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TNO report

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Observer report about field tests with a FALCON 4G stand-off detector by SEC Technologies

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Summary

Field testing of the large distance stand-off CB detector FALCON 4G by SEC Technologies in Lipovsky Mikulas (Slovakia) was observed by 2 employees of TNO on 28 and 29 September 2016. Based on the experimental set-up as well as the execution by SEC Technologies TNO observed the tests employing the simulant SF_6 (sulfur hexafluoride) and evaluated the results.
The first test series with no SF_6 present aimed to indicate the limit of detection and the (lack of) false alarms at a distance of 2.5 km. The results clearly showed that the device gave no false alarms during the background test and was subsequently able to detect SF_6.
The second test series aimed at detecting SF_6 at a distance of approx. 4.5 km of which is close to its maximum detection range. By several methods SF_6 was released in the air. The results clearly show that the device was able to detect SF_6 over that long distance. Furthermore, the device gave no false alarms during the background tests over that same long distance and also measured the distance reliably.
TNO concludes that SEC Technologies have successfully demonstrated some detection capabilities of the FALCON 4G, i.e. the capabilities of the device as claimed earlier by SEC Technologies were confirmed based on observing the field experiments. These claims included the range (4.5 km was clearly possible), the noise level and the related detection limit for SF_6.

Contents

1 Introduction

SEC Technologies is a company stationed in Lipovsky Mikulas (Slovakia) with roots in military research institutes in Slovakia that develops and produces laser based (active) stand-off detection equipment for the CB threat at long distances (up to 6 km).
Early 2016 SEC Technologies has approached TNO with the request to act as a so-called smart observer during field testing at large distance by SEC Technologies of their standoff detector model FALCON 4G.
On 28 and 29 September 2016 2 TNO employees (authors of this report) visited SEC Technologies to witness field tests with the aim to demonstrate some detection capabilities employing the simulant gas SF_6.
In this report TNO provides its findings. It should be noted that TNO did not act as the experimental 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

The experimental efforts that were performed aimed at determining:

- Measurements at a distance e.g. of 2.5 km with no agent present to indicate limit of detection and the (lack of) false alarms.
- Measurements at a distance of at least 4.5 km of the release of SF_6 to showcase the maximum detection range of the device.

2.1 Short description of the FALCON 4G stand-off detection system

FALCON 4G is a 4th generation laser-based CBRN stand-off detector, that can, according to SEC Technologies, detect, identify and quantify chemical warfare agents and toxic industrial chemicals using absorption of laser radiation caused by molecules of agents and biological warfare agents by evaluating particle size using DISC technology. Figure 1 is showing the device.

Figure 1 The SEC Technologies FALCON 4G.

2.2 Measurements without SF_6 at 2.5 km distance

In order to check the stability, the lower detection limit and to indicate the (lack of) false alarms a first experiment was performed at the SEC Technologies home base. From a window (Figure 2) on the 4th floor of the SEC Technologies company building the test device (FALCON 4G 007E in the SF_6 mode) was pointed at a reflecting surface at a distance 2.5 km (indicated by the device) across the valley (Figure 3). It should be noted that due to industrial activities (power plants) SF_6 sources occur at 10 km and 12 km distances. Concentrations are usually very low and the line-of-sight (from one elevated position to the other hill at the other side of the valley) “overlooks” possible SF_6 in the valley below.

Figure 2 Position of the test device in the window.

Figure 3 Test site and line-of-sight depicted in Google Earth.

The experimental set up as designed by SEC Technologies is described in a protocol in Appendix A. The resulting measurements were noted and are given in Appendix B.
After the morning fog was almost vanished in total 100 data points were acquired at time intervals of approx. 10 sec. Subsequently, a gas cell (approx. 1 liter) containing SF_6 was positioned in front of the device (Figure 4) to yield a positive signal. Out of a bottle containing a mixture of approx. 50% SF_6 in air, 0.2 ml was injected into the gas cell after which a number of data points were collected.

Figure 4 FALCON 4G with gas cell.

2.3 Measurements with SF_6 at 4.5 km distance

Two sites were chosen on both sides of the valley mentioned above. On the first location the FALCON 4G as described in 2.2. was installed. At a distance of approx. 4.5 km (Figure 5) various SF_6 releases took place. The weather situation was sunny with high clouds and a moderate wind coming from W-SW.

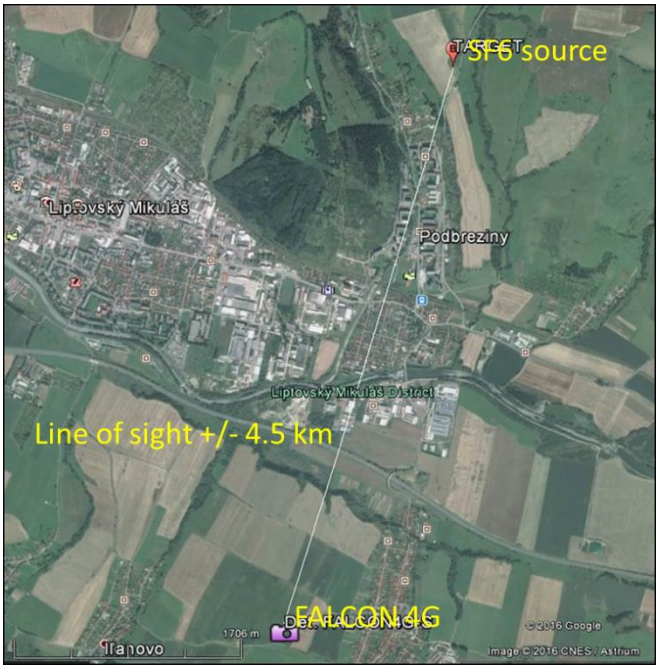

Figure 5 Test sites and line-of-sight depicted in Google Earth.

