the exit of the lidar transmitter and the calibration target and, α_{λ_0} and $\Delta\alpha_{\lambda_0}$ are derived from the MODTRAN model and error consideration from that model, respectively, and where the statistical independency between the two parameters was assumed.

Similarly, the terms on the right side of eq. 23 can be defined as follows:

- $\Delta t^a_\lambda(R_0)/t^a_\lambda(R_0)$ is the relative error in the atmospheric spectral transmission. This quantity is also derived from the definition of the atmospheric transmission modeled by eq. 25 and produces the following relative error contribution:

$$\frac{\Delta t_\lambda^a(R_0)}{t_\lambda^a(R_0)} = \sqrt{\left(R_0 \Delta\alpha_\lambda\right)^2 + \left(\alpha_\lambda \Delta R_0\right)^2}\,, \tag{27}$$

where ΔR_0 is again the error from the range meter used to measure the distance between the aperture stop of the lidar collector and the calibration target but, α_λ and $\Delta\alpha_\lambda$ are the spectral attenuation factor derived from the MODTRAN model and the spectral error considerations associated with that model, respectively;

- $\Delta\gamma/\gamma$ is the relative error in the fraction of the laser power incident on the calibration target. This error will be derived as the variation of the power incident on the calibration target when the laser spot is displaced by an angle equal to half of the angular resolution of the scanner. This power variation should be derived from the power distribution of the laser spot at the target plane in comparison with the exposed area of the calibrated target;
- $\Delta\Lambda(\lambda_0)/\Lambda(\lambda_0)$ is the relative error in the averaged quantum yield of the calibration material over the exposed target area. This relative error shall be provided by the manufacturer of the calibration material (INO) or from specific measurements made by the contractor in collaboration with DRDC personnel with the calibration target before being deployed. Furthermore, these measurements should be designed based on Lambertian assumptions attributed to the fluorescing target;
- $\Delta\rho_\lambda(\lambda_0)/\rho_\lambda(\lambda_0)$ is the relative error in the spectrally distributed probability that an induced-fluorescent photon is emitted within a spectral bin for the excitation wavelength λ_0. This spectrally distributed quantity shall be provided by the manufacturer of the calibration material (INO) or from specific measurements made by the contractor in collaboration with DRDC;
- $\Delta S_\lambda^{cal}(\lambda_0, R_0, \Delta R)/S_\lambda^{cal}(\lambda_0, R_0, \Delta R)$ is the relative error in the spectrally distributed signal made during the measurement with the calibration target. With the fluorescent target, it is expected that the amplitude of the detected signal will be sufficient to make this error essentially dictated by the fluorescing photons' shot noise. This allows the following definition

$$\frac{\Delta S_\lambda^{cal}(\lambda_0, R_0, \Delta R)}{S_\lambda^{cal}(\lambda_0, R_0, \Delta R)} = \frac{1}{\sqrt{S_\lambda^{cal}(\lambda_0, R_0, \Delta R)}}\,. \tag{28}$$

This completes the description of all sources of relative errors to insert in eqs. 20-28 that will dictate the relative error in the inelastic Detection Sensitivity Parameter Se_{355}^i using the fluorescent calibration target. It is possible that some of these distinct parameters will be measured simultaneously as a product of parameters. In this case, the model described above will be modified accordingly.

4.2.1.3 Evaluation of the inelastic Detection Sensitivity Parameter Se_{355}^i using the Raman signal from atmospheric nitrogen

A second measurement of Φ_λ at the wavelength of the Raman signal from atmospheric nitrogen, identified as Φ_{N2}, will be performed to confirm the validity of the measurement made with the fluorescence target. To combine the result based on this nitrogen Raman signal with the one based on the calibrated fluorescence target, any variations associated with the product of the five

key parameters associated with the evaluation of the Detection Sensitivity Parameters (left side of eq. 16) shall be monitored. Particular attention should be attributed to the variation of the laser power P_{355}^{L}, the optical alignment dictating the optical spectral transmission t_{λ}^{o} and variations in the obscuration factor ξ_{∞} between the two measurements and shall be corrected before comparison.

For this second measurement, Φ_{N2} is derived as

$$\Phi_{N2} = \mathrm{K}\frac{S_{N2}(\lambda_0, R_0, \Delta R)}{t_{N2}^{a}(R_0)\mathbf{N}_{N2}\,\Delta R\,\sigma_{N2}(\lambda_0)}. \tag{29}$$

In this equation, K is determined following the same method as the one used with the fluorescing targets. The values associated with t_{N2}^{a} are derived by evaluating t_{λ}^{a} at the nitrogen Raman wavelength and ΔR is defined as $c(\Delta t + \Delta t_L + \Delta t_{N2})/2$ where Δt, Δt_L and Δt_{N2} are the electronic gate duration, the laser pulse duration and the nitrogen Raman relaxation time, respectively. Since the nitrogen Raman relaxation time Δt_{N2} is negligible in comparison with the two other quantities, only Δt and Δt_L are needed to determine the lidar range-gate for this specific acquisition.

The quantities N_{N2} and σ_{N2} are obtained as follows.

- N_{N2}**,** the concentration of the atmospheric nitrogen within the probed volume in molecules/litre, is obtained from the ideal gas law as

$$\mathbf{N}_{N2} = \frac{n_{N2}}{V} = \frac{P_{N2}}{RT} = \frac{0.781\times P}{RT}, \tag{30}$$

  where P_{N2} and P are the nitrogen partial and full atmospheric pressures in Pascals, respectively (volume fraction of atmospheric nitrogen is approximately 78.1% of the total atmospheric pressure), T is the absolute temperature in kelvin and R is the ideal gas constant equal to 1.380 6504(24) x 10^{-20} litre-Pascal/molecule-K where the number 24 between parentheses is the uncertainty (Ref.1). P and T will be monitored and recorded during the CPE with the BioSense weather station.

- σ_{N2}, **the Raman cross section of atmospheric nitrogen when submitted to a laser excitation at wavelength λ_0 and producing a Raman radiation at wavelength λ_0^R**, is derived with the following relation

$$\frac{\sigma_{N2}}{\sigma_{N2-337}} = \left(\frac{\lambda_{337}^{R}}{\lambda_0^{R}}\right)^4, \tag{31}$$

  where $\sigma_{N2\text{-}337}$ is the nitrogen Raman cross section with a light excitation wavelength at 337.1 nm and is given in scientific literature as 3.5x10^{-30} cm^2 sr^{-1} (Ref. 2). In this model, the Raman spectral shift in wavenumber ($\omega = 1/\lambda$) between the excitation wavelength and the Raman wavelength is independent of the excitation wavelength and is given, for nitrogen (Ref. 2), by

$$\Delta\omega_{N2} = \omega_0 - \omega_R = 2330.7\ cm^{-1}. \tag{32}$$

4.2.1.4 Error estimation associated with the measurement of the inelastic Detection Sensitivity Parameter at the Raman signal from the atmospheric nitrogen

Similar to the acquisition made with the fluorescence calibration target, the relative error associated with the second method evaluating Φ_λ at the specific wavelength where a Raman signal is generated from atmospheric nitrogen, Φ_{N2}, is determined as follows:

$$\frac{\Delta\Phi_{N2}}{\Phi_{N2}} = \sqrt{\left(\frac{\Delta K_{N2}}{K}\right)^2 + \left(\frac{\Delta t_{N2}^a(R_0)}{t_{N2}^a(R_0)}\right)^2 + \left(\frac{\Delta(\Delta R)}{\Delta R}\right)^2 + \left(\frac{\Delta \mathbf{N}_{N2}}{\mathbf{N}_{N2}}\right)^2 + \left(\frac{\Delta\sigma_{N2}(\lambda_0)}{\sigma_{N2}(\lambda_0)}\right)^2 + \left(\frac{\Delta S_{N2}(\lambda_0,R_0,\Delta R)}{S_{N2}(\lambda_0,R_0,\Delta R)}\right)^2}, \qquad (33)$$

where

$$\frac{\Delta K_{N2}}{K} = \sqrt{\left(\frac{\Delta t_{mea}}{t_{mea}}\right)^2 + \left(\frac{\Delta\tilde{\kappa}_{N2}}{\kappa}\right)^2 + \left(\frac{2\Delta R_0^{N2}}{R_0}\right)^2 + \left(\frac{\Delta\chi}{\chi}\right)^2 + \left(\frac{\Delta t_{\lambda_0}^a(R_0)}{t_{\lambda_0}^a(R_0)}\right)^2}. \qquad (34)$$

The principles dictating the evaluation of the terms defining the relative errors in eq. 34 are identical to those itemized following eq. 24 and will not be repeated here except for the term $2\Delta R_0^{N2}/R_0$ which must take into account the range distribution of the cloud. For this type of measurement, the considerations dictating the evaluation of this error source are as follows:

- $2\Delta R_0^{N2}/R_0$, the relative error in the range to the probed volume, is derived as the sum of two contributions as follows,

$$\frac{2\Delta R_0^{N2}}{R_0} = 2\sqrt{\left(\frac{\Delta R_0}{R_0}\right)^2 + \left(\frac{\Delta R_0^{rg}}{R_0}\right)^2}. \qquad (35)$$

  As for the acquisition with the calibration target, the first contribution ΔR_0 is the error of the range meter in reporting the distance from the aperture stop of the lidar transmitter to the center of the probed volume. The second contribution ΔR_0^{rg} results from the range distributed lidar gate defining the probed nitrogen column. This last error source on the range to the probed volume can be determined as the half of the cloud column as $c(\Delta t + \Delta t_L)/4$ where Δt_{N2}, the relaxation time of the Raman signal from nitrogen, is ingnored.

The principle dictating the evaluation of the relative error contributions identified on the right side of eqs. 33 and 34 are identical to those detailed for eqs. 23 and 24, where ΔR_0 is replaced with ΔR_0^{N2} defined in the above paragraph, except for the following three contributions:

- $\Delta(\Delta R)/\Delta R$ is the relative error in the range interval of the probed volume. For this acquisition where atmospheric nitrogen contained in the range-gate represents the challenging inelastic scatterers, the error in ΔR is derived as $c\sqrt{(\Delta(\Delta t))^2 + (\Delta(\Delta t_L))^2}/2$ where the error contribution originating from the nitrogen Raman relaxation time has been ignored.

Furthermore, since the statistics dictating these errors in time interval are expected to be symmetrical with respect to the average, the resulting time interval errors should be reduced by the square root of the number of laser pulses fired for the measurement;

- $\Delta \mathbf{N}_{N2}/\mathbf{N}_{N2}$ is the relative error in the concentration in atmospheric nitrogen. This quantity is derived from eq. 30 as follows:

$$\frac{\Delta \mathbf{N}_{N2}}{\mathbf{N}_{N2}} = \sqrt{\left(\frac{0.001}{0.781}\right)^2 + \left(\frac{\Delta P}{P}\right)^2 + \left(\frac{\Delta T}{T}\right)^2}, \tag{36}$$

where ΔP, P, ΔT and T are derived from the weather monitoring station. The first numeral ratio reports the error in the fraction of nitrogen in the atmosphere where the error in the ideal gas constant has been ignored; and

- $\Delta\sigma_{N2}(\lambda_0)/\sigma_{N2}(\lambda_0)$, the relative error in the nitrogen cross section, is assumed to be dictated essentially by the error in the numerical value of $3.5\text{x}10^{-30}$ $\text{cm}^2\text{sr}^{-1}$, expressed as half the last digit as

$$\frac{\Delta\sigma_{N2}(\lambda_0)}{\sigma_{N2}(\lambda_0)} = \frac{0.05}{3.5} = 1.4\%. \tag{37}$$

To obtain this result, it is assumed that the error associated with the extrapolation of the cross section from a value measured at a wavelength 337.1 nm to the one of BioSense, 355 nm, is negligible in comparison with the experimental error when measuring the cross section at the original wavelength.

4.2.2 The elastic channels

The derivations of the modeling equations that will direct the evaluation methodology for the elastic channels are somewhat simplified since the measured quantities are a single time-dependent scalar for each elastic channel. Furthermore, most modeling results developed for the inelastic model can be readily applied to the elastic model if the elastic scatters returned by the selected targets (solid surfaces or confined air volumes) are integrated over time, providing a measurement of the detected electronic charge. That can be achieved by simply recording the transient return associated with the intended target and correcting it for signal contributions not related to that target. This correction could be obtained by measuring the transient return without the target in position.

Once corrected for background contribution, eq. 11 can be re-written to express a measurement of the detected electronic charge of the elastic channel $S^i_{\lambda_0}(\lambda_0, R_0, \Delta R)$ for a giving cloud of elastic scatterers *i* as

$$S^i_{\lambda_0}(\lambda_0, R_0, \Delta R) = \kappa_e \, \Psi_{\lambda_0} \, n_p \, E^i_{\lambda_0}(\lambda_0, R_0, \Delta R)$$

$$= \underbrace{\kappa_e \, \Psi_{\lambda_0}}_{\text{electronic conversion}} \; \underbrace{n_p E_L}_{\text{laser energy}} \; \underbrace{\xi_\infty \frac{A_{AS}}{R_0^2}}_{\text{geometry}} \; \underbrace{\left(t^a_{\lambda_0}(R_0)\right)^2}_{\text{atmospherics}} \; \underbrace{t^e_{\lambda_0} t^c_{\lambda_0}}_{\text{optics}} \; \underbrace{\Delta R \, \mathbf{N}_i}_{\text{cloud column}} \; \underbrace{\sigma^i_{\lambda_0}(\lambda_0)}_{\text{scatterers}} . \tag{38}$$

In this equation, all parameters have the same definitions as in eq. 11 but for the laser wavelength λ_0 and the targeted elastic scatterers i. Furthermore, since the elastic channel detectors are quantum types (i.e., they detect photons) and their output is connected to an impedance, R_L (nominally 50 Ω, such as is found for a recording oscilloscope), the elastic instrument electronic conversion factor κ_e in eq. 38 can be expressed as

$$\kappa_e = R_L \times \frac{e\lambda_0}{hc} \quad [V/W]. \tag{39}$$

With this model, $S^i_{\lambda_0}$ corresponds to an electronic voltage integrated over the backscatter signal duration, having units of Volt-seconds.

