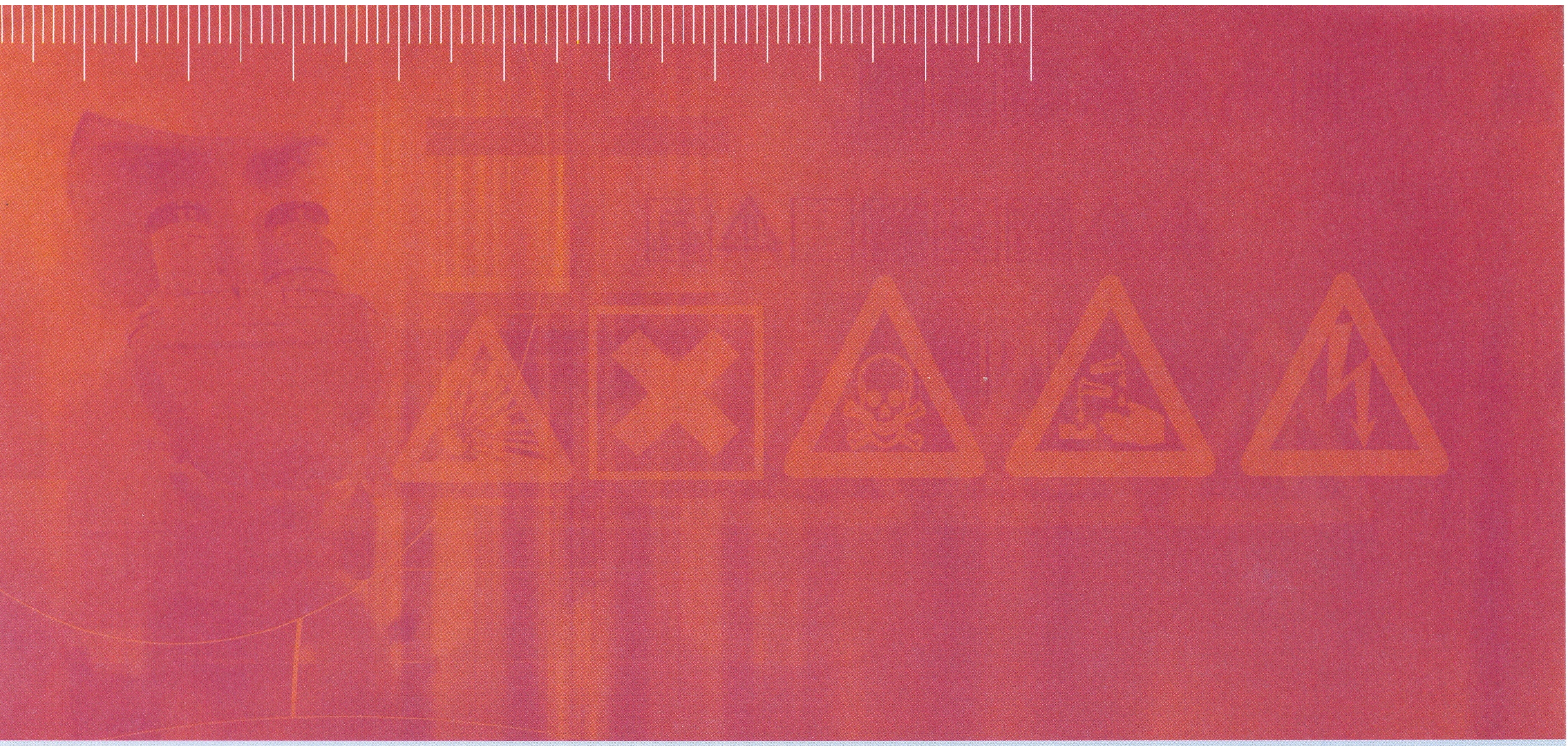

STUDY REPORT 05/08/2011

N° DRA-11-117743-08553A

Program EAT-DRA73: Assessment of Technical Safety Barriers Performance

Comparative performance tests on flame detectors

INERIS

maîtriser le risque
pour un développement durable

Program EAT-DRA73: Assessment of Technical Safety Barriers Performance

Comparative performance tests on flame detectors

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This report was reviewed by SP Technical Research Institute of Sweden and manufacturers involved into the project.