The various ways of releasing SF_6 from the source are depicted in Figure 6 (by opening the valve and releasing in open air during 15 sec. and 30 sec., respectively) and Figure 7 (by releasing the SF_6 from a plastic bag into a half open tent of approx. 30 m^3). It was estimated that a release of 30 seconds resulted in an amount of 450 grams of SF_6.
The experimental set up as designed by SEC Technologies is described in a protocol in Appendix C. The resulting measurements were noted and are given in Appendix D.

Figure 6 Release of SF_6 by opening the gas bottle.

Figure 7 Release of SF_6 into the tent.

3 Results and Discussion

In the two paragraphs below a summary of the findings is presented with some discussions regarding the two sets of experiments that took place.

3.1 Measurements without SF_6 at 2.5 km distance

The results were obtained by manually starting the device and writing down the obtained distance and concentration (Appendix B). The results were then plotted in a graph (Figure 8) that shows the series of background measurements (1-100) and the measurements after introduction of SF_6 in the gas cell in front of the device (measurements 100-110).
The distance as measured by the device averaged to approx. 2560 m, which clear equals the distance measured on the map. The average background concentration was -0.2 ng/L with a dispersion (error of individual detection) of 0.8 ng/L.
This negative concentration results from sub-optimal calibration according to SEC Technologies staff. As soon as this negative value becomes too big the system gives a failure indication, which was not the case now. The detection limit was calculated by using a SEC Technologies procedure and resulted in 1.5 ng/L.
This number was found earlier by SEC Technologies and based on that the device was preprogrammed at a threshold of 1.5 ng/L. This resulted in a false alarm rate of 0% over 100 measurements, indicated ("Agent not detected") in the display (Figure 9).
The introduction of SF_6 by way of the gas cell resulted in immediate positive detection by showing "Agent detected" indicated in the display (Figure 10) and a concentration of approx. 17.3 ng/L. These results clearly shows that the device gave no false alarms during the background test and was able to detect SF_6 with the same detection settings as used for the background measurements.

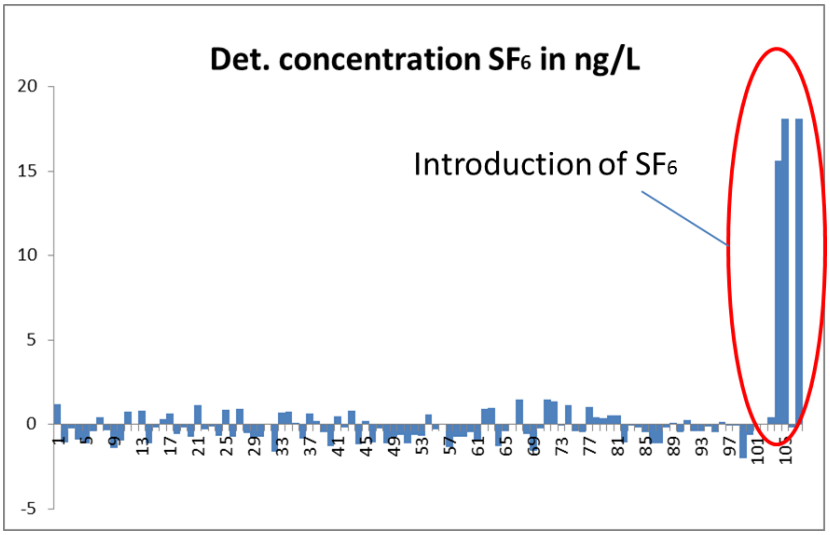

Figure 8 Plotted results of measurements without SF_6 at a distance of 2.5 km followed by a SF_6 measurement employing a gas cell.

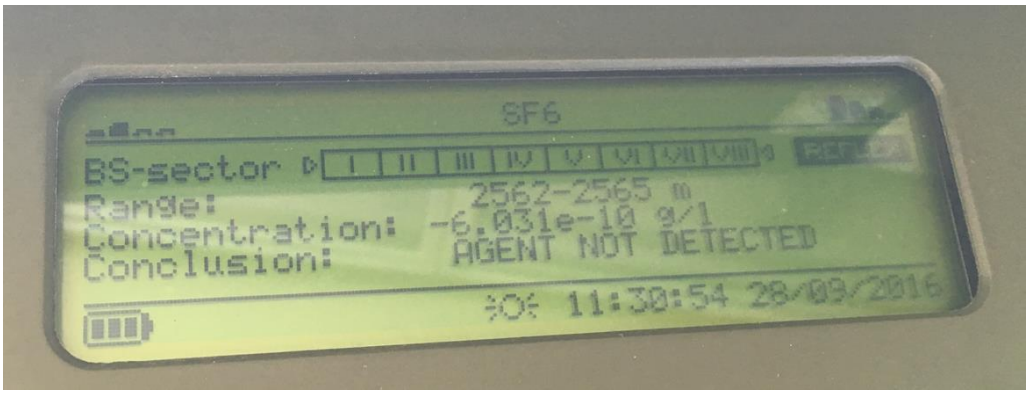

Figure 9 Snapshot of display during series of background measurements.