With this model adapted to the elastic channel, most results of Subsection 4.2.1 developed for the inelastic channel are directly transferable to the elastic channel. By adapting eqs. 16-17 for the elastic channels, the Detection Sensitivity parameters for the BioSense Core elastic channels can be re-written as

$$\left[Se^e_{\lambda_0}\right]^{-1} = \Phi_{\lambda_0} = P^L_{\lambda_0}\, A_{AS}\, t^o_{\lambda_0}\, \Psi_{\lambda_0}\, \xi_\infty = \mathrm{K} \frac{S^i_{\lambda_0}(\lambda_0, R_0, \Delta R)}{t^a_{\lambda_0}(R_0)\, \mathbf{N}_i\, \Delta R\, \sigma^i_{\lambda_0}(\lambda_0)}, \tag{40}$$

where

$$\mathrm{K} = \frac{R_0^2}{t_{mea}\, \kappa_e\, \chi\, t^a_{\lambda_0}(R_0)}, \tag{41}$$

and where λ_0 corresponds to one of the two lasing wavelengths (355 nm or NIR) associated with the two elastic channels and where the definitions of the other parameters can be found in Subsection 4.2.1.

Since the characterizations of the Detection Sensitivity parameters for the elastic channels will be performed only with calibrated hard targets, only a model similar to the one used for the fluorescence calibration target developed in Subsection 4.2.1.2 is required but without the spectrally distributed characteristics. This allows modifying eq. 19 to

$$\Phi^{cal}_{\lambda_0} = \mathrm{K} \frac{2\pi\, S^{cal}_{\lambda_0}(\lambda_0, R_0, \Delta R)}{t^a_{\lambda_0}(R_0)\, \gamma\, \Re_e(\lambda_0)}, \tag{42}$$

where the fluorescent calibration target is replaced with a hard target calibrated as a Lambertian elastic reflector of reflectance $\Re_e$ known for the two wavelengths of the elastic channels. Furthermore, the model estimating the error in $\Phi^{cal}_{\lambda_0}$ as a function of the parameters on the right side of equation 42 can be derived directly from the one developed with the fluorescent calibration target in Subsection 4.2.1.2 but without the spectral distribution of the parameters and will not be repeated here.

4.3 Evaluation methodology of the Day Time Capability Parameters

The Day Time Capability Parameters have been defined in the BioSense main contract technical specifications as follows:

$$D^{i}_{355} = \left[\Omega^{i}_{355} \times PRF\right]^{-1} \quad [\text{mrad}^2 \text{ x Hz}]^{-1}; \tag{43}$$

$$D^{e}_{355} = \left[\Delta\lambda_{355} \times \Omega^{e}_{355} \times PRF\right]^{-1} \quad [\text{nm x mrad}^2 \text{ x Hz}]^{-1}; \text{ and} \tag{44}$$

$$D^{e}_{NIR} = \left[\Delta\lambda_{NIR} \times \Omega^{e}_{NIR} \times PRF\right]^{-1} \quad [\text{nm x mrad}^2 \text{ x Hz}]^{-1}; \tag{45}$$

where:

Ω^{i}_{355} : Solid angle field of view of the inelastic channel.

Ω^{e}_{355} : Solid angle field of view of the elastic channel at 355 nm.

Ω^{e}_{NIR} : Solid angle field of view of the elastic channel at the NIR wavelength.

PRF : Laser pulse repetition frequency[13].

$\Delta\lambda_{355}$: Equivalent spectral bandwidth of collection of the elastic channel at 355 nm.

$\Delta\lambda_{NIR}$: Equivalent spectral bandwidth of collection of the elastic channel at the NIR wavelength.

The evaluation of the Day Time Capability Parameters represents another secondary objective of the CPE but less critical than the evaluation of the Detection Sensitivity Parameters. Two approaches will be deployed to achieve this objective. The first approach will be to evaluate quantitatively these parameters by analysis. It is this first method that will produce the numerical evaluations that will be compared with the Day Time Capability Parameter objectives stated in the contractor's proposal. The second method will aim at evaluating the degradation of the detection sensitivity of the BioSense Core instrument between day and night time scenarios of operation which is the phenomenon that the Day Time Capability Parameters aim at characterizing.

4.3.1 Quantitative evaluation of the Day Time Capability Parameters

The quantitative evaluation of the Day Time Capability Parameters will be based on the analysis of the BioSense instrument delivered for the CPE. To achieve this task, the contractor will report the numerical quantities at the right of equations 43-45 with valid supportive arguments to the Technical Authority shortly before or at the start of the CPE. These supportive arguments may be specifications sheets of key components provided by the manufacturer of the component, specific measurements made in laboratory by the contractor, well accepted modeling considerations associated with the instrument design or a combination of these three sources of supportive arguments. Then, the corresponding Day Time Capability Parameters will be computed and

[13] The PRF is defined as the equivalent pulse repetition frequency demonstrated by the BioSense instrument for background radiance corrected acquisitions, each lasting typically 10 seconds. The PRF is derived as the total number of laser pulses divided by the time interval between the first and last laser pulses fired to obtain the background radiance corrected acquisition.

compared with those identified in the Technical Bid made by the main contractor on May 2007 (Proposal # 01-4518). This comparison should also be presented with the other CPE results at the Senior Review Board of the DRDC Technology Demonstration Program where decision to progress forward with the BioSense main contract (and project), to repeat the CPE or to stop this effort, will be taken, depending on the experimentally derived bio-cloud sensitivity in ACPLA and the agreement between these experimental radiometric results and those identified by the contractor in his proposal.

4.3.2 Experimental evaluation of the BioSense detection sensitivity changes between day and night times

The experimental evaluation of the BioSense detection sensitivity change between day and night times aims at directly characterizes the capability rated by the Day Time Capability Parameters. This evaluation will not be used to evaluate if the contractor meets the Day Time Capability Parameters he proposed with his Technical Bid but rather the difference in the BioSense instrument performance in measuring aerosol lidar scattering between night and day times.

This evaluation will be performed by acquiring the background spectral signal $S_{\lambda}^{B}(\lambda_0, R_0, \Delta R)$ and the background transient signal $S_{\lambda_0}^{B}(\lambda_0, R_0, \Delta R)$ with the different channels of BioSense during day and night time while stopping the scattered laser pulses from being detected by the lidar collector (or simply stopping the laser pulse from exiting the lidar emitter). The measurements during night time will also be repeated by stopping all external radiation from reaching the detectors to evaluate precisely the electronic only noise contribution (this should be achievable by closing the lidar collector optical path). These measurements will be performed at multiple occasions during the CPE while varying the numbers of fired laser pulses n_p and with different lidar time gates Δt. Note that these measurements will not require challenging aerosol clouds. However, special attention will be taken by the contractor and DRDC to make sure that the measurements will be performed under identical BioSense instrumental configurations. The key instrumental configuration parameters that shall be identical between day and night time measurements under comparison are the electronic gain κ; the number of binned laser pulses n_p, the lidar collector spectral transmission t_{λ}^{c} and the electronic lidar time-gate Δt. Furthermore, day time acquisitions should be performed with at least two different background scenes.

During night time, each measurement will be repeated twice. One will be done by blocking the laser pulses from exiting the lidar emitter but keeping the lidar collector open. The second will be done by screening (shutting off the optical path to) the lidar detector. For the first measurement, special attention should be taken by the contractor and DRDC to point the BioSense lidar at a scene that shows minimal (ideally non-observable) parasitic background lighting. A short description of that background scene shall be recorded for subsequent analyses. Several measurements with different n_p and Δt will be taken at these occasions. The selections of the different values for these parameters should be dictated by the anticipated operational configurations of BioSense.

From these measurements, the inelastic channel noise floor $\langle N \rangle_{f,i}^{N}$ that will dictate the BioSense sensitivity of the inelastic channel during night time will be derived as follows

$$\langle N \rangle_{f,i}^{N} = \sqrt{\sum_{\Delta\lambda} \left(S_{\lambda}^{BN} - \overline{S}_{\lambda}^{BN} \right)^2} , \tag{46}$$

where S_λ^{BN} is a single background collected spectrum during night time taken from a successive number of binned acquisitions and where $\overline{S}_\lambda^{BN}$ is the spectrum averaged over these successive binned acquisitions, each to be considered stable over the acquisition time and statistically independent. The integration of the collected spectra is done over the BioSense spectral interval $\Delta\lambda$ (375-700 nm for the inelastic channel). In this computation, S_λ^{BN} may be expressed in counts or in photons, depending on the electronic conversion factor κ.

During day time, several measurements will be performed using the same configuration as those taken during night time for comparison with various n_p and Δt. Several of these measurements should be taken with at least two different background scenes and a description of these scenes should be recorded. Concurrently, DRDC plans to measure the ambient spectral radiance Π_λ (calibrated or not) with its own spectroradiometer. During the different day time sensitivity measurements, if possible, special attention should be taken to point the spectroradiometer at a scene representative of the one seen by the BioSense instrument for the specific background measurements performed. From these measurements, the inelastic channel noise floor $\langle N \rangle_{f,i}^{D}$ that will dictate the BioSense sensitivity of the inelastic channel during day time will be derived as follows

$$\langle N \rangle_{f,i}^{D} = \sqrt{\sum_{\Delta\lambda} \left(S_\lambda^{BD} - \overline{S}_\lambda^{BD} \right)^2} \ , \tag{47}$$

where S_λ^{BD}, as for the night time measurements, is a single collected spectrum taken from a successive number of binned acquisitions but obtained during day time and where $\overline{S}_\lambda^{BD}$ is the spectrum averaged over these successive binned acquisitions, each to be considered stable over the time of measurement and statistically independent. Also, the integration of the collected signal is done over the BioSense spectral interval $\Delta\lambda$ (375-700 nm for the inelastic channel) and where the acquisitions may be expressed in counts or in photons, depending on the electronic conversion factor κ.

After the CPE, the analysis of these measurements will allow to evaluate the degradation of the sensitivity of the inelastic channel between night and day time surveillance operations. This analysis should also include the validation of the principle reported by Simard (Ref. 2, Section 3.5) stating that the ratio of the sensitivity between day and night time measurements with the BioSense instrument should be approximated by the following relation

$$\frac{\langle N \rangle_{f,i}^{D}}{\langle N \rangle_{f,i}^{N}} = \sqrt{\frac{2 A_{AS}\, \xi_\infty\, \Omega\, n_p\, \Delta t \int t_\lambda^c \Pi_\lambda d\lambda}{\left(\langle N \rangle_{f,i}^{e} \right)^2}} \ , \tag{48}$$

where Ω is the field of view of the lidar collector, Π_λ is the spectral background radiance and $\langle N \rangle_{f,i}^{e}$ is the equivalent optical noise that would correspond to the noise floor of a measurement resulting only from the electronics of detection (as obtained with the BioSense lidar collector

shutter closed). In this equation, the product $t_{\lambda}^{c}\,\Pi_{\lambda}$ is integrated over the BioSense spectral interval (375-700 nm for the BioSense inelastic channel).

Similar measurements will be made for the two elastic channels, producing transient vectors. These transient vectors contain multiple measurements of the background elastic signals $S_{\lambda_0,t}^{BD}$ (for day time measurements) or $S_{\lambda_0,t}^{BN}$ (for night time measurements), each sequentially distributed with a time increment equal to the electronic time interval Δt, one of the key parameters defining the lidar map sampling range interval ΔR in eq. 38 (the other parameter being the laser pulse length). From these transient measurements, the elastic channel noise floors during night $\langle N \rangle_{f,\lambda_0}^{N}$ and during day time $\langle N \rangle_{f,\lambda_0}^{D}$ are derived as

$$\langle N \rangle_{f,\lambda_0}^{N} = \sqrt{\frac{1}{N_{\Delta t}} \sum_{\Delta t} S_{\lambda_0,t}^{BN}}\,, \text{ and} \tag{49}$$

$$\langle N \rangle_{f,\lambda_0}^{D} = \sqrt{\frac{1}{N_{\Delta t}} \sum_{\Delta t} S_{\lambda_0,t}^{BD}}\,, \tag{50}$$

where $N_{\Delta t}$ indicates the number of time resolved background elastic signals used to calculate the mean background elastic noise floor and λ_0 refers either to the elastic channel at 355 nm or at the NIR wavelength.

As for the inelastic channel, the goal in deriving the background noise floors of the elastic channels given by eqs. 49 and 50 from day and night time measurements is to compare the ratio of these noise floors with the following expression

$$\frac{\langle N \rangle_{f,\lambda_0}^{D}}{\langle N \rangle_{f,\lambda_0}^{N}} = \sqrt{\frac{2A_{AS}\,\xi_{\infty}\,\Omega\;n_p\,\Delta t\,t_{\lambda_0}^{c}\,\Pi_{\lambda_0}\Delta\lambda_{\lambda_0}}{\left(\langle N \rangle_{f,\lambda_0}^{e}\right)^2}}\,, \tag{51}$$

where $\Delta\lambda_{\lambda_0}$ is the equivalent spectral bandwidth of collection of the elastic channel at 355 nm or NIR light excitation.

