Defence, Safety & Security
www.tno.nl
+31 88 866 80 00
info@tno.nl

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Observer report regarding field tests with an upgraded FALCON 4G stand-off detector

Author(s)	ing. J.A. van der Meer, Dr. ir. M.J. van der Schans
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Contents

1 Introduction

SEC Technologies is a company stationed in Liptovsky Mikulas (Slovakia) with roots in military research institute in Slovakia that develops and manufactures laser based active stand-off equipment for the detection of chemical threat at long distances (up to 6 km).
In 2016, at the request of SEC Technologies, TNO visited SEC Technologies for the first observation exercise. The results were published in TNO report TNO 2016 R11290.

In 2019 TNO was requested to act as a smart observer during field testing at large distance by SEC Technologies of their long- range active stand-off detector model Falcon 4G.

On the 18th and 19th of July 2023 two TNO employees (authors of this report) visited SEC Technologies to witness field tests with the aim to demonstrate the application of the newly developed Multi-Line detection algorithm. Basically, two types of experiments were performed. The first type of experiment was performed by placing a PVC tube (gas cell) filled with a chemical in front of the optical receiver of the Falcon 4G and demonstrated the detector's ability to selective detect five different chemicals. The second experiment involved the selective detection of Ammonia and Methanol released at a distance of 1600 m.

In this report TNO provides its findings. It should be noted that TNO did not act as the experiment leader, it did not qualify, let alone certify, the experimental set-up as well as the execution of the tests or the detecting achievements of the FALCON 4G as a product, i.e. TNO was primarily a (smart) observer.

2 Experiments

2.1 Short description of the Falcon 4G Long-Range Active Stand-off Chemical Detector test setup

The Falcon 4G (Figure 2.1) is a 4th generation laser-based Chemical stand-off chemical detector, that can, according to SEC Technologies, detect, identify and quantify chemical warfare agents and toxic industrial chemicals using the absorption of laser radiation caused by molecules of agents.

Figure 2.1: The SEC Technologies Falcon 4G.

For the field demonstration a R&D Falcon 4G version was used, loaded with the newly developed ‘Multi-Line’ detection Algorithm. This algorithm was developed to allow automatic discrimination between a pre-set selection of chemicals, using multiple relevant spectral lines. By making use of 20 spectral lines a unique spectral profile was obtained. That facilitated the determination of the presence and concentration of a chemical in the line of sight.

2.2 Demonstration location

The Falcon 4G detector was positioned inside the SEC Technologies building in front of an open window with a clear line of sight. The detector was aimed at three different target locations (backgrounds):

1. A pine tree at 500 m distance;
2. A chimney at 1750 m distance;
3. A tent at 1600 m distance.

Figure 2.2 shows an aerial photo of the target locations.