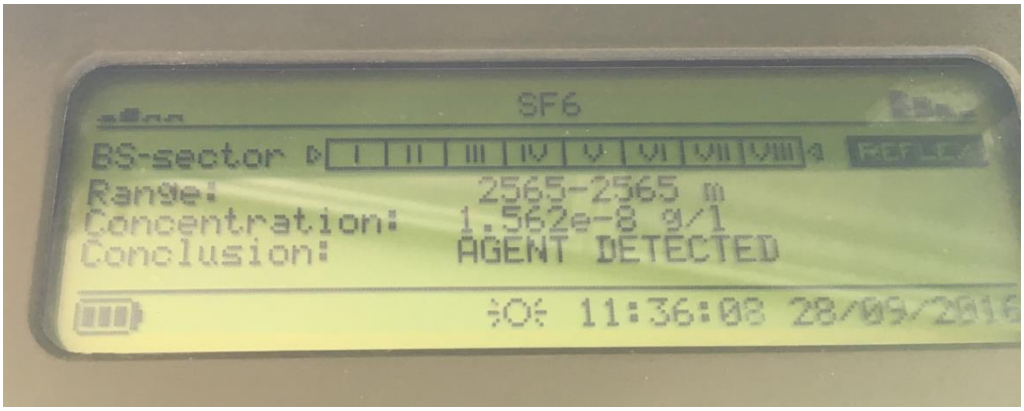

Figure 10 Snapshot of display indicating a positive SF_6 detection.

3.2 Measurements with SF_6 at 4.5 km distance

The long distance experiments results are depicted in Figure 11. The tests started with a series of blank measurements (10 in total) to determine the background of SF_6 in the line of sight and to determine the distance to the target (water reservoir was used as reflecting surface). The threshold of 1.5 ng/L was not exceeded and the average background was calculated at -1.0 ng/L. The device clearly showed “Agent not detected”. The distance was measured by the device and averaged on approximately 4570 meter. The first release was performed in free air under windy conditions resulting in a very short period (15 sec, 225 gram SF_6) with a cloud of SF_6 in the line of sight. Therefore only a limited number of detections could be performed. Measurement 1 was negative, showing “Agent not detected”. Measurements 2-4 were successful in detecting SF_6 resulting in a display showing “Agent detected” (Figure 12), a maximum concentration of 15.2 ng/L and an average concentration of 8.5 ng/L (Figure 13). For confirmation, this experiment was repeated one more time by opening the bottle longer (30 sec, 450 gram SF_6) which resulted in a maximum concentration of 7.8 ng/L and an average concentration of 5.7 ng/L SF_6.

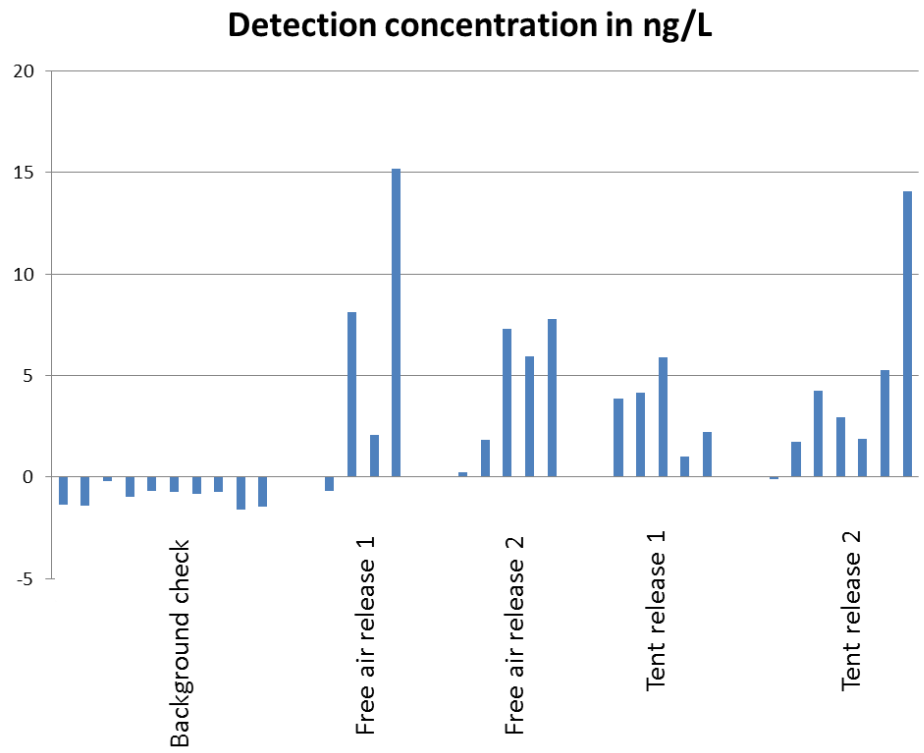

Figure 11 Plotted results of measurements with SF_6 at a distance of 4.5 km.