5 CPE test and evaluation procedures

This chapter describes in some detail the different kinds of information that will be gathered before and during the CPE. The information gathered before the CPE are technical specifications related to some of the BioSense Core hardware components. During the CPE, it is intended to acquire a first set of environmental parameters. These environmental acquisitions should be performed more or less automatically with dedicated autonomous systems. The next set of acquisitions performed during the CPE will involve the BioSense Core system. There will be two main types of acquisition made with the BioSense Core system. They will involve challenging the BioSense Core with well characterized clouds of simulants of bio-agents and with calibrated elastic/inelastic hard targets. The challenge with well characterized clouds of simulants of bio-agents is a BioSense project Go/NoGo evaluation. It is expected to involve the use of the lidar adapted bioaerosol chamber developed at DRDC Suffield. If this chamber is not available then, the Colin Watson Aerosol Layout (CWAL) facility will be deployed with bioaerosols released in open air. The challenge of the BioSense Core with calibrated elastic/inelastic hard targets is planned as risk mitigation to the challenge with bio-clouds (since weather conditions at the CPE may preclude bioaerosol disseminations) and to allow an evaluation of the technical rated parameters stated in the main contract technical specifications. A last task performed during the CPE is the background acquisitions made during day and night times. These acquisitions will allow evaluating the degradation of the sensitivity of the BioSense Core between day and night times. In the description of these tasks, the responsibilities (between DRDC and the contractor) associated with the acquisitions of the different parameters are identified. In general, all specifications, optimizations or acquisitions associated with the BioSense Core or with its uses during the CPE are the responsibilities of the contractor leaving the responsibilities of the acquisitions of the other parameters, the field support and the preparation of the challenges presented to the BioSense Core to DRDC personnel. However, for clarity, the responsibilities in the acquisition of each parameter are reported in Tables 1 to 9.

The CPE is expected to last five working days in November 2008 at DRDC Suffield. During these days, four nights (8-12 hours per night) will be dedicated to the characterization of the sensitivity of the BioSense Core instrument. Also, up to two days (6-8 hours per day), but a single day may be sufficient, will be devoted to evaluate its day time detection capability. Following the production of the present document, a CPE test plan that will contain a detailed schedule will be made available to the contractor in early October 2008.

Section 5.1 describes the parameters required before the CPE. These parameters are directly associated with components of the BioSense Core. Some of these can be obtained from the manufacturers while others may have to be measured by the contractor during experimental manipulations. Section 5.2 describes the acquisitions performed during the CPE. These includes the acquisitions of the environmental conditions (Subsection 5.2.1), those associated with the evaluation of the inelastic channel (Subsection 5.2.2) and, those performed to characterize the NIR elastic channels (Subsection 5.2.3) and UV elastic channel (Subsection 5.2.4). Finally, subsection 5.2.5 details the acquisitions made during night and day times that will be used to assess the day time capability of the BioSense Core instrument.

5.1 Parameters characterized before CPE

Several parameters associated with the BioSense Core instrument (see Table 1) will be produced by the contractor before the CPE unless DRDC is identified as the provider of the required

information. Most of these basic parameters are not expected to change during (or after) the CPE. For each of these parameters, the contractor will provide supportive arguments unless stated otherwise. These supportive arguments may originate from manufacturer's technical specifications, system design analyses or laboratory measurements made at the contractor facilities. Table 1 shows the list of these basic parameters and the expected evaluation methods.

Table 1: List of basic parameters & expected evaluation methods

Symbols	Definitions	Evaluation Methods
κ	Number of electronic counts per detected photon.	Based on laboratory measurements made by the contractor. Averaged number of counts derived from multiple successive acquisitions (or randomly selected) cumulating more than 50 single detected photon events. Counts from a single photon event should be added over the few adjacent CCD columns defined by the intensified electronic cloud resolution. The zero count reference is provided by averaging the number of counts over columns where no detected photon event occurred. The electronic files containing the acquisitions must be provided by the contractor in an ASCII format easily readable with Excel, Matlab or IDL. A group of acquisition files must be provided for each intensifier gain to be used during the CPE.
$\Delta\kappa$	Standard deviation of κ	Based on laboratory measurements made by the contractor. Standard deviation derived from the groups of acquisition files containing more than 50 single detected photon events and used to evaluate the average number of electronic counts per detected photon.
R_L	Values of the electrical resistance associated with the transient recorders of the elastic channels	The value of this resistance is expected to be 50 Ω for the two elastic channels. If not, please provide the values of these resistances.
ΔR_L	Error in the value of the electrical resistance associated with the transient recorder of the elastic channels	Provide the errors associated with the values of the resistances associated with the transient recorders of the two elastic channels and the supportive arguments for the errors identified.
Δt_L	Laser pulse duration at 355 nm and NIR wavelength	Based on laboratory measurements made by the contractor. Averaged number of nanoseconds measured at half the maximum light power amplitude for the two wavelengths of the BioSense Core laser. Must result from a random number of laser pulse acquisitions detected with high speed electronic detection hardware having sub-nanosecond response time. This number of acquisitions must be sufficient to obtain less than 1 nanosecond error in the averaged laser pulse duration. The electronic files containing the acquisitions must be provided by the contractor in an ASCII format easily readable with Excel, Matlab or IDL.
$\Delta(\Delta t_L)$	Standard deviation of Δt_L	Based on laboratory measurements made by the contractor. Standard deviation derived from the groups of acquisition files used to evaluate the averaged number of nanoseconds measured at half the maximum light power amplitude for the two lasing wavelengths of BioSense.
Ψ_λ	Spectral quantum efficiency	Based on Sensor manufacturer's technical specifications of the detector for the inelastic channel of the BioSense Core.
$\Delta\Psi_\lambda$	Standard deviation of Ψ_λ	Derived from the best reasonable assumptions associated with the Manufacturer's technical specifications of the inelastic channel of the BioSense Core.
Ψ_{λ_0}	Quantum efficiencies of the high speed detectors of the two elastic channels	Based on Sensor manufacturer's technical specifications of the two detectors for the two elastic channels (355 nm and NIR) of the BioSense Core.
$\Delta\Psi_{\lambda_0}$	Standard deviations associated with the high speed detectors of the	Derived from the best reasonable assumptions associated with the Manufacturer's technical specifications of the two detectors of elastic channels (355 nm and NIR) of the BioSense Core.

	two elastic channels	
$\Lambda(\lambda_0)$[14]	Quantum yield of the fluorescent spectral calibration target	Based on the calibration methodology provided with the fluorescence calibration targets under contract W7701-061901. Defined as the ratio of total induced fluorescence radiance between 375-700 nm to incident 355 nm excitation irradiance with the assumption that the induced fluorescent radiance obeys Lambertian law. The procedure to evaluate this quantity will be performed by DRDC in collaboration with the contractor.
$\Delta(\Lambda(\lambda_0))$[14]	Standard deviation of $\Lambda(\lambda_0)$	Standard deviation derived from the best reasonable assumptions associated with the manufacturer of the fluorescent material, system design analyses or laboratory measurements deployed to measure $\Lambda(\lambda_0)$ will be derived by DRDC in collaboration with the contractor.
$\Re_e(\lambda_0)$	Reflectance of the calibrated elastic target at 355 nm and NIR wavelengths	Based on manufacturer's technical specifications. These quantities (as the target itself) will be provided by DRDC.
$\Delta\Re_e(\lambda_0)$	Standard deviations of $\Re_e(\lambda_0)$ at 355 nm and NIR wavelengths of the two elastic channels	Derived from the best reasonable assumptions associated with the Manufacturer's technical specifications, system design analyses or laboratory measurements used to measure $\Re_e(\lambda_0)$. These quantities (as the target itself) will be provided by DRDC.
$\rho_\lambda(\lambda_0)$[14]	Spectral probability distribution of the calibrated fluorescence targets when excited with 355 nm radiation	Based on the calibration methodology provided with the fluorescence calibration targets under contract W7701-061901. Defined as the fraction of fluorescence energy per spectral interval as a function of the wavelength between 375-700 nm. The integral of the spectral probability distribution over the 375-700 nm spectral interval shall be equal to 1. The procedure to evaluate this quantity will be performed by DRDC in collaboration with the contractor.
$\Delta\rho_\lambda(\lambda_0)$[14]	Standard deviation of $\rho_\lambda(\lambda_0)$	Derived from the best reasonable assumptions associated with the Manufacturer's technical specifications, system design analyses or laboratory measurements used to measure $\rho_\lambda(\lambda_0)$. The procedure to evaluate this quantity will be performed by DRDC in collaboration with the contractor.
A_{AS}	Area of the Aperture Stop of the BioSense lidar Receiver	This parameter will be used only as a reference in the analysis of the performance of the BioSense Core instrument.
ξ_∞	BioSense Core obscuration factor at an infinite range	This parameter will be used only as a reference in the analysis of the performance of the BioSense Core instrument. However, if the BioSense Core instrument cannot be operated in conjugated imaging modes where the factor ξ_∞ still holds for short ranges, the contractor shall provide estimates of the obscuration factors for the specific operational ranges with valid justifying arguments.
Ω_L^{355}	Laser irradiation divergence at 355 nm ($1/e^2$)	This information should also include all modelling parameters allowing the derivation of the laser beam diameter ($1/e^2$) as a function of range. This parameter will be used to derive the fraction of the laser power on the fluorescence calibration target during CPE and as a reference in the planning and analysis of the CPE.
Ω_L^{NIR}	NIR laser irradiation divergence ($1/e^2$)	This information should also include all modelling parameters allowing the prediction of the laser beam diameter ($1/e^2$) as a function of range. This parameter will be used to derive the fraction of the laser power on the elastic calibration target during CPE and as a reference in the planning and analysis of the CPE.
PRF_{355}^i	Effective laser pulse repetition frequency for a measurement with the inelastic lidar channel	This parameter will be used to compute the Day Time Capability Parameters. Based on contractor supportive arguments, it will be derived as the ratio of the number of laser pulses fired to obtain a measurement with the inelastic lidar channel divided by the time interval between the first and the last pulses fired.

[14] This parameter may also have to be evaluated shortly before an acquisition depending on the dynamic variability of the calibrated fluorescing target.

PRF^{e}_{355}	Effective laser pulse repetition frequency for a measurement with the elastic lidar channel at 355 nm	This parameter will be used to compute the Day Time Capability Parameters. Based on contractor supportive arguments, it will be derived as the ratio of the number of laser pulses fired to obtain a measurement with the elastic lidar channel at 355 nm divided by the time interval between the first and the last pulses fired.
PRF^{e}_{NIR}	Effective laser pulse repetition frequency for a measurement with the NIR elastic lidar channel	This parameter will be used to compute the Day Time Capability Parameters. Based on contractor supportive arguments, it will be derived as the ratio of the number of laser pulses fired to obtain a measurement with the NIR elastic lidar channel divided by the time interval between the first and the last pulses fired.
Ω^{i}_{355}	Field of View of the inelastic lidar collector channel	This parameter will be used to compute the Day Time Capability Parameters. To be provided by the contractor with supportive arguments.
Ω^{e}_{355}	Field of View of the elastic lidar collector channel at 355 nm	This parameter will be used to compute the Day Time Capability Parameters. It will be provided by the contractor with supportive arguments.
Ω^{e}_{NIR}	Field of View of the NIR elastic lidar collector channel	This parameter will be used to compute the Day Time Capability Parameters. It will be provided by the contractor with supportive arguments.
$\Delta\lambda_{355}$	Spectral bandwidth of the elastic lidar collector channel at 355 nm	This parameter will be used to compute the Day Time Capability Parameters. It will be provided by the contractor with supportive arguments.
$\Delta\lambda_{NIR}$	Spectral bandwidth of the NIR elastic lidar collector channel	This parameter will be used to compute the Day Time Capability Parameters. It will be provided by the contractor with supportive arguments.

5.2 Description of the measurements performed during CPE

5.2.1 Recording of the environmental conditions

The recording of the environmental conditions during the CPE will be performed with four main instruments: **the SINBAHD's weather station and visibility meter (the later TBC), a transmission meter (TBC) and a spectral radiometer**, all to be operated by DRDC personnel. The SINBAHD's weather station will be deployed to acquire the atmospheric pressure, temperature and humidity level. lidar measurements will also be taken with the SINBAHD lidar system in parallel with BioSense for reference as long as it does not interfere with the BioSense acquisition. The SINBAHD's visibility meter will be deployed to record the atmospheric visibility. The transmission meter aims at providing a precise measurement of the transmission of the atmosphere, and the spectral radiometer will provide a relative measurement of the spectral background radiance seen by BioSense during day time. These environmental parameters acquired during the CPE are listed in Table 2.