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1. BACKGROUND & OBJECTIVES

This test campaign related to flame detectors was funded by the French Ministry of Ecology, Sustainable Development, Transportation and Housing (MEDDTL) as part of a program assessing performances of technical safety barriers used in industrial plants for major risk reduction purposes.

Flame detectors are aimed for fire safety. Their function is to detect the birth of a fire and to trigger an alarm. They are generally established to protect industrial installations such as:

- Refineries,
- Offshore drilling and production platforms,
- Fuel loading facilities,
- Compressor stations,
- LNG/LPG processing and storage,
- Gas turbines,
- Chemical plants,
- Aircraft hangers.

In Europe, flame detectors are covered by the Construction Products Directive 89/106/CEE and shall be compliant with the European harmonized standard EN 54-10 "*Fire detection and fire alarm systems – Part 10: Flame detectors – Point Detectors*". This standard specifies requirements, tests methods and performance criteria for point-type and resettable flame detectors intended to be used in fire detection systems installed inside buildings. There is no European standard covering outdoor industrial use.

The objective of this campaign was therefore to conduct a comparative study of performances and limitations of flame detectors on the market for outdoor industrial use (mainly in oil & gas process industry). Performance parameters of detectors were studied in both laboratory (indoor bench tests) and realistic conditions (outdoor tests) when exposed to different types of fire1. Robustness against hard climatic conditions and electromagnetic disturbances was also evaluated as well as immunity to false alarm sources.

The results of this study should be used to inform end users and public institutions about the important aspects to consider to implement flame detectors and not to alter their effectiveness, especially when considered in hazard studies as a component of a technical safety barrier.

The project was initiated in 2008 and tests were performed between 2009 and 2010 in collaboration with SP Technical Research Institute of Sweden. Five manufacturers gave their support to this project and about 30 detectors were tested.

[1] Methane, propane, hydrogen in laboratory conditions; methane, hydrogen, heptane, ethanol, cardboard in outdoor conditions.

2. PRINCIPLE OF FLAME DETECTION

Flames produce radiation characterized by a flickering frequency, more or less intense, in specific spectral bands. Flame detectors respond to the electromagnetic radiation emitted by flames and distinguish this radiation from the interfering radiation in the environment of use. Optical flame detectors are made of UV and/or IR sensors.

2.1 SINGLE FREQUENCY IR DETECTION

Single frequency IR detectors are sensitive to a narrow band of radiation around the 4,4 µm range. This range corresponds to the relaxation of excited CO_2 emitted in predominance by hydrocarbon fueled fires.

Single frequency IR detectors implement a pyroelectric crystal sensor whose principle is based on the thermic effect of radiation. A current is generated by polarization of the crystal subjected to a change of temperature occurring when exposed to the flickering flame. An electronic circuitry then generates an output signal processed by a low frequency band pass filter.

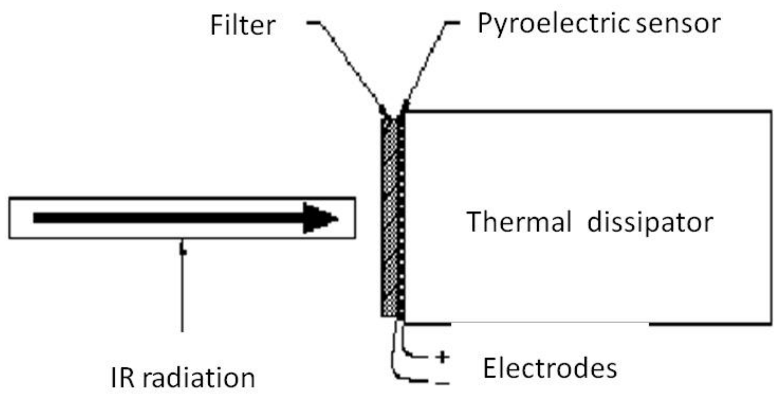

Figure 1: Pyroelectric sensor (IR technology)