Fgure 12 Snapshot of a positive detection at 4.5 km.

Due to strong wind the third and fourth experiment where performed using the semi enclosed tent to contain the vapour longer. Immidiately after releasing the gas, the first measurement was positive for SF_6 and gave a concentration of 3.9 ng/L. The repeating measurements (5 in total) resulted in a maximum concentration of 5.9 ng/L an average concentration of 3.4 ng/L. In total the vapour could be detected during 1-2 minutes. The last experiment resulted in 7 detections of SF_6, a maximum concentration of 5.3 ng/L an average concentration of 5.0 ng/L. These results clearly show that the device was able to detect SF_6 over a long distance of 4.5 km and at a relatively low concentration and small quantities. Detection of lowers

quantities could be possible but where not part of this test. The device measured the distance reliably and gave no false alarms during the background test over a long distance.

4 Conclusions

SEC Technologies have demonstrated some detection capabilities of the FALCON 4G to TNO personnel successfully during a 2 days field test session.
TNO concludes that, based on the observed set of field experiments employing the simulant agent SF_6, the capabilities of the device as claimed earlier by SEC Technologies can be confirmed based on observing these field experiments. These claims included the range (4.5 km was clearly possible), the noise level and the related detection limit for SF_6.

5 Signature

Rijswijk, October 2016

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A Test protocol for measurements without SF6

Certification Tests of Stand-off Detector of CWA model FALCON 4G

I. Detection range of „Stand-off Detector of CWA model FALCON 4G“

1. Purpose of the Test :
Estimate the maximum range of stand-off detector of CWA, model FALCON 4G.

2. Required equipment and material
- Tripod version of FALCON 4G under test with all accessories
- SF_6
- Tent

3. Conditions of the test[1] :
- Good weather (not rainy; range of visibility 10 km at least, low humidity);
- Target, which should be used during test, should feature medium and diffuse reflectivity (e. g. brick-walled or concrete building);
- Dimensions of target in vertical plane should be 7 x 7 m at least;
- Range of the target should be approx 90 % of the FALCON 4G maximum range, which should be certified.

4. Procedure of the test :

4.1 FALCON 4G should be aimed at the bottom of a solid target[2], which meets the requirements stated above;

4.2 The detection range (the range of the chosen target) should be 4 500 m at least;

4.3 F4G has to be set for detection of SF_6;

4.4 10 detections has to be executed by F4G and detected ranges have to be recorded;

4.5 Small amount of SF_6 (approx 200 g) has to be dispersed close to the target; to limit amoun of SF_6, which has to be released, side wind should be blocked[3];

4.6 Few attempts to detect SF_6 should be done; windy weather makes such tests difficult.

5. Evaluation of the test
- At least 8 of 10 attempts to estimate the range of a target, which meets requirements stated in part 3., by F4G under test should be successful; that means the range should be estimated by F4G without receiving the “Range Not Found” message;
- At least 8 measured ranges have to be within “real range + / - 30 m” (as a “real range” the ”mean range” can be used);
- If a range approx.. 4 500 m was achieved under real (not ideal) conditions, it can be considered like confirmation of 5 000 m range under ideal conditions;
- If it is not windy, F4G is aimed to the bottom of the target and the amount of released SF6 is sufficient, than detection of SF6 is very probable.

[1] – Maximum range of most optoelectronics and laser sensors is usually stated for "ideal" conditions; that means very good visibility, large and high reflectivity target, e.t.c. To achieve such combination of all conditions is not easy. Therefore, achieving some range under "real" (not ideal) condition can be considered like confirmation of 1.1-times larger range under ideal conditions;

[2] – Aiming of F4G at the bottom of the target is important for detection of SF6, because this gas is heavy (m_{MOL} = 146 g; molecular weight of CWAs are similar or higher) and can be found only close to ground;

[3] – SF6 is considered as a "super-greenhouse" gas and its releasing should be limited; the best solution would be to use a chamber, but… Therefore, release inside an opened tent is recommended; it can limit movement of the cloud and thus minimise consumption of SF6.

6. Explanations

To understand the methodology proposed for certification tests of the FALCON 4G maximum range understanding of its operation principles is necessary. Therefore, it is highly recommended to study the explanations stated below.

The best results in stand-off detection of CWA can be achieved using absorption of infrared radiation by molecules of CWA.
FALCON 4G (= F4 G) is an active stand-off detector of CWA; "active" means that for the detection of CWA an infrared radiation generated by integrated sources of radiation is used. Precise designation of the technology used by F4G is "CO2 DIAL"; the acronym DIAL means "Differential Absorption LIDAR" (LIDAR = LIght Detection And Ranging).
The block diagram of F4G is enclosed.

