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# Description of the Area Detection and Identification System (ADIS) bid evaluation laboratory test

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**Prepared for:** Daan Beijer, DPM, Chemical Agent Sensors (DCSEM)



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## Context

The Area Detection and Identification System (ADIS) project [1] is a Department of National Defence (DND) procurement program that aims to provide the Canadian Armed Forces (CAF) with stand-off chemical sensors for area protection and early warning. It is expected that DND will receive several bids from various vendors, which will have to be evaluated. As sensor performance depends on a multitude of parameters [2], it is desirable to have all sensors subjected to the same performance tests in order to be unequivocally compared. Defence Research and Development Canada (DRDC) has been tasked by Director Combat Support Equipment Management (DCSEM) to design and implement a laboratory test to evaluate the sensitivity of each ADIS candidate. This document presents an overview of the planned laboratory test.

## Objectives

The laboratory test described in this document will be used primarily to evaluate the sensitivity of the ADIS sensor candidates, using a simple setup that can be easily replicated so that all sensors are tested in the exact same conditions. The test also includes several repetitions of the same manipulations, allowing the accumulation and computation of statistics about each sensor's probability of detection at different signal strength levels.

The strength of the signal coming from a sample is affected by a variety of parameters. In the proposed test, some of these parameters are fixed (such as the viewing geometry and sample concentration) while others can be adjusted (such as the thermal contrast and nature of the sample). Adjusting thermal contrast and using different samples will help find the detection limits of each sensor.

## Methodology

The test presented in this document is very similar to the laboratory phase for the 2008 ADIS Invitational Performance Trials (IPT) [3] and will use the same basic setup, equipment and location. The methodology has been slightly updated so that the test is now blind.

## Setup

The test setup consists in a gas cell placed in front of a temperature-controlled plate. The sensor under test aims at the plate through the gas cell, probing its content. A mask is used to hide and then reveal the gas cell at each test event. The sensors will not be scanning during the test. The setup is illustrated at Figure 1.

The gas cell is a stainless steel Cylinder, 5 cm in diameter and approximately 15 cm in length, offering a 10 cm internal optical path. Each end is composed of a KBr window offering good transmittance in the LWIR band[1]. Ports allow the cell to be connected to a vacuum pump in order to be purged, then injected with a known amount of sample gas, and filled up with nitrogen to standard atmospheric pressure. Volatile liquid-phase samples can also be injected in the cell using a syringe. A thermocouple measures the temperature of the gas inside the cell. Concentration into the gas cell is adjusted using pressure readings from a manometer or volume readings from the syringe.

In order to simulate the viewing geometry of a 50 m cloud at a range of 3 km, the sensor is placed 3 m away from the 5 cm-wide gas cell. Concentration inside the gas cell will be adjusted so that the product of the peak aborbance cross-section of the sample gas, the optical path inside the cell, and the concentration inside, corresponds to the ADIS requirement for sarin (GB). Thus:

$$
\begin{aligned}
(\alpha CL)_{\mathrm{GB}} &= (\alpha CL)_{\mathrm{cell}} \,, \\
C_{\mathrm{cell}} &= \frac{(\alpha CL)_{\mathrm{GB}}}{(\alpha L)_{\mathrm{cell}}} = C_{\mathrm{GB}} \cdot r_L \cdot r_\alpha \,,
\end{aligned}
$$

where

$$
r_L = \frac{L_{\mathrm{GB}}}{L_{\mathrm{cell}}} \quad \text{and} \quad r_\alpha = \frac{\alpha_{\mathrm{GB}}}{\alpha_{\mathrm{cell}}} \,.
$$