Main strengths and limitations of single frequency IR detectors are listed below:

Strengths:

- Not highly impacted by contaminants like oil, dirt and dust
- High speed responses
- Insensitive to solar, welding, lightening, sparks, arcs & corona

Limitations:

- Not suitable for non-carbon fires
- Potentially sensitive to modulated IR sources
- Sensitive to rain, ice & water vapors

2.2 MULTI-SPECTRUM IR DETECTION

Multi-spectrum IR detectors incorporate two, three or four sensors (IR2, IR3, IR4) which are sensitive to a different frequency of radiation. They compare specific wavelength bands within the IR spectral region.

The principle of operation of detectors is based on:

- A spectral analysis that identifies the IR signature of fire products due to relaxation of emitted substances as typically CO_2 in the 4.2 - 4.7 µm range and/or H_20 (2.7-3.0 µm). Additional spectral bands (above and below these bands) are analyzed to distinguish background interferences
- A flickering analysis at frequencies typical to the considered flame

Fire alarm is only issued when all the parameters of the spectral analysis and the flickering analysis meet the predetermined values.

Main strengths and limitations of single frequency IR detectors are listed below:

Strengths:

- High immunity to false alarms
- High sensitivity and long detection distance
- Insensitive to solar, welding, lightening and black body radiation

Limitations:

- Not suitable for non-carbon fires (except for detection based on H_2O peak)
- Long time of response when compared to single frequency detector
- Sensitive to ice
- Detection distance for detection based on H_2O peak

2.3 UV DETECTION

A UV detector is constituted of a photo-tube containing an inert gas in an electric field (figure 2). Detection uses the photoelectric effect of metal. Photons from the UV radiation of a flame reach the cathode and induce electron emission in the tube. Electrons react on the anode by ionizing gas molecules (chain reaction). The sensor then generates a series of pulse that are electronically converted into an alarm output. To ensure good immunity against solar radiation, the range of sensitivity of the detector is narrow, from 185 nm to 265 nm.

Main strengths and limitations of single frequency IR detectors are listed below:

Strengths:

- Response to hydrocarbon and non-hydrocarbon fires (hydrogen, metals, ammonia, etc.)
- High speed response

Limitations:

- Possible inhibition by gases, vapors or smokes
- Not systematically solar blind according to detection range (some sensors are intended for indoor use only)
- Sensitive to welding, lightening, sparks, arcs and corona

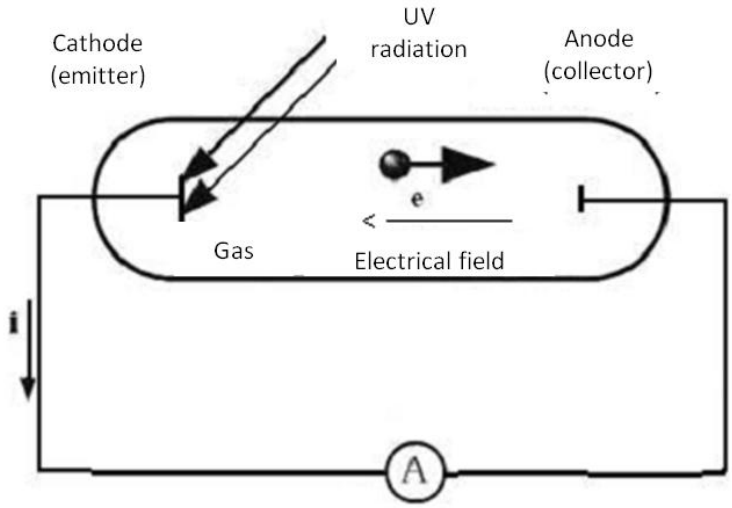

Figure 2: UV sensor

2.4 UV/IR DETECTION

UV/IR detectors consist of an UV sensor associated with one or two IR sensors. Electric circuitries process signals from both sensor types in order to better confirm the fire signal.