F4G operates using two tuneable pulse CO_2 lasers. To detect an agent, F4G has to be aimed at properly chosen background (target); after starting the detection process the following sequence of operations will take place:

- Both "Left Laser" and "Right Laser" are tuned to specific CO_2 laser lines (two different lines are used);
- "L Laser" is triggered and the respective electrical signals from "Optical Receiver" are digitised signals corresponding to reflected laser radiation up to 5 000 m range are digitised and recorded;
- Subsequently, the recorded return signals are processed, "reflection" of the target is identified and the respective range – "L Range" is estimated and displayed;
- Approx 300 μs after the "L Laser" was triggered, "R Laser" is triggered and the procedure described above takes place with "R Laser". As a result, "R Range" is estimated and displayed;
- "L Range" and "R Range" are compared;
- If ("L Range" - "R Range") > 40 m, than a message "Range Not Found" is displayed and the detection process is stopped;
- If ("L Range" - "R Range") < 40 m, than the detection process continues by the following steps:
- Lasers are tuned to λ_{ON} (L Laser) and to λ_{OFF} (R Laser) for the chosen agent and a pair of pulses (the delay is 300 μs) is fired. Parts of the respective signals from output of "Optical Receiver" are processed. The processing is very simple : signal from [("L Range" + "R Range") / 2] to [("L Range" + "R Range") / 2 + Δ] is integrated (Δ corresponds to full width of laser pulse); integrated values E_{LI}" and E_{RI} for "L Laser" and "R Laser" respectively are stored;
- Lasers are tuned to λ_{OFF} (L Laser) and to λ_{ON} (R Laser) and a pair of pulses is fired.

Parts of the respective signals from output of “Optical Receiver” are processed using procedure described above; integrated values E_{LII} and E_{RII} are stored;

- Using E_{LI}, E_{PI}, E_{LII} and E_{PII} an average concentration of the chosen agent along the measuring line is calculated.

Commentaries:

- Estimating the range of a “target” (background) is the critical step of the F4G detection process; subsequent estimating of reflected energies on λ_{OFF} and λ_{ON} is relatively simple;
- Therefore, if an active stand-off detector (operating using the above described procedure) is able to estimate a range of a specific target, it is also able to detect the agent along this specific measuring line (on condition the concentration – length product of agent is above detector’s threshold);
- The key to F4G reliable detection is using two lasers and estimation of two ranges, which have to be (nearly) identical; this feature gives extremely low “false negative alarm rate”, which cannot be achieved using other technologies (e. g. passive).

B Collected data for measurements without SF6

Record from measurements executed in accordance with methodology "Detection Limit an False Alarm Rate of Stand/off Detector of CWA model FALCON 4G"

Measurements were done on 28th of September 2016 from SEC Technologies lab. Target : Building, range 2 560 m

Visibility was approx 5 000 m, target partly covered by fog, temperature approx 16 °C, wind from west, wind speed approx 2 m/s

Detections were executed approx each 10 seconds.

Measur. No.	Range L / R	Det. concentration [ng / l]	Result of detection (Threshold = 1,5 ng / l)
1	2 562 m / 2 568 m	1,190	Agent not detected
2	2 578 m / 2 565 m	-1,090	Agent not detected
3	2 565 m / 2 568 m	-0,250	Agent not detected
4	2 565 m / 2 565 m	-0,910	Agent not detected
5	2 568 m / 2 568 m	-1,140	Agent not detected
6	2 562 m / 2 568 m	-0,390	Agent not detected
7	2 562 m / 2 568 m	0,440	Agent not detected
8	2 562 m / 2 568 m	-0,350	Agent not detected
9	2 571 m / 2 568 m	-1,390	Agent not detected
10	2 568 m / 2 565 m	-0,940	Agent not detected
11	2 568 m / 2 568 m	0,780	Agent not detected
12	2 565 m / 2 568 m	0,040	Agent not detected
13	2 571 m / 2 565 m	0,810	Agent not detected
14	2 565 m / 2 565 m	-1,150	Agent not detected
15	2 568 m / 2 565 m	-0,200	Agent not detected
16	2 568 m / 2 562 m	0,310	Agent not detected
17	2 578 m / 2 565 m	0,620	Agent not detected
18	2 575 m / 2 565 m	-0,570	Agent not detected
19	2 571 m / 2 562 m	-0,160	Agent not detected
20	2 562 m / 2 568 m	-0,710	Agent not detected
21	2 568 m / 2 565 m	1,160	Agent not detected
22	2 565 m / 2 565 m	-0,320	Agent not detected
23	2 571 m / 2 565 m	-0,150	Agent not detected
24	2 565 m / 2 565 m	-0,670	Agent not detected
25	2 562 m / 2 565 m	0,880	Agent not detected
26	2 565 m / 2 565 m	-0,720	Agent not detected
27	2 578 m / 2 565 m	0,930	Agent not detected
28	2 565 m / 2 568 m	-0,500	Agent not detected
29	2 565 m / 2 565 m	-0,860	Agent not detected
30	2 578 m / 2 568 m	-0,730	Agent not detected
31	2 568 m / 2 565 m	0,030	Agent not detected
32	2 562 m / 2 571 m	-1,620	Agent not detected
33	2 565 m / 2 565 m	0,700	Agent not detected