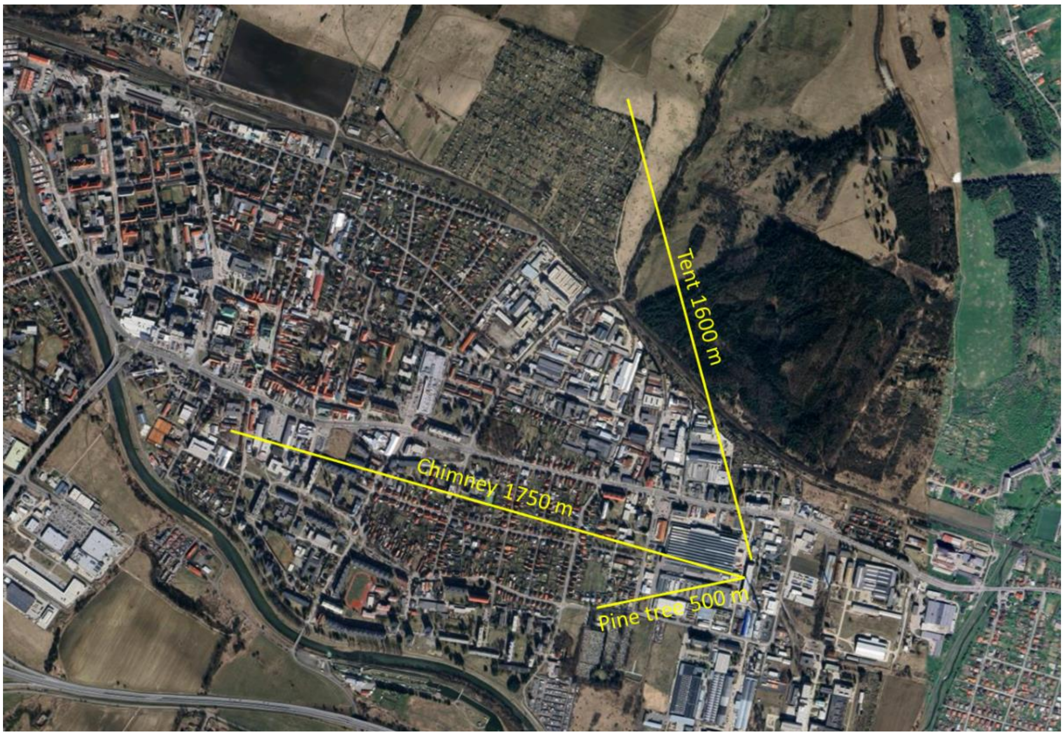


Figure 2.2: Map of Liptovsky Mikulas indicating the lines of sight used for the experiments (map: Google Maps).

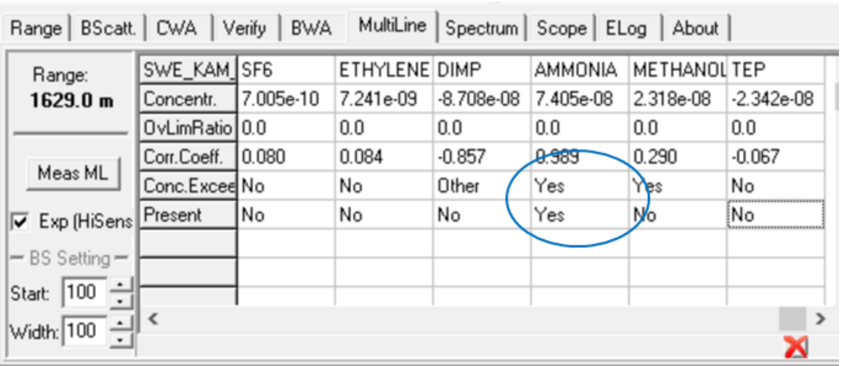
2.3 Measurements using the gas cell with various chemicals.

The first set of experiments involved the selective detection of five chemicals using a library that contained 10 chemicals. The Falcon 4G was connected to a laptop for live display of the algorithm output. The algorithm was evaluating the presence of the following chemicals in the total line of sight:

1. Tabun (GA)
2. Soman (GD)
3. Sarin (GB)
4. Sulfur Mustard (HD)
5. SF_6*
6. Ethylene*
7. Diisopropyl methylphosphonate (DIMP)
8. Ammonia (NH_3)*
9. Methanol (MeOH)*
10. Triethyl phosphate (TEP)*

*Chemicals used for the demonstration

The output of the detectors algorithm resulted in a list for each chemical displaying the calculated average concentration over the pathlength (grams/L, L=10 x 10 x 10 cm), correlation coefficient, whether the concentration exceeded the threshold concentration and the likelihood of a chemicals presence (Yes, No, Maybe) (Figure 2.3).



SWE_KAM	SF6	ETHYLENE	DIMP	AMMONIA	METHANOL	TEP
Concentr.	7.005e-10	7.241e-09	-8.708e-08	7.405e-08	2.318e-08	-2.342e-08
OvLimRatio	0.0	0.0	0.0	0.0	0.0	0.0
Corr.Coeff.	0.080	0.084	-0.857	0.989	0.290	-0.067
Conc.Excee	No	No	Other	Yes	Yes	No
Present	No	No	No	Yes	No	No

Figure 2.3: Example for the output of the Multi-Line Algorithm displaying the presence of NH_3 over a measured distance of 1629 m.

After the startup of the detector (within 3-4 minutes) the detector was aimed at the reflecting background that was needed for the demonstration using a scope (see Figure 2.4). When the target was found first, a series of test measurements without chemicals were conducted to verify the distance of the path length and to exclude of false positives while measuring against the background.

Figure 2.4: A scope was used to aim the detector to a reflecting background, in this case a chimney at 1750 meters.