Main strengths and limitations of single frequency IR detectors are listed below:

Strengths:

- High immunity to false alarms
- High speed response

Limitations:

- Not suitable for non-carbon fires due to IR limitations (except for IR detection based on H_2O peak)
- Possible inhibition by gases, vapors or smokes

3. EQUIPMENT UNDER TEST

75 % of tested detectors are multispectral IR versions and are generally configured to detect hydrocarbon fires (CO_2 emission peak). The complete list of tested detectors is given in table below.

Detector 1	IR3_CO2	M1	**Detector 19**	IR3_CO2	M3
Detector 2	IR3_CO2	M2	**Detector 20**	IR3_CO2	M3
Detector 3	UV/IR_CO2	M1	**Detector 21**	IR_H2O	M3
Detector 4	IR4_H2O+CO2	M2	**Detector 22**	UV/IR_CO2	M3
Detector 5	IR3_CO2	M1	**Detector 23**	IR4_H2O+CO2	M5
Detector 6	IR3_CO2_LD*	M1	**Detector 24**	IR4_H2O+CO2	M5
Detector 7	UV/IR_CO2	M3	**Detector 25**	IR4_H2O+CO2	M5
Detector 8	IR3_H2O	M3	**Detector 26**	IR3_CO2	M2
Detector 9	IR3_CO2	M4	**Detector 27**	IR4_H2O+CO2	M2
Detector 10	IR3_CO2	M3	**Detector 28**	IR4_H2O+CO2	M2
Detector 11	UV/IR_H2O	M2	**Detector 29**	UV/IR_H2O	M2
Detector 12	IR3_CO2	M4	**Detector 30**	UV/IR_H2O	M2
Detector 13	IR3_CO2	M4	**Detector 31**	IR3_CO2	M2
Detector 14	IR3_CO2	M4	**Detector 32**	UV/IR_CO2	M1
Detector 15	IR3_CO2	M4	**Detector 33**	IR3_CO2_LD	M1
Detector 16	IR3_CO2	M4	**Detector 34**	IR3_CO2_LD	M1
Detector 17	IR_H2O	M3	**Detector 35**	UV/IR_CO2	M1
Detector 18	UV/IR_CO2	M3	**Detector 36**	IR3_CO_2	M1

Table 1: List of detectors under tests

** Long distance multi-IR version*

Whatever the brand and technology may be, flame detectors are mostly furnished with :

- Dry contact relays (fire, fault, auxiliary relays)
- 24 VDC operating voltage
- 4 to 20 mA output
- Communication network RS-485
- Microprocessor based digital signal processing
- Flashing led
- Data logging
- Self test functions: Automatic/Manual Optical Integrity test (OI) or Built In Test (BIT) to check electronic circuitries, sensors & window cleanliness
- Front heated optics to improve performance in case of ice, condensation or snow

The sensitivity of detectors – i.e. their range of detection – can be configured by different means according to the brand of the apparatus:

- Software/PC
- Handheld unit
- Hardware switch on electronic board

The setting of the sensitivity level of the detector is not always accessible to the user so the detectors were tested in their default configuration (factory setting). Note that this setting is not necessary the maximum level of sensitivity.

In terms of certification and standards, flame detectors are supposed to be compliant with European CPC, ATEX & EMC directives and relevant standards. Most of them were also evaluated by a third party according to SIL & FM 3260 requirements.

4. INDOOR TESTS

4.1 TEST METHOD

4.1.1 OPTICAL BENCH TEST

4.1.1.1 LOCATION

Small scale tests were performed between June 2009 and August 2010 in Verneuil-en-Halatte – France by the Accident Risk Department of INERIS.