Table 2: Environmental parameters acquired during CPE

Symbols	Definitions	Evaluation Methods
υ	Visibility	Recorded at a maximum interval of 5 minutes by the SINBAHD's visibility meter during the trial. This system will be operated by DRDC personnel. This visibility will be one of the weather conditions parameter used by Modtran to derive the spectral visibility. If this quantity cannot be provided by the SINBAHD' visibility meter, it will be derived from local/civilian generic weather station.
$\Delta\upsilon$	Error in υ	Derived from the technical specifications of the commercial visibility meter or reasonable technical considerations. This will be produced by DRDC personnel.
τ	Transmission	Recorded at a maximum interval of 5 minutes by a commercial

		transmission meter. This transmission will be one of the meteorological parameters used by Modtran to derive the spectral attenuation factor that will determine the spectral transmission of the atmosphere. If the transmission meter is not available, this parameter will be obtained from local/civilian weather broadcasting station. The acquisition of this parameter will be the responsibility of DRDC personnel.
$\Delta\tau$	Error in τ	Derived from the technical specifications of the commercial transmission meter or the weather broadcasting station and provided by DRDC personnel.
P	Atmospheric pressure	Quantity sampled by the SINBAHD weather station at a maximum sampling interval of 5 minutes. This quantity will be used to calculate the concentration of atmospheric nitrogen during the Raman acquisition made with the BioSense Core instrument. This quantity will be provided by DRDC personnel.
ΔP	Error in P	Derived from the technical specifications of the commercial weather station of the SINBAHD platform. This quantity will be derived by DRDC personnel.
T	Atmospheric temperature	Quantity sampled by the SINBAHD weather station at regular intervals (a minimum of 5 minute sampling intervals). The temperature sampling will be the responsibility of DRDC personnel. This quantity will be used to calculate the concentration of atmospheric nitrogen during the Raman acquisition made with the BioSense Core instrument.
ΔT	Error in T	Derived from the technical specifications of the commercial weather station of SINBAHD. This quantity will be provided by DRDC personnel.
Π_λ	Spectral radiance from the background scene seen by BioSense	Recorded at a maximum interval of 1 minute by a commercial spectral radiometer during the day time measurements. Special attention should be taken to perform this measurement with a background scene comparable with the one seen by the BioSense Core during the acquisitions. This value will be one of the meteorological parameters used to analyze the background noise during day time measurements. These acquisitions will be performed by DRDC personnel.
$\Delta\Pi_\lambda$	Error in the spectral radiance	Derived from the technical specifications of the commercial spectral radiometer. This quantity will be derived by DRDC personnel.

5.2.2 Test and evaluation procedures with the inelastic channel

This subsection describes the procedure that should be followed for the acquisitions of the parameters that will allow the derivations of the sensitivity of the inelastic channel of the BioSense Core with challenging clouds of aerosolized bio-agent simulants, the Raman signals generated from atmospheric nitrogen and the calibrated fluorescence targets.

The procedure followed with the calibrated fluorescence targets for the inelastic channel consists essentially in operating the instrument in staring mode. The staring mode requires to precisely aim the instrument at a predetermined direction. Then, the lidar fires multiple laser pulses at a target located at a given range and records separately the lidar induced scattering and a precise measurement of the background parasitic electronic and photonic signals. The parasitic signal contribution is measured between laser pulses.

5.2.2.1 Acquisition with bio-agent simulant clouds

Measurements made with challenging clouds of bio-agent simulants are the main priority of the CPE. The procedure followed to perform this task will be similar to the one followed during past trials with the SINBAHD platform over the last several years. This procedure consists in time

correlating the measurements of the BioSense Core with referee sensors characterizing (in ppl and ACPLA) the same air volume where a bio-cloud is generated. This volume of air where bioaerosols are generated may be confined spatially with the lidar adapted bioaerosol chamber developed at DRDC Suffield or in open-air at the Colin Watson Aerosol Layout (CWAL) if the chamber is not available at the execution of the CPE. Based on this time correlation, a linear relation is derived between the amplitude of the signal detected by the BioSense Core corrected from the background contributions and the concentration measured with the referee sensors. This factor is then used to express the BioSense Core noise floor acquired before and after the dissemination of the bio-clouds in limits of sensitivity in ppl and ACPLA.

For the measurements performed with clouds of disseminated bio-agent simulants, the five steps describing the measurement process can be detailed as follows:

1 After the BioSense core has been installed at the desired location for the measurements, the distance R_0 (approximately 1 km) between the lidar aperture stop and the center of the range interval where the air volume targeted by the disseminated cloud of bio-simulants (a solid target may be temporarily used to mark this position) are measured with a commercial range meter. The error ΔR_0 associated with the measurement of R_0 is also recorded.

2 The artificial attenuation χ of the optical component inserted in the BioSense Core collector optical path is recorded. The error $\Delta\chi$ associated with this quantity is also recorded.

3 The preliminary parameters defining the configuration of the measurement are recorded. These include: the number of pulses contributing to a measurement n_p, the electronic time gate interval Δt and delay t_{delay} (and associated errors $\Delta(\Delta t)$ and Δt_{delay}) and the gated range interval ΔR.

4 With the scanner of the BioSense core, the laser beam at 355 nm is positioned precisely at the center of the atmospheric volume targeted. This precise angular adjustment performed by the scanner should be monitored by observing the image of the laser beam at the target plane with a white cotton sheet.

5 Once the UV laser beam is carefully pointed at the center of the probed atmospheric volume, a run of quasi-continuous measurements (a measurement results from the binning of n_p acquisitions) lasting a minimum of 20 minutes will be performed. Each run of measurements will include at least 5 minutes of background measurements acquired before the dissemination of the bio-simulant clouds (BG), then about 10 minutes of measurements during cloud dissemination followed by 5 minutes of background measurements after the cloud dissemination. For each of these measurements, the duration of the lasing period t_{mea} (about 10 s.) and associated error Δt_{mea}, and the averaged laser energy per pulse E_{355}^{L} are recorded. Also, each spectral measurement combining the inelastic scatterers and the parasitic contributions resulting from each laser pulse fired as well as each spectral measurement estimating precisely that corresponding parasitic background contributions are collected. These spectra may be binned during the BioSense Core measurement process or during the analysis of the data collected to form the raw measurements, $S_{\lambda}^{BG}(tot)$ and $S_{\lambda}^{BG}(back)$, respectively, and the binned spectra corrected for background contribution $S_{\lambda}^{BG}(\lambda_0, R_0, \Delta R)$ will be derived as $S_{\lambda}^{BG}(tot) - S_{\lambda}^{BG}(back)$ and forms the run of measurements. It is these

binned corrected spectra, $S_{\lambda}^{BG}(\lambda_0, R_0, \Delta R)$, once integrated over the spectrum or after being processed with the multi-variate analysis, that will be correlated with the referee sensors to derive the sensitivity of the BioSense Core instrument in ppl and ACPLA. This approach assumes an optically thin bioaerosol cloud.

During the CPE, at least three valid runs of measurements with disseminated clouds of BG at a range of about 1 km will be performed with the inelastic channel. These runs of measurements will be made during night time only. If time permits, this type of measurements may be repeated at a range of 200 meters or with other simulants of bio-agents. These other measurements will be performed mainly to verify the BioSense lidar model and to initiate the construction the spectral fluorescent characteristics and sensitivities associated with other simulants of bio-agents. The parameters and measurements recorded during the trial with bio-agent simulants as the inelastic targets are listed in Table 3.

Table 3: List of parameters acquired with the cloud of bio-agent simulants

Symbols	Definitions	Evaluation Methods
R_0	Distance between the BioSense Core collector aperture stop and the center of the probed volume	Measure with a commercial range meter using a temporary solid target positioned at the center of the probed volume. This measurement will be made by DRDC personnel in collaboration with the contractor.
ΔR_0	Error in the measurement of R_0 made with the commercial range meter	Derived from the error specified by the manufacturer of the commercial range meter. This information will be provided by DRDC.
χ	Artificial spectral attenuation factor between 375-700 nm generated by the optical component inserted in the collector optical path of the BioSense Core	Quantity derived from the manufacturer's specifications and/or laboratory measurements made by the contractor. This quantity is expected to be spectrally independent (neutral filter). If not, the spectral attenuation factor χ_{λ} shall be provided.
$\Delta\chi$	Error in χ	This error, provided by the contractor, will be derived from the manufacturer's specifications and/or laboratory measurements made by the contractor. If χ is spectrally dependent, $\Delta\chi_{\lambda}$ will be provided.
n_p	Number of laser pulses fired at a bio-cloud to produce a measurement $S_{\lambda}^{BG}(\lambda_0, R_0, \Delta R)$	Quantity provided by the contractor and derived from the BioSense Core instrument during the run of measurements. This parameter should be identical for all measurements of a given run. This parameter will be used as a reference during the analysis of the CPE results.
Δt	Electronic time gate interval	Quantity to be provided by the contractor from the configuration of the BioSense Core for a run of measurements. This parameter should be identical for all measurements of a given run. Will be used to define the error associated with the range distribution of the probed atmospheric volume.
$\Delta(\Delta t)$	Error in the electronic time gate interval	This error is associated with the electronics controlling the range gate size and position. This quantity should be derived from the technical specifications from these electronic components and reasonable arguments, the two provided by the contractor.
t_{delay}	Electronic time delay	Quantity provided by the contractor and derived from the BioSense Core instrument during a run of measurements. This time delay corresponds to the time interval between the moment a laser pulse leaves the lidar emitter and the moment the electronic time gate interval is initiated. This parameter will be used as a reference for the analysis of the

		measurements.
Δt_{delay}	Error in the electronic time delay	This error is associated with the electronics controlling the range location. This quantity will be derived from the technical specifications of the BioSense electronic components and reasonable arguments, the two provided by the contractor. This parameter will be used as a reference for the analysis of the measurements.
ΔR	Dimension of the BioSense Core range gate for an acquisition	Quantity derived from the BioSense Core instrument during a run of measurements. This parameter derived from the electronic time gate interval and the UV laser pulse duration will be used as a reference for the analysis of the measurements and will be provided by the contractor.
t_{mea}	Duration of the laser firing period corresponding to a run of measurements	Derived from the laser firing pulse repetition frequency, the total number of pulses fired for the measurement and considerations associated with the procedure to sample the radiance and electronic parasitic background contributions. This quantity should be constant for a given run of measurements. The contractor should provide this parameter as well as the methodology to derive it. The background parasitic sampling methodology should be discussed between the TA and the contractor well in advance of the CPE.
Δt_{mea}	Error in the evaluation of t_{mea}	Provided by the contractor based on reasonable arguments.
E_{355}^{L}	Averaged laser energy per UV pulse	Quantity to be provided by the contractor based on the BioSense Core monitoring parameters during a run of measurements. This parameter should be approximately constant during a run and will be used as a reference during the analysis of the CPE collected data.
$S_{\lambda}^{BG}(tot)$	BioSense core spectral measurements of the laser induced inelastic scatters from the bio-cloud of BG plus the parasitic background contributions	These are the binned spectra obtained with the BioSense Core instrument when a run of measurements is performed while irradiating the probed atmospheric volume. They result from the inelastic scattering produced by a given number of laser pulses fired at the bio-cloud and the parasitic background photonic and electronic contributions collected simultaneously. If technically feasible, the provided data should include the spectra collected with each laser pulse fired. During the analysis, these spectra will be binned and corrected for the parasitic contribution to obtain $S_{\lambda}^{BG}(\lambda_0, R_0, \Delta R)$, the spectral measurements associated solely with the BG induced fluorescence. $S_{\lambda}^{BG}(tot)$ will be provided by the contractor.
$S_{\lambda}^{BG}(back)$	BioSense core spectral measurements estimating the parasitic background contributions within of the corresponding $S_{\lambda}^{BG}(tot)$ measurements.	These are binned spectra produced by the BioSense instrument (or by the analysis of the BioSense collected data) during a run of measurements and estimating precisely the parasitic photonic and electronic background contributions contained in corresponding $S_{\lambda}^{BG}(tot)$. If technically feasible, the provided data should include the spectra collected with each parasitic background acquisitions which will be binned during the CPE analysis. The resulting measurements will be use to correct for the parasitic contribution and obtain $S_{\lambda}^{BG}(\lambda_0, R_0, \Delta R)$, the spectral measurements associated solely with the BG induced fluorescence. $S_{\lambda}^{BG}(back)$ will be provided by the contractor.

5.2.2.2 Acquisitions with calibrated fluorescing targets

For the measurements made with the calibration fluorescing target, the five steps describing the measurement process can be summarized as follows:

1. After the BioSense core has been installed at the desired location for the series of measurement, the distance R_0 (approximately 1 km) between the lidar aperture stop and the calibrated fluorescing target are measured with a commercial range meter. The error ΔR_0 associated with the measurement of R_0 is also recorded.

2. The artificial attenuation χ of the optical component inserted in the BioSense Core collector is recorded. The error $\Delta\chi$ associated with this quantity is also recorded.

3. The preliminary parameters defining the configuration of the measurement are recorded. These include: the number of pulses contributing to a measurement n_p, the electronic time gate interval Δt and delay t_{delay} (and associated errors $\Delta(\Delta t)$ and Δt_{delay}) and the gated range interval ΔR. n_p will be derived based on an approximate 10 s. binned measurement.

4. With the scanner of the BioSense core, the laser beam at 355 nm is centered precisely on the exposed area of the calibrated fluorescence target. This precise angular adjustment performed by the scanner should be monitored by observing the image of the laser beam at the target with a large white cotton sheet or by maximizing the fluorescent return. This may also be achieved by centering the hard target on the laser spot. From this precise angular adjustment, the size of the exposed fluorescing area and the characterization of the UV laser beam divergence model Ω_L^{355} obtained from the contractor before the CPE, the fraction of the laser power incident on the fluorescing surface γ and associated error $\Delta\gamma$ will be derived during the analysis of the CPE acquired data.

5. Once the UV laser beam is carefully positioned on the fluorescing target, ten successive measurements are performed. For each of these measurements, the duration of the lasing period t_{mea} and associated error Δt_{mea}, and the averaged laser energy per pulse E_{355}^{L} are recorded. If technically possible, each spectral acquisition combining the inelastic scatters and the parasitic background contributions resulting from each laser pulse fired as well as each corresponding spectral acquisition estimating precisely the background contribution are collected. If not, the binned results will be provided by the contractor during the CPE. Once these spectra are binned (during the analysis of the data collected at the CPE or directly provided by the BioSense Core during the CPE), they will form $S_\lambda^{cal}(tot)$ and $S_\lambda^{cal}(back)$, respectively, and the binned spectra (or measurements) corrected for background contribution $S_\lambda^{cal}(\lambda_0, R_0, \Delta R)$ will be derived as $S_\lambda^{cal}(tot) - S_\lambda^{cal}(back)$.