34	2 571 m / 2 565 m	0,770	Agent not detected
35	2 568 m / 2 568 m	0,110	Agent not detected
36	2 565 m / 2 565 m	-0,870	Agent not detected
37	2 568 m / 2 568 m	0,660	Agent not detected
38	2 568 m / 2 562 m	0,220	Agent not detected
39	2 565 m / 2 565 m	-0,450	Agent not detected
40	2 568 m / 2 568 m	-1,300	Agent not detected
41	2 568 m / 2 568 m	0,480	Agent not detected
42	2 571 m / 2 562 m	-0,170	Agent not detected
43	2 559 m / 2 568 m	0,790	Agent not detected
44	2 568 m / 2 565 m	-1,200	Agent not detected
45	2 568 m / 2 565 m	0,200	Agent not detected
46	2 565 m / 2 568 m	-1,050	Agent not detected
47	2 565 m / 2 565 m	-0,220	Agent not detected
48	2 562 m / 2 565 m	-1,100	Agent not detected
49	2 568 m / 2 565 m	-0,760	Agent not detected
50	2 559 m / 2 565 m	-0,600	Agent not detected
51	2 571 m / 2 568 m	-1,140	Agent not detected
52	2 559 m / 2 565 m	-0,620	Agent not detected
53	2 565 m / 2 568 m	-0,700	Agent not detected
54	2 565 m / 2 568 m	0,580	Agent not detected
55	2 571 m / 2 568 m	-0,280	Agent not detected
56	2 568 m / 2 565 m	0,060	Agent not detected
57	2 568 m / 2 568 m	-1,340	Agent not detected
58	2 562 m / 2 565 m	-0,750	Agent not detected
59	2 562 m / 2 565 m	-0,750	Agent not detected
60	2 562 m / 2 565 m	-0,440	Agent not detected
61	2 571 m / 2 562 m	-1,000	Agent not detected
62	2 562 m / 2 565 m	0,940	Agent not detected
63	2 565 m / 2 565 m	0,950	Agent not detected
64	2 562 m / 2 565 m	-1,280	Agent not detected
65	2 565 m / 2 562 m	-0,380	Agent not detected
66	2 562 m / 2 565 m	0,050	Agent not detected
67	2 562 m / 2 562 m	1,490	Agent not detected
68	2 565 m / 2 565 m	-0,560	Agent not detected
69	2 565 m / 2 562 m	-1,590	Agent not detected
70	2 569 m / 2 565 m	-0,250	Agent not detected
71	2 565 m / 2 565 m	1,480	Agent not detected
72	2 562 m / 2 565 m	1,340	Agent not detected
73	2 562 m / 2 568 m	-0,030	Agent not detected
74	2 559 m / 2 565 m	1,160	Agent not detected
75	2 559 m / 2 565 m	-0,390	Agent not detected
76	2 559 m / 2 565 m	-0,440	Agent not detected
77	2 559 m / 2 565 m	1,050	Agent not detected
78	2 562 m / 2 568 m	0,420	Agent not detected
79	2 565 m / 2 565 m	0,350	Agent not detected
80	2 568 m / 2 562 m	0,560	Agent not detected
81	2 568 m / 2 565 m	0,540	Agent not detected
82	2 562 m / 2 565 m	-1,050	Agent not detected
83	2 562 m / 2 565 m	-0,080	Agent not detected

84	2 562 m / 2 565 m	-0,200	Agent not detected
85	2 562 m / 2 565 m	-0,440	Agent not detected
86	2 568 m / 2 565 m	-1,130	Agent not detected
87	2 562 m / 2 562 m	-1,100	Agent not detected
88	2 562 m / 2 565 m	-0,190	Agent not detected
89	2 559 m / 2 562 m	0,070	Agent not detected
90	2 562 m / 2 565 m	-0,470	Agent not detected
91	2 562 m / 2 565 m	0,260	Agent not detected
92	2 565 m / 2 568 m	-0,380	Agent not detected
93	2 568 m / 2 568 m	-0,420	Agent not detected
94	2 565 m / 2 568 m	-0,140	Agent not detected
95	2 565 m / 2 565 m	-0,480	Agent not detected
96	2 562 m / 2 565 m	0,160	Agent not detected
97	2 559 m / 2 562 m	-0,040	Agent not detected
98	2 559 m / 2 565 m	-0,090	Agent not detected
99	2 562 m / 2 565 m	-2,000	Agent not detected
100	2 562 m / 2 565 m	-0,600	Agent not detected
Tests using chamber			
1	2 550 m / 2 568 m	0.43	Agent not detected (empty chamber)
2	2 565 m / 2 565 m	15,6	Agent detected ($0,2$ ml SF_6 in chamber)
3	2 562 m / 2 540 m	18,1	Agent detected ($0,2$ ml SF_6 in chamber)
4	2 562 m / 2 565 m	- 0,21	Agent not detected (without chamber)
5	2 553 m / 2 565 m	18,1	Agent detected ($0,2$ ml SF_6 in chamber)

Evaluation :

The above stated data were processed in the following manner:

1. An average concentration value "C_m" detected thorough "clean air" was
$$C_m = (1 / N) \cdot \Sigma_i C_i, \qquad (1)$$

where i goes from 1 to N (total number of detections, N = 100) and Ci is the result of individual detection having consecutive number "i";

$$C_m = - 0,207 \cdot 10^{-9} \text{ g /l} \qquad (2)$$

2. Dispersion "D" of detected values (probable error of individual detection) was calculated using the following formula:

$$D = SQRT [(\Sigma i (Ci - Cm)2) / (N – 1)] \qquad (3)$$

D = 0,766 . 10-9 g /l (4)

3. The “Detection Limit”– detection threshold concentration of tested stand-off system “CTHR“, for detection of SF6 is equal to:

CTHR = 2 . D (5)

CTHR = 1,532 . 10-9 g /l (6)

Recommendation : To achieve the best results, the C_{THR} estimated above should be set in firmware of the tested F4G as a detection threshold.