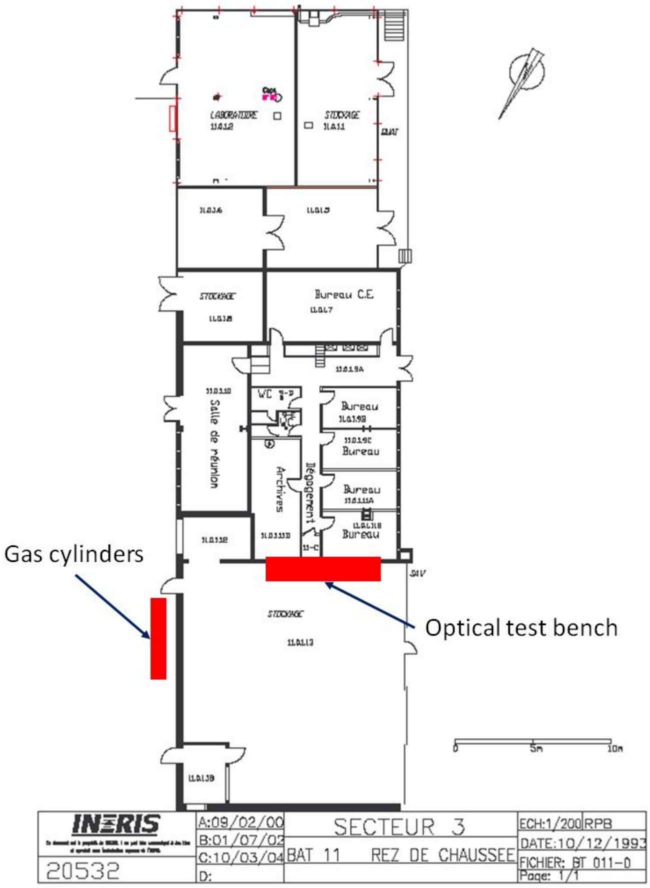

Figure 3: Optical bench arrangement

4.1.1.2 EQUIPMENT

An optical bench test was used to evaluate flame detector response sensitivity and directional dependence.

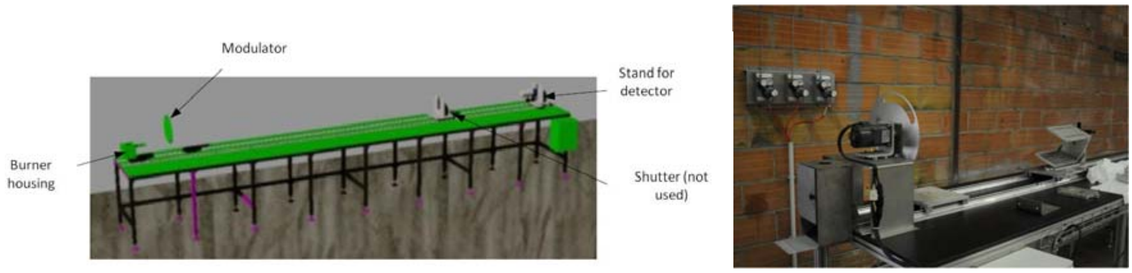

Figure 4: Optical bench

The optical bench was designed with a maximum effective working length of 6 m. Detection distances were measured thanks to a metric index with a precision of ± 10 mm intended on the length of the bench.

A mounting device was specifically provided to allow adjustment of the height and orientation of detectors such that their optical axis could coincide with the optical axis of the source.

The mounting device was also made up to allow rotation of the detector around its optical axis - angle β - and, around a second axis perpendicular to the optical axis - angle α -, (figures 5 and 6). An angular index was also appended on the rotating device to measure angles α and β with an accuracy of ± 5°.

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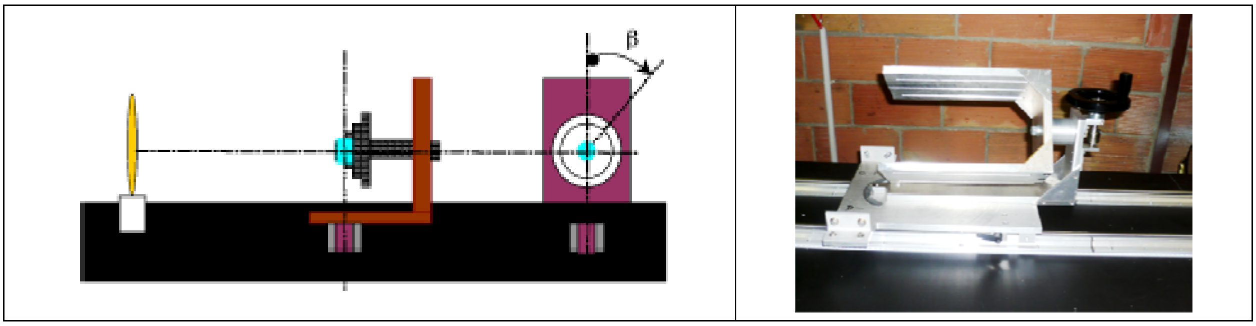