For the actual identification experiments, a gas cell (PVC tube, 1.2L internal volume) filled with the chemical vapor of interest was placed in front of the optical receiver of the Falcon 4G (Figure 2.5). The tube was closed at both ends with polyethylene screens in order to contain the chemical vapors inside the tube. The chemicals were introduced into the tube using a small syringe for both liquids and gas via a small opening that was closed after injection of the respective chemical (Table 2.1).
No measures were taken to homogenize and/or actively evaporate the injected chemical. Since experiments were performed at approximately room temperature, most chemicals did not completely evaporate while performing experiments.
No qualitative and quantitative measurements were performed to check concentration and identity of the chemical. TNO solely recorded the information provided on the label of the flasks used. After a short 'stabilization' time of a few minutes (not registered) the tube was installed in front of the detector' optical receiver Figure 2.5) for a measurement. The benefit of using a gass cell (PVC tube) in front of the optical receiver is that the laser pulse travels the full distance from source to the reflective surface and back while passing the chemical 'cloud' in the cell only on its return path to the detector. This approach offers a constant length of cloud for which the location has no effect on the results. Also, since under realistic conditions the laser would pass a chemical cloud twice meaning the sensitivity would be two times better compared to the reference cell method.

Table 2.1: Volumes used for spiking

Chemical	Concentration	Volume	Form
Methanol	>98%	30 µL	Liquid
Ammonia	25%	30 µL	Water solution
SF6	>98%	0.6 mL	Gas
Ethylene	>98%	6 mL	Gas
Triethyl phosphate	>98%	0.5 mL	Liquid

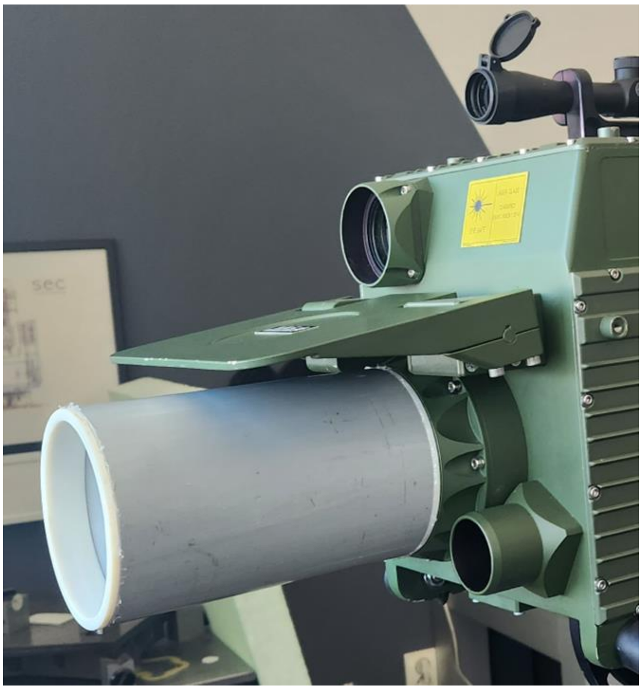


Figure 2.5: Gas Cell (PVC tube) installed in front of the Falcon 4G 'detector' optical receiver.

2.4 Measurements using open air releases.

A series of experiments was conducted to demonstrate the ability to use the Multi-Line algorithm over large distance using an uncontrolled open air release. For this setup a different target was used that allowed the installation of a tent (3 x 3 x 2 m) to shortly retain vapor in the line of sight (Figure 2.6). The distance covered was approximately 1600 m.

Figure 2.6: Falcon 4G (left) pointed on a tent installed on hill side for open air releases (right).

The chemicals Ammonia and Methanol were evaluated over the course of two days.
On the first, day both chemicals were released in the open tent. On the second day, experiments with Ammonia were conducted in a background of diesel car exhaust to demonstrate the ability to discriminate between strong relevant background and the actual chemical present.

Vapor was generated by introducing liquid Methanol (>98%) and Ammonia (25% in water) into a plastic tray (approximately 25 x 20 cm) that was positioned inside the tent. An amount of 300ml was poured onto the tray. Liquids were left to evaporate by influence of the local weather conditions (25C°, 35% RH, 0.5-2 m/s windspeed). After about two minutes, the measurements were started. Prior to each release, a background measurement was taken to ensure a negative response for the chemical to be released. When sufficient data was gathered the tray with, the chemical was removed from the tent, and the tent was fully opened to ensure a swift cleanout.