4. The FALCON 4G was able to detect SF6, small amount of SF6 was injected into small chamber, which was placed in front of FALCON 4G and positive detection was recorded (the test was done in accordance with above cited methodology). The detected value was 15,0 – 18,1 . 10-9 g /l; it is in accordance with expectations.

5. None of the 100 detections performed during step 4.3 of the mentioned methodology was positive.

C Test protocol for measurements with SF6

Certification Tests of Stand-off Detector of CWA model FALCON 4G

II. Detection Limit and False Alarm Rate of „Stand-off Detector of CWA model FALCON 4G“

1. Purpose of the Test :

- Estimate the detection limit for detection of SF_6 [1)] and false alarm rate of stand-off detector of CWA, model FALCON 4G

2. Required equipment and material

- Tripod version of FALCON 4G (= F4G) under test with all standard accessories;
- Small chamber fitted with IR transparent windows, which can be attached in front of the F4G optical receiver;
- SF6;
- Tent.

3. Conditions of the test :

- Good weather (not rainy, not windy, range of visibility 10 km at least, low absolute humidity);
- The measuring path should be free of interfering gases (solvents, vinegar, gases produced by agriculture, SF6, carbohydrates, etc.) 2);
- Target, which should be used during test, should have medium and diffuse reflectivity (e. g. brick-walled or concrete building);
- Dimensions of the target in vertical plane should be 4 x 4 m at least;
- Range of the target should be approx 50 % of the F4G maximum range;
- At least 8 hours before starting the test, no manipulation with SF6 should take place inside the lab, in which F4G will be placed during test.

4. Procedure of the test :

4.1 F4G should be prepared for operation and aimed at a solid target, which meets the requirements stated in part 3; (the range of the target should be approx 2 500 m);

4.2 F4G has to be set for detection of SF6;

4.3 100 detections have to be performed by F4G; displayed ranges, detecte concentrations and results of detection’s automatic evaluation have to be recorded;

4.4 Subsequently, an empty small chamber has to be attached in front of F4G Optical Receiver;

4.5 Detection by F4G through the empty chamber has to be accomplished and the result should be negative (if it is not so, the chamber has to be ventilated);

4.6 Small amount of SF6 (less than 0.2 cm3 = 1.3 mg) has to be injected into the chamber;
4.7 Detection by F4G through the chamber has to be accomplished and the result has to be positive;

5. Evaluation of the test

Data recorded executing step 4.3 have to be processed in the following manner:

- An average concentration value "Cm" has to be calculated using the following formula :

$$Cm = (1 / N) \cdot \Sigma i\ Ci, \qquad (1)$$

Where i goes from 1 to N (total number of detections, N = 100) and C_i is the result of individual detection having consecutive number "i";

- Dispersion "D" of detected values (probable error of individual detection) has to be calculated using formula:

$$D = SQRT\ [\ (\Sigma i\ (Ci\ - Cm)2)\ /\ (N - 1)] \qquad (2)$$

- The "Detection Limit" 4) – detection threshold concentration of tested stand off system "CTHR", for detection of SF6 is equal to:

$$CTHR = 2 \cdot D \qquad (3)$$

Recommendation : To achieve the best results, the CTHR estimated above should be set in firmware of the tested F4G as a detection threshold.

- The above stated is valid only on condition that the detection performed in step 4.7 was positive (that means the tested device is really sensitive to detected stuff). In addition, the concentration of SF_6 detected during step 4.7 should be similar to predicted value; (if the volume of the small chamber is 1.1 l, its length is 0.14 m, and 1.2 mg of the SF_6 was injected into the chamber, than for 2 500 m long measuring path the average detected concentration should be apporx 30.10^{-9} g / l) [5)]

- If conditions stated in part 3. of this document are satisfied, none of the 100 detections performed during step 4.3 should be positive;
- If some results are positive, the "false alarm rate" (= FAR) 6) is a ratio of number of positive detections - NPOS to total number of detections executed during the test – NTOT, that means:

$$FAR = NPOS / NTOT \qquad (4)$$

1) There are several good reasons for using SF_6 for evaluation of stand-off detectors of CWA :

- SF_6 is non-toxic; therefore, it is easy to work with such stuff;
  Molecular weight of SF_6 (146 g/mol) is similar to that of CWAs (140 g/mol orhigher); therefore, behaviour of SF_6 cloud in real environment is similar to behavior of cloud of CWA in gaseous state;
- Both SF6 and CWAs have strong absorption of optical radiation in far IR part of the spectra.

Therefore, using reliable spectroscopic data, stand-off detector of CWA able to detect a small amount of SF_6 (less than 0.5 kg) in terrain should be able to detect also CWAs under real conditions.