Figure 5: Rotating device for angle β determination (360° rotation)

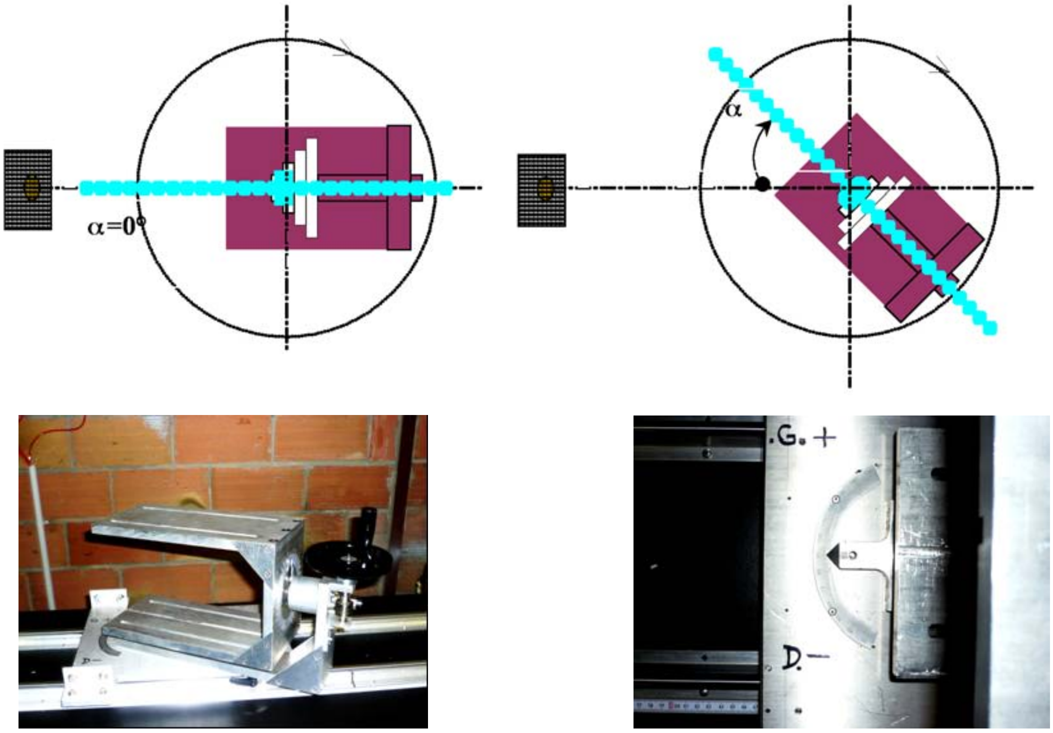
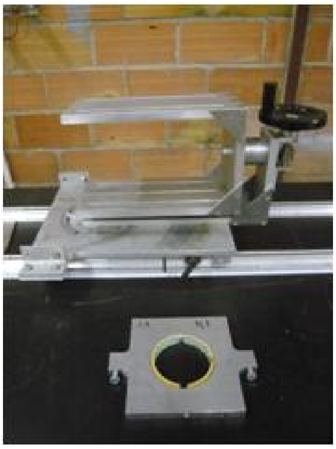


Figure 6: Rotating device for angle α determination (from -65° to +65°)

Detectors were maintained by custom made mechanical brackets as shown in picture 1.



Picture 1: Mounting device for detector

The radiation was produced by the flames generated by the burning of methane, propane and hydrogen. Gas cylinders with purity of more than 98 % were used.

Picture 2: Gas cylinders for hydrogen, methane & propane

The combustion chamber was constituted of a burner and a metallic enclosure. An opening, placed in front of the flame, provided an area of 8 cm^2 to the detectors under tests.