In the previous equations, $\alpha$ denotes peak absorbance cross section, $C$ is concentration and $L$ is the optical path, while index “GB” denotes the value in the ADIS requirements for sarin detection and index “cell” denotes values found in the gas cell. The ratios of peak absorbances and optical paths are noted $r_\alpha$ and $r_L$. The ADIS mandatory detection level for sarin is given as a column density of 135 $\mathrm{mg/m^2}$. For a 50 m cloud, this translates into a concentration of $C_{\mathrm{GB}} = 2.7\ \mathrm{mg/m^3}$. The optical path ratio is $r_L = 50/0.1 = 500$. Values for $r_\alpha$ are provided for each sample in Table 1. Peak absorbances are evaluated in the 700–1300 $\mathrm{cm^{-1}}$ wavenumber range on absorbance spectra resampled to 1 $\mathrm{cm^{-1}}$ resolution (0.48 $\mathrm{cm^{-1}}$ spectral bin spacing). If the required concentration cannot be reached in a gas cell for a given sample, the thermal contrast will be adjusted to provide the same equivalent density-contrast product.

The temperature-controlled plate is approximately 1 square foot (0.093 $\mathrm{m^2}$), made in aluminum painted with high emissivity black Krylon so as to present a surface close to an

[1] Gas cells may also be fitted with KCl windows.

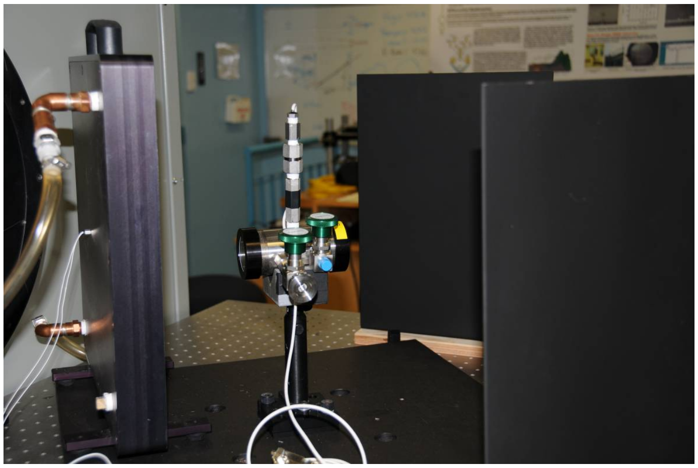

***Figure 1:*** *Laboratory test setup. On the left, the temperature-controlled aluminum plate is seen with tubes for ethylene glycol circulation and thermocouple wiring in the back. In the center, the stainless steel gas cell contains the gas sample. Ports allow for purging and filling the cell; a thermocouple measures the temperature inside. On the right, painted aluminum plates allow to hide the gas cell from the sensor.*

ideal black body. The plate might be either heated or cooled using ethylene glycol circulation, providing positive or negative thermal contrast with respect to the gas sample. An infrared thermometer will be used to monitor the surface temperature of the plate independently from its control set point.

## Test sequence

Testing is divided into a series of test *events*. For each event, a gas cell is chosen that might include one of the possible samples (see Section 4) or a blank cell containing only nitrogen (no gas sample), and is placed in the setup. The nature of the cell sample is not revealed to the sensor operator. The gas cell is then revealed to the sensor. The sensor operator must announce within one minute whether the sensor alarmed or not, and if so, for which substance. The result is deemed a *success* if the sensor did not alarm on the nitrogen-only gas cell, or if the alarm was for the correct substance. The result is deemed an *error* otherwise. The success rate is computed as the ratio of successes over the total number of events for a given thermal contrast level. Both false alarms and mis-identifications are thus treated as errors, and true negatives are included in this metric.

Up to 30 events are recorded for each thermal contrast tested. The test will include both positive and negative thermal contrasts in order to generate both absorption and emission lines from the sample. The test will start with a thermal contrast sufficient for the sensor to alarm and above the ADIS requirement value of 2 K, after which thermal contrast will be reduced until either the sensor cannot alarm anymore, or the precision of the temperature control is reached. The event results will be used to compute an estimated detection probability and confidence interval for each thermal contrast level. Thus, it is expected that every passive sensor will experience an increasing number of *error* results as thermal contrast is reduced. The overall results will only be shared with the corresponding sensor vendor and won't be made public. They will be used within the ADIS project to verify if the sensors satisfy performance requirements.