During the CPE, this process of ten successive valid measurements will be repeated at least three times for a given range. These measurements with calibrated fluorescing targets during night time are planned to be performed at two ranges: 1000 meters (priority) and a shorter range close to 200 meters. The parameters and acquisitions recorded during the trial with the calibrated fluorescing targets are listed in Table 4.

Table 4: List of parameters acquired with calibrated fluorescing targets

Symbols	Definitions	Evaluation Methods
R_0	Distance between the BioSense Core collector aperture stop and the fluorescent calibration target	Measure at the CPE using the calibrated fluorescent hard target (or a larger hard target placed at the same position) as the target for the range meter. This measurement will be made by DRDC in collaboration with the contractor.
ΔR_0	Error in the measurement of R_0 measured with the commercial range	Derived from the error specified by the manufacturer of the commercial range meter. This information will be provided by DRDC.

	meter	
χ	Artificial spectral attenuation factor between 375-700 nm generated by the optical component inserted in the collector optical path of the BioSense Core	Quantity derived from the manufacturer's specifications and/or laboratory measurements made by the contractor. This quantity is expected to be spectrally independent (neutral filter). If not, the spectral attenuation factor χ_λ shall be provided.
$\Delta\chi$	Error in χ	This error, provided by the contractor, will be derived from the manufacturer's specifications and/or laboratory measurements made by the contractor. If χ is spectrally dependent, $\Delta\chi_\lambda$ will be provided.
A_{cal}	Area of the fluorescing calibration target	Derived by physically measuring the dimension of the effective area of the calibration target contributing to the measured fluorescence. This quantity will be provided by DRDC personnel.
ΔA_{cal}	Error associated with the measurement of A_{cal}	Derived from the error associated with the measured dimension of the effective area of the calibration target contributing to the acquired fluorescence. The evaluation of this error will be provided by DRDC personnel.
n_p	Number of laser pulses fired at the fluorescent calibration target for an measurement $S_\lambda^{cal}(\lambda_0, R_0, \Delta R)$	Quantity provided by the contractor and derived from the BioSense Core instrument during the run of measurements. This parameter should be identical for all measurements of a given run. This parameter will be used as a reference during the analysis of the CPE results.
Δt	Electronic time gate interval	Quantity to be provided by the contractor from the configuration of the BioSense Core for a run of measurements. This parameter should be identical for all measurements of a given run. This parameter will be used a reference during the analysis of the CPE results.
$\Delta(\Delta t)$	Error in the electronic time gate interval	Quantity provided by the contractor and derived from the BioSense Core instrument during a run of measurements. This parameter will be used only as a reference during the analysis of the CPE results.
t_{delay}	Electronic time delay	Quantity provided by the contractor and derived from the BioSense Core instrument during a run of measurements. This time delay corresponds to the time interval between the moment a laser pulse leaves the lidar emitter and the moment the electronic time gate interval is initiated. This parameter will be used as a reference for the analysis of the measurements.
Δt_{delay}	Error in the electronic time delay	This error is associated with the electronics controlling the range location. This quantity will be derived from the technical specifications of the BioSense electronic components and reasonable arguments provided by the contractor. This parameter will be used as a reference for the analysis of the measurements.
ΔR	Dimension of the BioSense Core range gate for a measurement	Quantity derived from the BioSense Core instrument during a run of measurements. This parameter derived from the electronic time gate interval and the UV laser pulse duration will be used as a reference for the analysis of the measurements and will be provided by the contractor.
γ	Fraction of the laser power incident on the fluorescent calibration target	Derived by DRDC personnel in collaboration with the contractor by comparing the size of the laser spot at the position of the calibration target and the size of the calibration target. The laser irradiation divergence Ω_L^{355} and laser size propagation model provided by the contractor before the CPE will also be used in this evaluation. An accurate evaluation of this parameter will first require carefully centering the laser beam on the calibration target (or inversely) before a run of measurements.
$\Delta\gamma$	Error in γ	Derived from the precision with which the BioSense scanner can point at the center of the calibration target (or inversely), the precision with which the size and intensity profile of the laser spot on the calibration target is derived and the precision of the size of the calibration target.

t_{mea}	Duration of the laser firing period corresponding to a run of measurements	Derived from the laser firing pulse repetition frequency, the total number of pulses fired for the measurement and considerations associated with the procedure to sample the radiance and electronic parasitic background contributions. This quantity should be constant for a given run of measurements. The contractor should provide this parameter as well as the methodology to derive it. The background parasitic sampling methodology should be discussed between the TA and the contractor well in advance of the CPE.
Δt_{mea}	Error in the evaluation of t_{mea}	Provided by the contractor based on reasonable arguments.
E_{355}^{L}	Averaged laser energy per pulse	Quantity to be provided by the contractor based on the BioSense Core monitoring parameters during a run of measurements. This parameter should be approximately constant during a run and will be used as a reference during the analysis of the CPE collected data.
$S_{\lambda}^{cal}(tot)$	BioSense core measurements of the laser induced inelastic scatters from the calibrated fluorescing target plus parasitic background contributions	These are the binned spectra obtained with the BioSense Core instrument from the acquisitions when irradiating the fluorescent calibration target. They result from the inelastic scattering from a given number n_p of laser pulses fired at the fluorescent calibration target and the parasitic background photonic and electronic contributions collected simultaneously. If technically feasible, the provided data should include the spectra collected with each laser pulse fired. During the analysis, these spectra will be corrected for the parasitic contributions and then binned to obtain $S_{\lambda}^{cal}(\lambda_0, R_0, \Delta R)$, the spectral measurements associated solely with the induced fluorescence from the calibration hard target. $S_{\lambda}^{cal}(tot)$ will be provided by the contractor.
$S_{\lambda}^{cal}(back)$	BioSense core spectral measurements estimating the parasitic background contributions within the corresponding $S_{\lambda}^{cal}(tot)$	These are the spectra obtained with the BioSense Core instrument when acquisitions are performed between laser pulses fired at the fluorescent calibration target. They result only from the parasitic background photonic and electronic contributions and are a close approximation of the parasitic signal collected simultaneously with the laser induced inelastic scatters. If technically feasible, the provided data should include the spectra collected with each background sampling. During the analysis, these spectra will be binned and use to correct for the parasitic contribution to obtain $S_{\lambda}^{cal}(\lambda_0, R_0, \Delta R)$, the spectral measurement associated solely with the fluorescing calibration hard target inelastic scatters. $S_{\lambda}^{cal}(back)$ will be provided by the contractor.

5.2.2.3 Acquisitions of the nitrogen Raman signal

Measurements made with the BioSense core during the CPE with atmospheric nitrogen as scattering targets are similar to those made with the calibrated fluorescing target with the exception that the signal of interest does not originate from a solid target but from a volume of gas. This implies a lower demanding precision in pointing the BioSense laser beam but requires additional parameters to characterize adequately the challenging target. Most of these additional parameters are acquired with the instruments recording the environmental conditions. It is therefore important to make sure that these environmental parameters are adequately recorded.

For the measurements using atmospheric nitrogen as the inelastic target, the five steps describing the measurement process can be detailed as follows:

1. After the BioSense core has been installed at the desired location for the measurement s, the distance R_0 (approximately 1 km) between the lidar aperture stop and the center of the range interval where the volume of atmospheric nitrogen will be used as target (a solid target may be temporary used to mark this position) are measured with a commercial range meter. The error ΔR_0 associated with the measurement of R_0 is also recorded.

2. The artificial attenuation χ of the optical component inserted in the BioSense Core collector optical path is recorded. The error $\Delta\chi$ associated with this quantity is also recorded.

3. The preliminary parameters defining the configuration of the measurement are recorded. These include: the number of pulses contributing to a measurement n_p, the electronic time gate interval Δt and delay t_{delay} (and associated errors $\Delta(\Delta t)$ and Δt_{delay}) and the gated range interval ΔR.

4. With the scanner of the BioSense core, the laser beam at 355 nm is centered precisely at the atmospheric volume targeted. This precise angular adjustment performed by the scanner should be monitored by observing the image of the laser beam (on a temporary hard target made of a white cotton sheet) at the target plane.

5. Once the UV laser beam is carefully pointed at the center of the probed atmospheric volume, ten successive measurements are performed. For each of these measurements, the duration of the lasing period t_{mea} (about 10 s.), and associated error Δt_{mea}, and the averaged laser energy per pulse E_{355}^{L} are recorded. Also, each spectral acquisition combining the inelastic scatterers and the parasitic background contributions resulting from each laser pulse fired as well as each spectral acquisition estimating precisely that corresponding parasitic background contribution are collected. These spectra may be binned during the BioSense Core measurement process or during the analysis of the data collected to form the raw measurements, $S_{\lambda}^{N2}(tot)$ and $S_{\lambda}^{N2}(back)$, respectively, and the binned spectra corrected for background contribution $S_{\lambda}^{N2}(\lambda_0, R_0, \Delta R)$ will be derived as $S_{\lambda}^{N2}(tot) - S_{\lambda}^{N2}(back)$ and forms the run of measurements. It is these binned corrected spectra, $S_{\lambda}^{N2}(\lambda_0, R_0, \Delta R)$, once integrated over the Raman spectral region or after being processed with the multi-variate analysis, that will be inserted in equation 29 to derive the inelastic Detection Sensitivity Parameters at the nitrogen Raman wavelength.

During the CPE, this process of ten successive valid measurements will be repeated at least three times at a range of about 1 km. Also, if time permits, these measurements of atmospheric nitrogen Raman signals made during night time should be repeated at two ranges of about 200 meters. These measurements made a shorter range will be performed mainly to verify the BioSense lidar model. The parameters and acquisitions recorded during the trial with atmospheric nitrogen as the inelastic target are listed in Table 5.

Table 5: List of parameters acquired with the nitrogen Raman signal

Symbols	Definitions	Evaluation Methods
R_0	Range between the BioSense Core receiver aperture stop and the center of the probed volume	Measure with a commercial range meter using a temporary solid target positioned at the center of the probed volume. This measurement will be made by DRDC in collaboration with the contractor.
ΔR_0	Error in the measurement of R_0 made with the commercial range meter	Derived from the error specified by the manufacturer of the commercial range meter. This information will be provided by DRDC.
χ	Artificial spectral attenuation factor	Quantity derived from the manufacturer's specifications and/or laboratory measurements made by the contractor. This quantity is

	between 375-700 nm generated by the optical component inserted in the lidar collector optical path of the BioSense Core	expected to be spectrally independent (neutral filter). If not, the spectral attenuation factor χ_λ shall be provided.
$\Delta\chi$	Error in χ	This error, provided by the contractor, will be derived from the manufacturer's specifications and/or laboratory measurements made by the contractor. If χ is spectrally dependent, $\Delta\chi_\lambda$ will be provided.
n_p	Number of laser pulses fired at the probed atmospheric volume to produce a measurement $S_\lambda^{N2}(\lambda_0, R_0, \Delta R)$	Quantity provided by the contractor and derived from the BioSense Core instrument during the run of measurements. This parameter should be identical for all measurements of a given run. This parameter will be used as a reference during the analysis of the CPE results.
Δt	Electronic time gate interval	Quantity to be provided by the contractor from the configuration of the BioSense Core for a run of measurements. This parameter should be identical for all measurements of a given run. Will be used to define the error associated with the range distribution of the probed atmospheric volume.
$\Delta(\Delta t)$	Error in the electronic time gate interval	This error is associated with the electronics controlling the range gate size and position. This quantity should be derived from the technical specifications from these electronic components and reasonable arguments, the two provided by the contractor.
t_{delay}	Electronic time delay	Quantity provided by the contractor and derived from the BioSense Core instrument during a run of measurements. This time delay corresponds to the time interval between the moment a laser pulse leaves the lidar emitter and the moment the electronic time gate interval is initiated. This parameter will be used as a reference for the analysis of the measurements.
Δt_{delay}	Error in the electronic time delay	This error is associated with the electronics controlling the range location. This quantity should be derived from the technical specifications from the electronic components and reasonable arguments, the two provided by the contractor. This parameter will be used as a reference for the analysis of the measurements.
ΔR	Dimension of the BioSense Core range gate for a measurement	Quantity derived from the BioSense Core instrument during a run of measurements. This parameter derived from the electronic time gate interval and the UV laser pulse duration will be used as a reference for the analysis of the measurements and will be provided by the contractor.
t_{mea}	Duration of the laser firing period corresponding to a run of measurements	Derived from the laser firing pulse repetition frequency, the total number of pulses fired for the measurement and considerations associated with the procedure to sample the radiance and electronic parasitic background contributions. This quantity should be constant for a given run of measurements. The contractor should provide this parameter as well as the methodology to derive it. The background parasitic sampling methodology should be discussed between the TA and the contractor well in advance of the CPE.
Δt_{mea}	Error in the evaluation of t_{mea}	Provided by the contractor based on reasonable arguments.
E_{355}^L	Averaged laser energy per pulse	Quantity to be provided by the contractor based on the BioSense Core monitoring parameters during a run of measurements. This parameter should be approximately constant during a run and will be used as a reference during the analysis of the CPE collected data.
$S_\lambda^{N2}(tot)$	BioSense core spectral measurements of the laser induced inelastic scatters from atmospheric nitrogen plus the parasitic	These are the binned spectra obtained with the BioSense Core instrument when a run of measurements is performed while irradiating the probed atmospheric volume. The result from the inelastic scattering produced by a given number of laser pulses fired at the atmospheric nitrogen and the parasitic background photonic and electronic contributions collected simultaneously. If technically feasible, the provided data should include the spectra collected with each laser pulse fired. During the analysis,

	background contributions	these spectra will be binned and corrected for the parasitic contribution to obtain $S_{\lambda}^{N2}(\lambda_0, R_0, \Delta R)$, the spectral measurements associated solely with the Raman signal from atmospheric nitrogen. $S_{\lambda}^{N2}(tot)$ will be provided by the contractor.
$S_{\lambda}^{N2}(back)$	BioSense core spectral measurements of the laser induced inelastic scatters from the atmospheric nitrogen plus the parasitic background contributions	These are binned spectra produced by the BioSense instrument (or by the analysis of the BioSense collected data) during a run of measurements and estimating precisely the parasitic photonic and electronic background contributions contained in corresponding $S_{\lambda}^{N2}(tot)$. If technically feasible, the provided data should include the spectra collected with each parasitic background acquisitions which will be binned during the CPE analysis. The resulting measurements will be use to correct for the parasitic contribution and obtain $S_{\lambda}^{N2}(\lambda_0, R_0, \Delta R)$, the spectral measurements associated solely with the induced nitrogen Raman signal. $S_{\lambda}^{N2}(back)$ will be provided by the contractor.