For the measurements performed in the presence of diesel exhaust, a car with a EURO 6 diesel engine was positioned with the exhaust of the car into the tent, which was closed on three sides (Figure 2.7).
The car was started with the gearbox in neutral position. Then for 6 minutes the engine was run at around 2000 rpm to ensure sufficient exhaust release in the tent. The car was removed and immediately a ‘car blank’ measurement was taken to check for false positives. Subsequently the car was put back in the tent on the right-hand side of the tent to add new exhaust fumes with a running engine, while introducing Ammonia (150 mL, 25% in water) in a tray. Measurements were taken, and after the tent was opened to clean out the fumes. Before the exhaust experiments, a single release of Ammonia was performed as a positive control.

Figure 2.7: Creating a diesel exhaust background in the tent.

3 Results

3.1 Measurements with gas cell

All data used for evaluation can be found in Appendix A. The blank measurements performed prior to or between exposures all resulted in ‘no detection’ responses for all listed chemicals, indicating no false positives. Apparently, chemicals that were in the air during these blank measurements, such as car exhaust or industrial fumes crossing the line of sight, did not have overlapping ‘lines’ that resulted in false alarms. The presence of a liquor factory nearby also did not elicit a response for methanol.

The presence of methanol itself was correctly detected. Methanol and sarin have partially overlapping spectral lines used for identification. With the selection of relevant spectral lines entered in the algorithm, the system was able to discriminate the presence of methanol from the presence of sarin.

Ammonia, SF6 and ethylene all showed positive identification for their respective chemicals. False positives were not recorded. Quantitative values were recorded during the experiments, but since the concentration in the cell was unknown, these values were not incorporated in the report. The positive identification of the chemicals proved that both the concentration threshold and correlation factors exceeded the minimum values of the algorithm, resulting in ‘yes’ for the presence of the introduced chemical.

Since TEP does not evaporate very quickly, the first two measurements over 1750 meters were inconclusive. Even though the concentration of TEP measured exceeded the threshold, the correlation factor was too low to confirm the presence of TEP. Allowing TEP the chance to evaporate, the last measurement resulted in both a good correlation factor and exceeding the concentration threshold, yielding a ‘yes’ for detection of TEP as output. The concentration threshold may be selected to critical to allow for good correlation. Alongside a ‘maybe’ or ‘yes’ response for TEP also GA had similar responses. The representative spectral lines overlap too much to discriminate between the two chemicals.

3.2 Measurements with open air releases

The blank experiments, recorded by pointing at the ‘empty’ tent, resulted in ‘No’ chemicals present for all ten components in the list. The Ammonia release resulted in a series of two measurements with sufficient concentration to confirm presence without false negatives. Before the concentration was sufficiently increased in the tent, the results of some other chemicals resulted in near false positives but were resulting in ‘No’ chemical present due to a low correlation factor.

The Methanol release resulted in a series of ‘Yes’ outputs for Methanol. However, since these experiments were conducted using an older version of the algorithm (before MeOH optimization) also GB was detected with ‘Maybe’ and also after addition of extra MeOH ‘Yes’ outputs. For the ‘tube experiments’ a newer version of the algorithm was used that resolved this issue. However, no additional experiments were conducted with MeOH releases after the update of the algorithm.

Since exhaust gases coming from cars/trucks helicopters etc., are a common chemical background in the neighborhood of a detector. On request of TNO, additional experiments were conducted to demonstrate the detector's ability to find the presence of the listed chemicals in a strong exhaust background.
As described in Chapter 2.4, a diesel car was used to create the background in the tent. Before these experiments were performed, a blank experiment was conducted resulting in 'No' chemicals present. A release of Ammonia was also performed to check the functioning of the system. This gave 'Yes' for Ammonia and further no chemicals were found giving sufficient confidence to proceed with the car exhaust experiments. The experiment performed with a tent filled with car exhausts resulted in a series of six measurements with only two registrations of 'Maybe' for both GA and Ammonia. Due to a low correlation factor these measurements both did not result in identification. When Ammonia was released in the tent while the car was still emitting exhaust fumes a series of five measurements were recorded resulting in 'Yes' Ammonia is present. No other chemicals were reported.