2) Evaluation of "detection threshold" and "false alarm rate" should be done through "clean air". The mentioned interfering gases have low difference in absorption on λON and λOFF of SF6, but having large concentration – length of the cloud product, such gases can cause false detection of SF6. Another phenomenon, which can affect the test, is atmospheric turbulence. It is very difficult to eliminate all the mentioned "outer" influences and evaluate imperfections of tested stand-off detector separately;

3) SF6 is considered as a "super-greenhouse" gas and its releasing should be limited; the best solution would be to use a chamber, but… Therefore, release inside an opened tent is recommended; it can limit movement of the cloud and thus minimise consumption of SF6;

4) Detected values of SF6, and also estimated Detection Limit, are as precise as precise is the respective spectra of optical absorption; the same is valid for all CWAs and for all other detectable stuffs. F4G is using data from VVÚ Brno (former VTÚO Brno), which is a certified laboratory capable to evaluate laser absorption spectra of CWAs;

5) Approximate value of detected concentrations of SF6 "CDET", which should be achieved using small chamber, can be calculated using the following formula :

$$CDET = CCH \cdot [LCH / (2 \cdot RT)] \qquad (5)$$

Where CCH is concentration of SF6 inside the chamber; LCH is length of chamber and RT is a range of the target.

6) For a specific stand-off detector, the detection threshold "CTHR" and false alarm rate (= FAR) should be balanced so that the detector will meet a customer's needs. At a cost of sensitivity, it is very easy to make FAR very low, but such detection system can be useless…

D Collected data for measurements with SF6

Record from measurements executed in accordance with the methodology "Detection Range of Stand-off Detector of CWA model FALCON 4G"

Measurements were done on 28th of September 2016, tests started at 14:00;

FALCON 4G was operating from meadow between "Ilanovo" and "Zavazna Poruba" (villages)

Target : Water reservoir building close to "Veterna Poruba", range 4 570 m;

Visibility was approx 10 km, temperature was approx 17 °C, wind from west, 1 – 5 m/s, gusts up to 10 m/s

Measurements were executed approx each 10 seconds after each event (e.g. release of SF_6)

Measur. No.	Range L / Range R	Aver. Range / Range Error	Det. Concent. [ng / l]	Result of detection (Threshold = 1,5 ng/l)
Verifying Range capability through "clean" air				
1	4 571 m / 4 581 m	4 576 m / + 5	-1,35	Agent not detected
2	4 553 m / 4 575 m	4 564 m / - 7	-1,40	Agent not detected
3	4 578 m / 4 559 m	4 569 m / - 2	-0,19	Agent not detected
4	4 575 m / 4 571 m	4 573 m / + 2	-0,96	Agent not detected
5	4 565 m / 4 568 m	4 567 m / - 4	-0,68	Agent not detected
6	4 571 m / 4 571 m	4 571 m / 0	-0,75	Agent not detected
7	4 578 m / 4 571 m	4 575 m / + 4	-0,81	Agent not detected
8	4 575 m / 4 571 m	4 573 m / + 2	-0,75	Agent not detected
9	4 575 m / 4 575 m	4 575 m / + 4	-1,60	Agent not detected
10	4 571 m / 4 571 m	4 571 m / 0	-1,46	Agent not detected
Mean Range = 4 571 m				
Release of SF_6 No. 1 (free air release)				
1	4 543 m / 4 546 m	4 545 m	-0,70	Agent not detected
2	4 543 m / 4 531 m	4 537 m	8,13	Agent detected
3	4 506 m / 4 506 m	4 506 m	2,10	Agent detected
4	4 546 m / 4 575 m	4 561 m	15,20	Agent detected
Release of SF_6 No. 2 (free air release)				
1	4 531 m / 4 543 m	4 537 m	0,22	Agent not detected
2	4 509 m / 4 503 m	4 505 m	1,83	Agent detected
3	4 493 m / 4 491 m	4 492 m	7,28	Agent detected
4	4 503 m / 4 518 m	4 511 m	5,94	Agent detected
5	4 575 m / 4 568 m	4 572 m	7,81	Agent detected

Release of SF_6 No. 3 (tent release)				
1	4 518 m / 4 518 m	4 518 m	3,88	Agent detected
2	4 528 m / 4 509 m	4 519 m	4,16	Agent detected
3	4 525 m / 4 543 m	4 534 m	5,91	Agent detected
4	4 553 m / 4 541 m	4 547 m	1,02	Agent not detected
5	4 512 m / 4 496 m	4 504 m	2,24	Agent detected
Release of SF_6 No. 4 (tent release)				
1	4 575 m / 4 562 m	4 569 m	-0,11	Agent not detected
2	4 575 m / 4 556 m	4 566 m	1,73	Agent detected
3	4 528 m / 4 515 m	4 522 m	4,25	Agent detected
4	4 493 m / 4 521 m	4 507 m	2,96	Agent detected
5	4 550 m / 4 562 m	4 556 m	1,89	Agent detected
6	4 550 m / 4 543 m	4 547 m	5,28	Agent detected
7	4 543 m / 4 528 m	4 536 m	14,1	Agent detected

Evaluation

The above stated data were evaluated and processed in the following manner:

1. Estimation of range through “clean” air was reliable : 10 from 10 attempts were successful;
2. An average estimated range of selected target was 4 571 m; the shortest range was 4 564 m (error was – 7 m), the longest range was 4 576 m (error was + 5 m);
3. After dispersion of small amounts of SF6 FALCON 4G has detected SF6 in accordance with expectations.