5.2.3 T&E procedures with NIR elastic channel

5.2.3.1 Acquisitions with bio-agent simulant clouds

The evaluation of the NIR elastic channel with challenging clouds of bio-agent simulants will be performed following a procedure similar to the one detailed above for the inelastic channel (see Subsection 5.2.2.1). This procedure is also based on a time correlation between the quantities acquired with the NIR elastic channels[15] of the BioSense Core and the referee sensors characterizing (in ppl and ACPLA) the same air volume where a bio-cloud is generated. Based on the linear analysis of this correlation and the noise floor of the NIR elastic channel collected before and after dissemination, a limit of sensitivity evaluated at 4x the standard deviation of the noise floor will be derived in ppl and ACPLA.

A procedure in cinq steps can be detailed for the measurements with the NIR channel:

1 After the BioSense core has been installed at the desired location for the measurements, the distance R_0 (approximately 1 km) between the lidar aperture stop and the center of the range interval of the air volume targeted by the disseminated cloud of bio-simulants (a solid target may be temporarily used to mark this position) are measured with a commercial range meter. The error ΔR_0 associated with the measurement of R_0 is also recorded.

2 The artificial attenuation χ of the optical component inserted in the BioSense Core collector is recorded. The error $\Delta\chi$ associated with this quantity is also recorded.

3 The preliminary parameters defining the configuration of the measurement are recorded. These include: the number of pulses contributing to a measurement n_p, the electronic time gate interval Δt and delay t_{delay} (and associated errors $\Delta(\Delta t)$ and Δt_{delay}) and the gated range interval ΔR corresponding to the returned elastic scatters of interest.

[15] During the analysis of the CPE, the two polarized elastic returns will be combined to form a single transient return per laser pulse fired. In this subsection, the elastic signals $S_{NIR}^{BG}(tot)$ and $S_{NIR}^{BG}(back)$ collected by the BioSense Core refer to the combined two polarized transient returns binned over several fired laser pulses.

4 With the scanner of the BioSense core, the NIR laser beam is centered precisely at the targeted atmospheric volume. This precise angular adjustment performed by the scanner will be monitored by observing the image of the laser beam at the target plane with a SWIR camera provided by DRDC.

5 Once the NIR laser beam is carefully pointed at the center of the probed atmospheric volume, a run of quasi-continuous measurements lasting about 20 minutes will be performed. Each run of measurements will include at least 5 minutes of background measurement acquired before the dissemination of the bio-simulant clouds, then about 10 minutes of measurements during cloud dissemination followed by 5 minutes of measurements of background measurements after the cloud dissemination. For each of these measurements, the duration of the lasing period t_{mea} (corresponding to the period necessary to scan a linear dimension of 5 m at a range of 1 km at a scanning speed of 3 deg/s, for a NIR laser PRF of 500 Hz, this period corresponds to about 50 fired laser pulses) and associated error Δt_{mea}, and the averaged laser energy per pulse E_{NIR}^{L} are recorded. Each measurement includes the transient signals returned along the path to the bio-cloud and the range interval where that cloud is generated. It is within that range interval that the scatter only corrected signal $S_{NIR}^{BG}(\lambda_0, R_0, \Delta R)$ will be constructed.

During the CPE, if technically feasible, the transient acquisitions from each laser pulse fired and from the corresponding parasitic background sampling should be recorded independently. During the analysis of the data collected, $S_{NIR}^{BG}(tot)$ and $S_{NIR}^{BG}(back)$ will result from the binning of approximately 50 of these acquisitions and will then be subtracted to derive $S_{NIR}^{BG}(\lambda_0, R)$, the transient signal from the bio-cloud corrected for the background parasitic contributions. It is from that transient signal, once integrated over the time interval corresponding to the probe volume to form $S_{NIR}^{BG}(\lambda_0, R_0, \Delta R)$ and correlated with the referee sensors, that the sensitivity of the BioSense Core instrument in ppl and ACPLA for the NIR channel will be derived.

During the CPE, at least three valid runs of measurements with disseminated cloud of BG at a range of approximately 1 km will be performed. These runs of measurements will be made during night time only. If time permits, these types of measurements may be repeated at a range of 200 meters or with other bio-agent simulants. These other measurements will be performed mainly to verify the BioSense lidar model and to evaluate the sensitivities associated with different bio-agent simulants. The parameters and acquisitions recorded during the trial with clouds of bio-agent simulants and the NIR channel are listed in Table 6.

Table 6: List of parameters acquired with the NIR channel during trials with clouds of bio-agent simulants

Symbols	Definitions	Evaluation Methods
R_0	Distance between the BioSense Core collector aperture stop and the center of the probed volume	Measure with a commercial range meter using a temporary solid target positioned at the center of the probed volume. This measurement will be made by DRDC in collaboration with the contractor.
ΔR_0	Error in the measurement of R_0 made with the commercial range meter	Derived from the error specified by the manufacturer of the commercial range meter. This information will be provided by DRDC.

χ	Artificial spectral attenuation factor at the NIR wavelength generated by the optical component inserted in the lidar collector optical path of the BioSense Core	Quantity derived from the manufacturer's specifications and/or laboratory measurements made by the contractor at the NIR wavelength.
$\Delta\chi$	Error in χ	This error, provided by the contractor, will be derived from the manufacturer's specifications and/or laboratory measurements made by the contractor.
n_p	Number of laser pulses fired at a bio-cloud to produce a measurement $S_{NIR}^{BG}(\lambda_0, R_0, \Delta R)$	Quantity provided by the contractor and derived from the BioSense Core instrument during the run of measurements. This parameter will define the number of transient acquisitions to be binned for a measurement during the analysis of the CPE (here, it is assumed that all transient acquisitions were recorded independently during the CPE) and is derived from the cloud mapping spatial sampling interval of 5 m at a range of 1 km and a scanning speed of 3 deg/s.
Δt	Electronic time gate interval corresponding to the targeted elastic return	Quantity to be provided by the contractor from the configuration of the BioSense Core for a run of measurements. This parameter should be identical for all measurements of a given run. Will be used to define the error associated with the range distribution of the probed atmospheric volume.
$\Delta(\Delta t)$	Error in the electronic time gate interval	This error is associated with the electronics controlling the samplings of the transient return. This quantity should be derived from the technical specifications from the electronic components and reasonable arguments provided by the contractor.
t_{delay}	Electronic time delay	Quantity provided by the contractor and derived from the BioSense Core instrument during the transient measurements made by the contractor. This time delay corresponds to the time interval between the moment a laser pulse leaves the lidar emitter and the moment the transient return corresponding to the bio-cloud scatters arrives at the lidar collector. This parameter will be used during the analysis of the CPE collected data.
Δt_{delay}	Error in the electronic time delay	This error is associated with the BioSense electronics controlling the transient sampling. This quantity will be derived from the technical specifications of the BioSense electronic components and reasonable arguments, the two provided by the contractor. This parameter will be used as a reference for the analysis of the measurements.
ΔR	Dimension of the range interval confining the elastic return from the bio-cloud	Quantity derived from the BioSense Core instrument during the measurements made by the contractor. This parameter will be used to define the range interval (or transient time interval) where the elastic scatter returns from the targeted BG cloud are located.
t_{mea}	Duration of the laser firing period corresponding to a measurement.	Derived by the contractor based on a BioSense cloud mapping spatial sampling interval of 5 meters at a range of 1 km and a scanning speed of 3 deg/s. Will depend on the BioSense NIR laser PRF.
Δt_{mea}	Error in the evaluation of t_{mea}	Provided by the contractor based on reasonable arguments.
E_{NIR}^{L}	Averaged NIR laser energy per pulse	Quantity to be provided by the contractor based on the BioSense Core monitoring parameters during a run of measurements. This parameter should be approximately constant during a run and will be used as a reference during the analysis of the CPE collected data.
$S_{NIR}^{BG}(tot)$	Binned transient returns corresponding to a measurement resulting from n_p acquisitions made by the BioSense core and containing the bio-cloud and parasitic	These are the binned results of n_p transient acquisitions resulting from each laser pulse fired at the disseminated bio-cloud by the BioSense Core during a run of measurement made by the contractor. It contained the scatters from the BG cloud plus the parasitic radiative and electronic parasitic contributions. If technically feasible, each acquisition resulting from a fired laser pulses should be recorded. During the analysis of the CPE, n_p of these acquisitions will be binned to form the

	background contributions.	measurements $S_{NIR}^{BG}(tot)$. These quantities or the individual transient returns will be provided by the contractor during the CPE.
$S_{NIR}^{BG}(back)$	Binned transient returns corresponding to a measurement estimating precisely the parasitic background contributions contained in a corresponding $S_{NIR}^{BG}(tot)$.	These are the binned transient acquisitions estimating the parasitic radiative and electronic background contributions contained in the corresponding $S_{NIR}^{BG}(tot)$. If technically feasible, the provided data should include the transient acquisitions estimating precisely these background acquisitions for each laser pulse fired and producing $S_{NIR}^{BG}(tot)$ once binned. The resulting measurements will be use to correct for the parasitic contributions and, once integrated along the range interval where the bio-cloud is located, to obtain $S_{NIR}^{BG}(\lambda_0, R_0, \Delta R)$, the transient measurements associated solely to the BG elastic scatters. This quantity or the corresponding raw transient acquisitions before binning will be provided by the contractor during the CPE and the method to obtain this estimation should be discussed with the TA.

5.2.3.2 Acquisitions with NIR calibrated hard targets

As for the inelastic channel, the procedure of measurements with a NIR calibrated elastic scattering hard target performed with the NIR elastic channel during the CPE consists essentially in operating the instrument in staring mode. The staring mode requires to precisely aim the lidar transmitter at the calibrated elastic target. A measurement results from the binning of n_p acquisitions, n_p being derived from the targeted cloud map spatial sampling interval of 5 m for a scanning speed of 3 deg/s. If technically possible, each transient acquisition (see footnote 15) resulting from each laser pulse fired at the calibrated elastic scattering target should be recorded. In this case, the binning of the acquisitions will be performed during the analysis of the data. Also, a precise estimation of the background parasitic electronic and photonic signals recorded simultaneously with each laser scatter transient return should be produced. It is anticipated that this estimation of the background parasitic contribution will be sampled between each fired laser pulses. In either case, the contractor will discuss the method of estimation of the parasitic background before the CPE.

For the measurements made with the NIR calibrated elastic target, the five steps describing a run of measurements can be detailed as follows:

1. After the BioSense core has been installed at the desired location for the series of measurement, the distance R_0 (approximately 1 km) between the lidar aperture stop and the calibrated elastic target is measured with a commercial range meter. The error ΔR_0 associated with this measurement is also recorded.

2. The artificial attenuation χ of the optical component inserted in the BioSense Core collector is recorded. The error $\Delta\chi$ associated with this quantity is also recorded.

3. The preliminary parameters defining the configuration of the run of measurements are recorded. These include: the number of pulses n_p fired corresponding to a measurement (this quantity corresponds to the number of laser pulses fired when the BioSense scan a linear dimension of 5 meters, the cloud map sampling interval, at a range of 1 km with a scanning speed of 3 deg/s), the electronic time gate interval Δt and delay t_{delay} (and associated errors $\Delta(\Delta t)$ and Δt_{delay}) and the range interval ΔR corresponding to the returned elastic scatters of interest.

4. With the scanner of the BioSense core, the NIR laser beam is centered precisely at the calibrated elastic target. This alignment process may also be performed by moving the calibrated target at the center of the laser beam. This precise angular adjustment will be monitored by observing the image of the laser beam on a large screen like a large white cotton sheet with a NIR camera (InGaAs technology) provided by DRDC. From this precise angular adjustment, the size of the exposed fluorescing area and the characterization of the NIR laser beam divergence model Ω_L^{NIR} obtained from the contractor before the CPE, the fraction of the laser power incident on the fluorescing surface γ and associated error $\Delta\gamma$ will be derived during the analysis of the CPE acquired data.