4 Conclusion

SEC Technologies have successfully demonstrated the new 'Multi-Line algorithm, used with Falcon 4G to TNO personnel during a 2-day field test session at distances ranging from 500 meters to 1750 meters. TNO concludes that, based on the observed set of experiments employing the chemicals Methanol, Ammonia, SF_6, Ethylene and Triethyl phosphate the new Multi-Line algorithm is able to discriminate between a background and the presence of the listed chemicals, whether the chemical is at 0 distance or at the end of the measurement path. This conclusion also holds when a background of diesel car exhaust was introduced in combination with an Ammonia release in the field. The updated algorithm had successfully mitigated false alarms on CWA, as no false alarms were detected apart from the 'maybe' outcome for Tabun during the TEP experiments, which can be explained by the strong overlapping spectra of both substances. There were no false negatives observed. Since the algorithm was still under development when the observations took place, the outcomes may be different when a new modification of the algorithm is implemented.

Signature

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Dr.ir. A.M.J. Kliphuis
Research manager

Ing. J.A. van der Meer
Author

Appendix A
Data acquired during experiments

Table A.1: Table of acquired results limited to the actual detection of the listed chemicals as described under 2.2. Output values were Yes/No/Maybe.

Measurement #	Chemical	Type	Distance (m)	Background	Tabun	Soman	Sarin	HD	SF6	Ethylene	DIMP	Ammonia	Methanol	TEP	Remarks
1	Blank	Cell	502	Pine	No	No	No	No	No	No	No	No	No	No	
2	Ammonia	Cell	502	Pine	No	No	No	No	No	No	No	Yes	No	No	
3	Ammonia	Cell	1750	Chimney	No	No	No	No	No	No	No	Yes	No	No	
4	SF6	Cell	1750	Chimney	No	No	No	No	Yes	No	No	No	No	No	
5	SF6	Cell	502	Pine	No	No	No	No	Yes	No	No	No	No	No	
6	Ethylene	Cell	502	Pine	No	No	No	No	No	Yes	No	No	No	No	
7	Ethylene	Cell	1750	Chimney	No	No	No	No	No	Yes	No	No	No	No	

8	TEP	Cell	1750	Chimney	Maybe	No	No	No	No	No	No	No	No	Maybe	
9	TEP	Cell	1750	Chimney	Maybe	No	No	No	No	No	No	No	No	Maybe	Longer evaporation time
10	TEP	Cell	502	Pine	Yes	No	No	No	No	No	No	No	No	Yes	Low correlation for GA
11	MeOH	Cell	1750	Chimney	No	No	No	No	No	No	No	No	Yes	no	
12	MeOH	Cell	502	Pine	No	No	No	No	No	No	No	No	Yes	no	
13	Blank	Open Air	1587	Tent	No	No	No	No	No	No	No	No	No	No	
14	Ammonia	Open Air	1602	Tent	No	No	No	No	No	No	No	Yes	No	No	
15	Ammonia	Open Air	1626	Tent	No	No	No	No	No	No	No	Yes	No	No	
16	MeOH	Open Air	1617	Tent	No	No	No	No	No	No	No	No	Yes	No	
17	MeOH	Open Air	1641	Tent	No	No	Yes	No	No	No	No	No	Yes	No	MeOH conc. low
18	MeOH	Open Air	1641	Tent	No	No	Maybe	No	No	No	No	No	Yes	No	MeOH added to increase conc.
19	Blank	Open Air	1641	Tent	No	No	No	Maybe	No	No	No	No	No	No	Low correlation for HD
20	Ammonia	Open Air	1641	Tent	No	No	No	No	No	No	No	Yes	No	No	
21	Blank	Open Air	1641	Tent	No	No	No	No	No	No	No	No	No	No	
22	Blank	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	No	No	No	
23	Blank	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	No	No	No	
24	Blank	Open Air Car exhaust	1641	Tent	Maybe	No	No	No	No	No	No	No	No	Maybe	Low correlation for GA and TEP
25	Blank	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	No	No	No	

26	Blank	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	Maybe	No	No	Low correlation for Ammonia
27	Blank	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	No	No	No	
28	Ammonia	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	Yes	No	No	
29	Ammonia	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	Yes	No	No	
30	Ammonia	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	Yes	No	No	
31	Ammonia	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	Yes	No	No	
32	Ammonia	Open Air Car exhaust	1641	Tent	No	No	No	No	No	No	No	Yes	No	No	