A full day per sensor is reserved for the test, with a backup day reserved for fixing technical issues. The exact test schedule is yet to be determined. The test will be held at DRDC – Valcartier Research Centre in Quebec City, Canada. It is expected that each vendor will operate their sensor during the laboratory tests.

### Limitations

While the test is designed to be as fair as possible, no setup is perfect, and the setup presented herein poses certain limitations.

For imaging sensors, focus might be fixed or impossible to adjust at the 3 m distance. This might lead to a blur of the gas cell window image, spreading the signal over multiple pixels. If this is an issue for a sensor, this might be taken into account by first evaluating the blur spot and adjusting the thermal contrast in order to simulate a focused cloud.

The setup completely neglects atmospheric absorption, but will do so equally for each sensor. In the same manner, the test does not offer an accurate representation of typical background clutter, and as such is not a stress test for detection algorithms. Sensor operation (ease of use, setup time, etc.) will not be evaluated in this test either.

This test is primarily aimed at evaluating passive sensors. The test will probably need to be modified to accommodate active sensors, for which signal strength is independent of thermal contrast. Active sensors might be tested by successively decreasing gas concentration in the gas cell instead. Issues related to illumination of the gas cell by the active sensor emitter (laser or otherwise) are expected and will have to be solved for each active sensor.

## Samples

Up to 5 gas cells will be used for the test, including the blank (nitrogen-only) cell. The gas samples used in the test will be picked from the list of Table 1. No gas sample mixture will be tested. Absorbance cross-section spectra will be made available to vendors for each of these substances if the sensor's library does not already include it. Vendors should notify DRDC if it is impossible to add the sample signature to their sensor's library, or if another issue prevents the sensor from working properly with one of these substances.

## Conclusion

The laboratory test presented in this document is believed to be simple, rapidly executed and fair to all vendors. It will allow computation of statistics leading to probability of detection figures associated with a confidence interval, and an accurate determination of sensor sensitivity and detection limits. A more extensive field test would be necessary to test other aspects of stand-off detection, such as the capacity for sensors to find a real gas cloud at long range in a realistic environment.

*Table 1: List of possible test substances.*

| **Substance** | **Other names** | **CAS number** | $r_\alpha$ |
|---|---|---|---|
| F-134a | 1,1,1,2-Tetrafluoroethane, R-134a | 811-97-2 | 1.34 |
| F-152a | 1,1-Difluoroethane, R-152a, DFE | 75-37-6 | 1.21 |
| F-125 | Pentafluoroethane, R-125 | 354-33-6 | 1.04 |
| F-22 | Chlorodifluoromethane, R-22 | 75-45-6 | 1.12 |
| $SF_6$ | Sulfur hexafluoride | 2551-62-4 | 0.0845 |
| $NH_3$ | Ammonia | 7664-41-7 | 2.14 |
| TEP | Triethyl phosphate | 78-40-0 | 0.503 |
| DMMP | Dimethyl methylphosphonate | 756-79-6 | 1.11 |

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## References

[1] Public Works and Government Services Canada (2018), Area Detection and Identification System (ADIS) Project (W8476-145109/B) Tender Notice. Letter of Interest (LOI) / Request for Information (RFI). https://buyandsell.gc.ca/procurement-data/tender-notice/PW-18-00829424.

[2] Bouffard, F. and Thériault, J.-M. (2018), Answers to an inquiry regarding the 2018 Area Detection and Identification System (ADIS) Request For Information (RFI), (DRDC-RDDC-2018-L223) Defence Research and Development Canada.

[3] Thériault, J.-M., Lavoie, H., Dubé, D., and Lacasse, P. (2008), Area Detection and Identification System - Invitational performance trial plan, (Technical Memorandum TM 2008-120) Defence R&D Canada — Valcartier.

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