5. With the NIR laser beam now carefully aimed at the elastic target, ten successive measurements are performed. For each of these measurements, the duration of the lasing period t_{mea} and associated error Δt_{mea}, and the averaged laser energy per pulse E_{NIR}^{L} are recorded. If technically possible, each transient acquisition combining the elastic scatters and the parasitic background contribution resulting from each laser pulse fired as well as each transient acquisition estimating precisely the corresponding background contributions are collected. If not, the binned results will be provided by the contractor during the CPE. Once these transient returns are binned (during the analysis of the data collected at the CPE or directly provided by the BioSense Core during the CPE), they will form $S_{\lambda_0}^{cal}(tot)$ and $S_{\lambda_0}^{cal}(back)$, respectively, and the binned transient returns (or measurements) corrected for background contribution $S_{\lambda_0}^{cal}(\lambda_0, R)$ will be derived as $S_{\lambda_0}^{cal}(tot) - S_{\lambda_0}^{cal}(back)$. These corrected transient measurements, once integrated over the time interval corresponding to elastic scatters returned from the calibrated elastic hard target, will form $S_{\lambda_0}^{cal}(\lambda_0, R_0, \Delta R)$ that will be introduced in eq. 42.

During the CPE, the process of acquiring ten successive valid measurements described above will be repeated at least three times for a given range. These measurements with a calibrated elastic scattering target during night time are planned to be performed at two ranges: 1000 meters (priority) and a shorter close to 200 meters. At the shorter range, it is expected that the contractor will provide an estimation of the new obscuration factor which should not be the same than the one at a range of 1 km. The parameters and acquisitions recorded during the trial with the calibrated elastic target are listed in Table 7.

Table 7: List of parameters acquired with the calibrated NIR elastic scattering target

Symbols	Definitions	Evaluation Methods
R_0	Distance between the BioSense Core collector aperture stop and the calibrated elastic target	Measure at the CPE using the NIR elastic scattering hard target (or a larger hard target placed at the same position) as the target for the range meter. This measurement will be made by DRDC in collaboration with the contractor.
ΔR_0	Error in the measurement of R_0 measured with the commercial range meter	Derived from the error specified by the manufacturer of the commercial range meter. This information will be provided by DRDC.
χ	Artificial spectral attenuation factor at the NIR wavelength generated by the optical component	Quantity derived from the manufacturer's specifications and/or laboratory measurements made by the contractor at the NIR wavelength.

	inserted in the lidar collector optical path of the BioSense Core	
$\Delta\chi$	Error in χ	This error, provided by the contractor, will be derived from the manufacturer's specifications and/or laboratory measurements made by the contractor.
A_e	Area of the elastic calibration target	Derived by physically measuring the dimension of the area of the calibration target effectively contributing to the elastic returns. This quantity will be provided by DRDC.
ΔA_e	Error associated with the measurement of A_e	Derived from the error associated with the measured dimension of the effective area of the calibration target contributing to the measured elastic return. The evaluation of this error will be provided by DRDC personnel.
n_p	Number of laser pulses fired at the elastic calibration target for a measurement $S_{\lambda_0}^{cal}(\lambda_0, R_0, \Delta R)$.	Quantity provided by the contractor and derived from the BioSense Core instrument during the run of measurements. This parameter should be identical for all measurements of a given run. This parameter, derived from the cloud map sampling interval of 5 meters for the given range, a scanning speed of 3 deg/s and the laser PRF, will be used during the analysis of the CPE to produce $S_{\lambda_0}^{cal}(\lambda_0, R_0, \Delta R)$.
Δt	Electronic time gate interval corresponding to the targeted elastic return	Quantity provided by the contractor and derived from the BioSense Core instrument for a run of measurements. This parameter will be used only as a reference during the analysis of the CPE.
$\Delta(\Delta t)$	Error in the electronic time gate interval	This error is associated with the electronics controlling the transient returns. This quantity should be derived from the technical specifications from the electronic components and reasonable arguments, the two provided by the contractor.
t_{delay}	Electronic time delay	Quantity provided by the contractor and derived from the BioSense Core instrument during a run of measurements. This time delay corresponds to the time interval between the moment a laser pulse leaves the lidar emitter and the moment the transient return corresponding to the calibrated elastic scatters arrives at the lidar collector. This parameter will be used as a reference during the analysis of the CPE.
Δt_{delay}	Error in the electronic time delay	This error is associated with the electronics controlling the transient returns. This quantity should be derived from the technical specifications from the electronic components and reasonable arguments, the two provided by the contractor. This parameter will be used as a reference for the analysis of the measurements.
ΔR	Dimension of the range interval confining the elastic return	Quantity derived from the BioSense Core instrument during the measurements and provided by the contractor. This parameter will be used as a reference for the analysis of the measurements.
γ	Fraction of the laser power incident on the elastic calibration target	Derived by DRDC personnel in collaboration with the contractor by comparing the size of the laser spot at the position of the calibration target (imaged with a NIR camera provided by DRDC) and the size of the calibration target. The laser irradiation divergence Ω_L^{NIR} and laser size propagation model provided by the contractor before the CPE will also be used in this evaluation. An accurate evaluation of this parameter will first require carefully centering the laser beam on the calibration target (or inversely) before a run of measurements.
$\Delta\gamma$	Error in γ	Derived from the precision with which the BioSense scanner is aimed at the calibration target (or inversely), the precision with which the size and intensity profile of the laser spot on the calibration target is derived and the precision of the size of the calibration target.
t_{mea}	Duration of the laser firing period corresponding to a measurement.	Derived from the laser firing pulse repetition frequency, the total number of pulses fired for the measurement and considerations associated with the procedure to sample the radiance and electronic parasitic background contributions. This quantity should be constant for a given run of measurements. The contractor should provide this parameter as well as the methodology to derive it. The background parasitic sampling methodology should be discussed between the TA and the contractor well

		in advance of the CPE.
Δt_{mea}	Error in the evaluation of t_{mea}	Provided by the contractor based on reasonable arguments.
E_{NIR}^{L}	Averaged NIR laser energy per pulse	Quantity to be provided by the contractor based on the BioSense Core monitoring parameters during a run of measurements. This parameter should be approximately constant during a run and will be used as a reference during the analysis of the CPE collected data.
$S_{\lambda_0}^{cal}(tot)$	BioSense transient measurements of the laser induced elastic scatters from the calibrated target plus parasitic background contributions	These are the binned transient returns obtained with the BioSense Core instrument from the measurements when irradiating the elastic calibration target. They result from the elastic scattering from a given number n_p of laser pulses fired at the elastic calibration target and the parasitic background photonic and electronic contributions collected simultaneously. If technically feasible, the provided data should include the transient returns collected with each laser pulse fired. During the analysis, these transient acquisitions will be corrected for the parasitic contributions and then binned to obtain $S_{\lambda}^{cal}(\lambda_0, R)$, the transient measurements associated solely with the laser induced elastic scatters. These corrected transient measurements, once integrated over the time interval corresponding to elastic scatters returned by the calibrated elastic hard target, will form $S_{\lambda_0}^{cal}(\lambda_0, R_0, \Delta R)$ that will be introduced in eq. 42. $S_{\lambda_0}^{cal}(tot)$ will be provided by the contractor.
$S_{\lambda_0}^{cal}(back)$	BioSense core transient measurements estimating the parasitic background contributions within the corresponding $S_{\lambda_0}^{cal}(tot)$	These are the transient returns obtained with the BioSense Core instrument when an acquisition is performed between laser pulses fired at the elastic calibration target. They result only from the parasitic background photonic and electronic contributions and are a close approximation of the parasitic signal collected simultaneously with the laser elastic scatters. If technically feasible, the provided data should include the transient returns collected with each background sampling. During the analysis, these transient returns will be binned and use to correct for the parasitic contribution to obtain $S_{\lambda_0}^{cal}(\lambda_0, R)$, the transient measurements associated solely to the laser induced elastic scatters. $S_{\lambda_0}^{cal}(back)$ will be provided by the contractor.

5.2.4 T&E procedures with the UV elastic channel

5.2.4.1 Acquisitions with bio-agent simulant clouds

The procedure characterizing the UV elastic channels with disseminated bio-clouds will be similar to the one described in Subsection 5.2.2.1 (including the 10 s binning corresponding to a measurement). In fact, it is expected that the two runs of measurements (UV elastic and fluorescence channels) will be performed simultaneously with the same disseminated clouds. However, the parameters to be recorded will be equivalent with those identified in Table 6 (NIR elastic and BG cloud) but for the UV elastic channel with n_p and t_{acq} derived from the duration of a measurement for the inelastic channel (about 10 s binning).

5.2.4.2 Acquisitions with calibrated hard targets

Similarly to the method given in the previous subsection, the procedure required to characterize the UV elastic channels will be greatly similar to the one deployed for the fluorescent channel including the approximate 10 s binned measurement (see Subsection 5.2.2.2). However, the characterization of the UV elastic channel will have to be done apart from the fluorescent channel as it is not targeting the same calibration target. The calibrated elastic hard target for the UV

channel will be the same than the one used for the NIR elastic channel. Furthermore, the parameters that need to be recorded are identical to those identified in Table 7 but for the UV channel with n_p and t_{mea} derived from the duration of a measurement for the inelastic channel (about 10 s binning).

5.2.5 Day/night times sensitivity comparison

To evaluate the change in the sensitivity of the BioSense Core instrument between night and day times, several measurements will be performed. The results will allow characterizing experimentally this property of the BioSense Core instrument. However, these results will not be used to rate the Day Time Capability Parameters stated by the contractor at contract award. The Day Time Capability Parameters rating will be computed by deriving the parameters on the right side of eqs. 43-45 based on the contractor inputs provided before the CPE (see Section 5.1 and Table 1) and by analysis (see Section 4.3 and Subsection 4.3.1).

In the following subsections, a very similar procedure is described for the measurements of the elastic and inelastic channels of the BioSense Core. The difference is essentially the types of the acquired data, one being a transient vector and the other a spectral vector, as discussed in Subsection 4.3.2.

5.2.5.1 Night time sensitivity measurements

For the measurements of the background signals during night time for the two elastic channels and the inelastic channel, the steps describing the measurement process (note that it is expected that no artificial optical attenuation should be inserted in the lidar collector optical path for the night or day time sensitivity measurements) can be detailed as follows:

1. After the BioSense core has been deployed at the desired location and has its optical alignment optimized for the measurements, the field of view of the lidar transmitter is aimed in a direction where little or no artificial light can be visually observed. A short description of the background seen by the instrument should be recorded.

2. The preliminary parameters defining the configuration of the measurement are recorded. These include: the collector channels evaluated (355 nm, NIR or inelastic), the number of pulses n_p (355 nm inelastic and elastic channels (done simultaneously)) – n_p equivalent to 10 s binning, NIR channel – 50 binned pulses when based on a 5 m spatial sampling map, 3 deg/s scanning speed and 500 Hz laser) fired for a measurement, the electronic time-gate interval Δt for the inelastic channel (equivalent to a 20 m range gate for the inelastic channel). For the elastic channels, Δt will be set during analysis of the recorded transient measurements and will reflect a BioSense cloud map sampling interval of 5 m and the typical range gates used with the inelastic channels. The electronic gain κ. The selected BioSense parameters must be identical to those used during the day time sensitivity measurements to enable comparison.

3. While stopping the laser pulses from exiting the BioSense emitter, record a minimum of 30 successive valid measurements with the BioSense collector opened.

4. Repeat step 3 while blocking the optical collector, stopping all radiant signal from reaching the lidar detectors. These measurements, corresponding to the inelastic electronic only signal S_{λ}^{e} and the transient ones corresponding to the elastic signals $S_{\lambda_0,t}^{e}$, will be used to evaluate the

electronics only noise floor $\langle N \rangle_f^e$ of the different collector channels. This step is performed only during night time measurements.

5. Repeat steps 2-4 with two different numbers of binned fired laser pulses n_p (355 nm inelastic and elastic channels (done simultaneously) – n_p equivalent to 5 and 20 s binning, NIR channel – 25 and 100 binned pulses when based on a 5 m linear sampling map at a range of 1 km, 3 deg/s scanning speed and 500 Hz laser).

6. Repeat steps 2-4 with two different electronic time gate durations Δt (inelastic channel only – equivalent to 10 and 50 m range gates).

During the CPE, these night time measurements with the three lidar channels will be performed at least during one night. If time permits, this campaign of measurements may be repeated during another night of the CPE. However, all BioSense configuring parameters should be kept identical, especially in comparison with the day time background noise measurements. This is necessary to compare the day and night time background noise measurements. The parameters and measurements recorded during the night time background noise campaigns are listed in Table 8.

Table 8: List of parameters to be acquired with each background noise measurement at night for the inelastic and the two elastic BioSense Core collection channels

Symbols	Definitions	Evaluation Methods
	Aiming directions	Notes taken by DRDC personnel in collaboration with the contractor describing possible sources of light observed by the field of view of BioSense for the series of measurements.
n_p	Number of laser pulses fired that determines the number of binned acquisitions for a measurement.	Quantity provided by the contractor and derived from the configuration of the BioSense Core instrument during the background noise measurements. This parameter will be used for the analysis of the background noise contributions. The different values of n_p should be selected to cover the intended variation of representative operational configurations of the BioSense staring durations and cloud map sampling interval stated in the description of the procedure of measurements in Subsection 5.2.5.1.
Δt	Electronic time gate intervals	Quantity provided by the contractor and derived from the configuration of the BioSense Core instrument during the inelastic background noise measurements. This parameter will be varied with the measurements for the inelastic channel only and should reflect representative BioSense operational range-gates stated in the description of the procedure in Subsection 5.2.5.1. For the elastic channels, Δt will be selected during the analysis of the transient measurements and should reflect the BioSense cloud map sampling interval of 5 meters.
κ	Electronic gain of the BioSense instrument	The exact value of the electronic gain is not necessary. However, the BioSense configuration determining the value of κ should be known and provided by the contractor. This configuration should be comparable, if not identical, to the electronic gain used during normal BioSense operation. Moreover, it has to be identical to the one used during day time background noise measurements.
S_λ^{BN}	Spectral measurements of the background noise made with the BioSense inelastic channel during night time.	This is the spectral measurement with the inelastic channel of the background noise during night time resulting from n_p binned acquisitions, where n_p is the number of laser pulses fired but that have been stopped from exiting the lidar emitter. This measurement provided by the contractor, once integrated along the spectra, will be used to evaluate the noise floor of the inelastic channel during night time.
S_λ^e	Spectral measurement made with the BioSense inelastic channel to	This is the spectral measurement with the inelastic channel of the background electronic noise with the lidar collector closed and resulting from n_p binned acquisitions, where n_p is the number of laser

	measure the background electronic noise.	pulses fired. This measurement provided by the contractor, once integrated across the inelastic spectral band, will be used to evaluate the electronic noise floor of the inelastic channel.
$S^{BN}_{\lambda_0,t}$	Transient measurement made with a BioSense elastic channel during a measurement of the night time background noise.	These are the transient signal of the measurements of the background signal contributions for the BioSense elastic channel at 355 nm and the NIR wavelength resulting from n_p binned acquisitions, where n_p is the number of laser pulses fired but that have been stopped from exiting the lidar emitter. It reports multiple measurements with a time sampling interval Δt that will be set during the analysis of the measurements and where the selected Δt will reflect the 5 meter BioSense cloud map range sampling interval. This vector provided by the contractor, once averaged along the time interval of valid transient signal, will be used to evaluate the noise floor of the elastic channels during night time.
$S^{e}_{\lambda_0,t}$	Transient measurement made with a BioSense elastic channel to measure the background electronic noise.	These are the transient signal of the measurements of the background electronic noise contributions with the lidar collector closed for the BioSense elastic channel at 355 nm and the NIR wavelength. These measurements result from n_p binned acquisitions, where n_p is the number of fired laser pulses. It reports multiple measurements with a time sampling interval Δt that will be set during the analysis of the measurements and where the selected Δt will reflect the 5 meter BioSense cloud map range sampling interval. These measurements provided by the contractor, once averaged along the time interval of valid transient signal, will be used to evaluate the electronic noise floor of the elastic channel.

5.2.5.2 Day time sensitivity measurements

For the measurements of the background signals during the day time for the two elastic channels and the inelastic channel, the steps describing the measurement process is similar to the one used for the night time sensitivity measurements (see Subsection 5.2.5.2). The main issue, since the objective is to compare the noise floors between day and night times, is to use the same BioSense instrument configuration as the one that was used during night time sensitivity measurements (see the previous subsection). The steps to execute are as follows:

1. After the BioSense core has been deployed at the desired location and has its optical alignment optimized for the measurements, the field of view of the lidar transmitter is aimed in a direction with a representative background. The selected background scenes should reflect some variability that may be encountered during normal operation of the BioSense instrument. Examples are landscapes with variable radiances and blue/covered sky. If possible, the acquisitions with a spectroradiometer should be made while point at the same/similar background scene seen by BioSense. A short description of the background seen by the instruments should be recorded for each runs of measurements.

2. The preliminary parameters defining the configuration of the measurements are recorded. These include: the collector channels evaluated (355 nm, NIR or inelastic), the number of pulses n_p (355 nm inelastic and elastic channels (done simultaneously)) – n_p equivalent to 10 s binning, NIR channel – 50 binned pulses when based on a 5 m linear sampling map, 3 deg/s scanning speed and 500 Hz laser) fired for a measurement, the electronic time-gate interval Δt for the inelastic channel (equivalent to a 20 m range gate for the inelastic channel). For the elastic channels, Δt will be set during analysis of the recorded transient measurements and will reflect the BioSense cloud map sampling linear interval of 5 m and the typical range gates used with the inelastic channels. The electronic gain κ will also be recorded. The selected BioSense parameters must be identical to those used during the night time sensitivity measurements for data comparison.

3. While stopping the laser pulses from exiting the BioSense emitter, record a minimum of 30 successive measurements with the BioSense collector opened.

4. Repeat steps 2-3 with two different numbers of binned fired laser pulses n_p (355 nm inelastic and elastic channels (done simultaneously) – n_p equivalent to 5 and 20 s binning, NIR channel – 25 and 100 binned pulses when based on a 5 m linear sampling map at a range of 1 km, 3 deg/s scanning speed and 500 Hz laser).

5. Repeat steps 2-3 with two different electronic time gate durations Δt (inelastic channel only – equivalent to 10 and 50 m range gates).

6. Repeat steps 1-5 for a different aiming point (to be performed during day time only, the two aiming points should target sky and earth background scenes).

During the CPE, these day time measurements with the three lidar channels will be performed during at least one day. The time of day of the measurement must be recorded. If possible, some efforts should be deployed to aim a spectroradiometer at the scene, or an equivalent scene, seen by the BioSense lidar during measurements. If time permits, this campaign of measurements may be repeated at different times of the day or different days during the CPE where ambient lighting may differ. However, only slight changes in the scenes seen by the BioSense instrument should occur between these day time measurements, keeping all other BioSense configuring parameters identical to those used during background noise measurements made during night time. This is necessary for comparison with the night time background noise measurements which must be done under the same BioSense Core instrumental configuration. The parameters and measurements recorded during the day time background noise measurements are listed in Table 9.

Table 9: List of parameters to be acquired with each background noise measurements during day time for the inelastic and the two elastic BioSense Core collection channels

Symbols	Definitions	Evaluation Methods
	Aiming directions	Notes taken by DRDC in collaboration with the contractor describing the scene seen by the field of view of BioSense for the series of measurements.
n_p	Number of laser pulses fired that determines the number of binned acquisitions for a measurement.	Quantity provided by the contractor and derived from the configuration of the BioSense Core instrument during the background noise measurements. This parameter will be used for the analysis of the background noise contributions. The different values of n_p should be selected to cover the intended variation of representative operational configurations of the BioSense staring durations and cloud map linear sampling interval stated in the description of the procedure of measurements in Subsection 5.2.5.2.
Δt	Electronic time gate intervals	Quantity provided by the contractor and derived from the configuration of the BioSense Core instrument during the inelastic background noise measurements. This parameter will be varied with the measurements for the inelastic channel only and should reflect representative BioSense operational range-gates stated in the description of the procedure in Subsection 5.2.5.2. For the elastic channels, Δt will be selected during the analysis of the transient measurements and should reflect the BioSense cloud map linear sampling interval of 5 meters.
κ	Electronic gain of the BioSense instrument	The exact value of the electronic gain is not necessary. However, the BioSense configuration determining the value of κ should be known and provided by the contractor. This configuration should be comparable, if not identical, to the electronic gain used during normal BioSense operation. Moreover, it has to be identical to the one used during night time background noise measurements.

S_{λ}^{BD}	Spectral measurements of the background noise made with the BioSense inelastic channel during night time.	This is the spectral measurement with the inelastic channel of the background noise during day time resulting from n_p binned acquisitions, where n_p is the number of laser pulses fired but that have been stopped from exiting the lidar emitter. This measurement provided by the contractor, once integrated along the spectra, will be used to evaluate the noise floor of the inelastic channel during day time.
$S_{\lambda_0,t}^{BD}$	Transient measurement made with a BioSense elastic channel during a measurement of the day time background noise.	These are the transient signal of the measurements of the background signal contributions for the BioSense elastic channel at 355 nm and the NIR wavelength resulting from n_p binned acquisitions, where n_p is the number of laser pulses fired but that have been stopped from exiting the lidar emitter. It reports multiple measurements with a time sampling interval Δt that will be set during the analysis of the measurements and where the selected Δt will reflect the 5 meter BioSense cloud map range sampling interval. This vector provided by the contractor, once averaged along the time interval of valid transient signal, will be used to evaluate the noise floor of the elastic channels during day time.

6 Conclusion

In this memorandum, the modelling considerations that identify the key parameters to acquire during the Critical Prototype Evaluation (CPE) have been described. These modelling considerations address the evaluation of the BioSense Core prototype and the associated errors in evaluated parameters with three sets of tests. The first set consists in challenging the core version of the prototype with well characterized aerosolized simulants of bio-agents using the lidar adapted bioaerosol chamber developed at DRDC Suffield under the BioSense TDP. The objective with this first test set is to demonstrate that the prototype has a sensitivity in concentration better than 20 Agent Content Particles per Litre of Air (ACPLA) at four times the standard deviation of the noise floor for a 10 meter thick aerosol cloud located at a range of 1 km and composed of Bacillus Globigii (BG), a simulant of bio-agents like Anthrax, having an average diameter of 3 μm. This is the main criterion to be evaluated at the CPE and will determine whether or not the project will continue. The second set of tests consists in challenging the prototype with well calibrated scattering hard targets and atmospheric nitrogen. The objective of this second test set is to assess the radiometric capacity of the instrument in order to confirm that the technical rated parameters evaluated experimentally correspond, within acceptable errors, to those projected by the contractor at contract award. This second set is also a risk mitigation of the main objective associated with the first test set, if weather during the CPE (planned to be held around November 2008) is not cooperative. The last set of tests consists in comparing the background clutter between night and day time measurements in order to assess the sensitivity degradation of the prototype during day time operations in comparison with night time operations. In addition to detailing the parameters to acquire during the CPE and the models necessary to define and understand these parameters, this document also describes the procedures to acquire these parameters. This document should form the bases in the preparation of the CPE Test Plan and the analysis of the data acquired at that occasion. If the details provided in the present document conflict with those of the CPE Test Plan, those in the present document should prevail.

References

[1] The NIST Reference on Constants, Units and Uncertainty, internet link: http://physics.nist.gov/cgi-bin/cuu/Value?klsearch_for=Boltzman .

[2] R. M. Measures, “Laser Remote Sensing: Fundamentals and Applications”, John Wiley & Sons, Inc., Chap. 3.5.2, 1984.

[3] Jean-Robert Simard, 'Short-range bioaerosol lidar detection: Transmitter design and sensitivity analysis', DRDC Valcartier TM 2005-303, August 2006, Unclassified.

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List of symbols/abbreviations/acronyms/initialisms and specific definitions

ACPLA	Agent Contained Particle per Litre of Air
APS	Aerosol Particle Sizer
CCD	Charged Coupled Device
CF	Canadian Forces
CPE	Critical Prototype Evaluation
DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
INO	Institut national d'optique
lidar	LIght Detection And Ranging
LIF	Laser Induced Fluorescence
MDA	MacDonald Dettwiler and Associates
NIR	Near InfraRed
ppl	Particle Per Litre
R&D	Research & Development
SINBAHD	Standoff Integrated Bioaerosol Active Hyperspectral Detection
T&E	Test & Evaluation
TA	Contract Technical Authority.
acquisition	Data acquired by the BioSense Core resulting from a single laser pulse fired or a single parasitic background sampling.
measurement	Result from the binning of multiple acquisitions or the arithmetic operation of multiple binned acquisitions (in the case of the polarized transient returns).
run	Successive measurements performed during a period of time.

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Introduction ou contexte: Défense Recherches et Développement Canada a récemment initié le développement et la construction d'un Projet de Démonstration Technologique visant le développement et la construction d'un système de détection, de cartographie, de poursuite et de classification à distance de bioaerosols (BioSense). BioSense est un capteur basé sur les technologies lidar et de Fluorescence Induite par Laser (FIL) et est construit afin de détecter les nuages de bioaerosols avec une portée de 5 km ou plus. En novembre 2008, la partie centrale de l'instrument BioSense sera soumise à une Évaluation Critique du Prototype (ECP), une évaluation contractuelle intermédiaire des performances, afin de vérifier qu'il rencontre les exigences minimums de sensitivités.

Résultats: Ce document s'attaque aux concepts de modélisation qui dicte la méthode expérimentale qui sera utilisée afin d'évaluer les capacités de BioSense à détecter le Bacillus Globigii (BG) sous forme d'aérosols ayant 3 □m et formant un nuage de 10 mètres d'épais et d'une concentration moyenne de 20 ACPLA à une portée de 1 km. Il établit aussi, en détails, les considérations expérimentales ainsi que la méthodologie qui sera utilisées afin d'exécuter l'évaluation et la qualification des paramètres techniques contractuelles de BioSense.

Importance: L'ECP constitue un jalon contractuel tout-ou-rien du Projet de Démonstration Technologique et du développement contractuel du capteur BioSense. L'approche proposée combine les notions fondamentales lidar et FIL, des défis sous forme de nuages de bioaerosols et des mesures faites à partir de capteurs locaux de référence afin de mesurer les performances de sensitivité du capteur durant la nuit et le jour, des erreurs associés ainsi que démontrer sa capacité à détecter un bio-nuage de BG ayant une épaisseur de 10 mètres et une concentration moyenne de 20 ACPLA pour une portée de 1 km.

Perspectives: Un plan de test détaillé de l'ECP sera produit d'ici quelques mois suite aux considérations rapportées dans ce document. Assument une réussite satisfaisante de l'ECP, le développement de BioSense sera autorisé à continuer avec une livraison finale anticipée en mai 2009. Les pleines capacités de BioSense seront évaluées durant des essais en champs en été/automne 2009.

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BioSense, bioaerosol, standoff, Lidar, LIF, spectrometry, radiometry

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