The radiation from the source was modulated at 2 Hz by mean of a rotating chopper disc (modulator) drilled with two openings (picture 3). Modulation characteristics of the radiation source were defined on the basis of preliminary tests that determined the optimal response configuration of detectors.

Picture 3: Combustion chamber & rotating chopper disc

4.1.1.3 GENERAL TEST PROCEDURE

The equipment was installed and used in the operating conditions specified by the manufacturer. In the absence of instructions, a warm-up of 15 minutes was observed.

Three types of flames were tested: methane, propane, hydrogen. For each type of flame, the followings tests were performed:

1. Sensitivity tests

The sensitivity of flame detectors was assessed by the measurement of the maximum detection distance at which the detectors gave a valid alarm within 30 seconds after exposure to the flame.

To do so, the detectors were gradually taken away from the radiation source, by steps of 10 cm, until there was no more detection. Response times were measured 10 times at the maximum detection distance measured (Dmax).

The response of flame detectors, at the maximum detection distance measured, was then tested to the high and low limit values of the voltage specified by the manufacturers.

2. Directional tests

Directional tests were performed at the maximum detection distance measured. A rotation of α, by steps of 5°, was performed up to α-max in both sides of the optical axe. Angle α being positioned at α-max, β angle rotations were then performed for 45°, 90°, 135°, 180°, 225°, 270° and 315°.

3. False stimuli response test

9 flame detectors were tested under following false alarm sources:

Halogen flasher: the detector was installed on the bench test and was exposed to a source of radiation generated by a halogen lamp positioned on the optical axis from a distance of 15 cm to Dmax.

Halogen lamp : 12 V/55W

160 flashs/min

Incandescent bulb: the detector was installed on the bench test and was exposed to the radiation of an incandescent bulb positioned on the optical axis from a distance of 15 cm to Dmax.

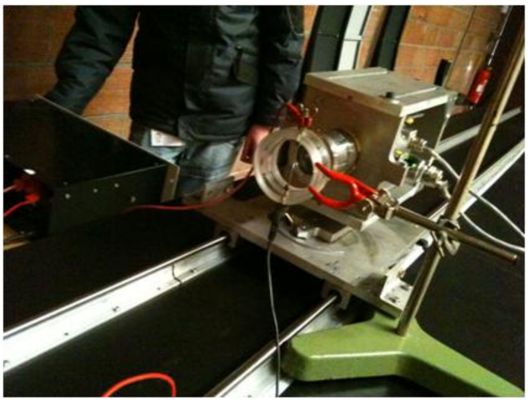
40 watts (x2)

Xenon flasher: the detector was installed on the bench test and was exposed to the radiation of a Xenon lamp positioned on the optical axis from a distance of 15 cm to Dmax.

90 flashs/min ; 5 W

Mechanical sparks: the detector was installed on the bench test and was exposed to the radiation of mechanical sparks generated by grindstoning on the optical axis at a distance of 15 cm and Dmax.

Electrostatic sparks*:* the detector was installed on the bench test and exposed to an electrostatic field influence of the order 0.9 Megavolt/m.



Voltage : 5.5 KV

Electrodes' gap : 6 mm

Arc welding*:* the detector was installed on the bench test and was exposed to the radiation of electrical arc between an electrode and the base material.

0.3 cm rod

Steel plate

70 amperes

Camera flash*:* the detector was installed on the bench test and was exposed to 3 camera flashes at a distance of 15 cm and Dmax.

4. Humidity cycling and conditioning

5 flame detectors were tested under the following climatic conditions:

- Dry heat: detectors were placed inside a climatic chamber and were subjected to a temperature of +55°C for a duration of 16 hours. At the end of the period, each detector was subjected to a functional test based on the EN 54-10 standard.
- Cold: detectors were placed inside a climatic chamber and were subjected to a temperature of -10°C or -30°C (according to manufacturer's instructions) for a duration of 16 hours. At the end of the period, each detector was subjected to a functional test based on the EN 54-10 standard.
- Damp heat: detectors were placed inside a climatic chamber and were subjected to a temperature of +40°C with a relative humidity of 90 % RH for a duration of 16 hours. At the end of the period, each detector was subjected to a functional test based on the EN 54-10 standard.

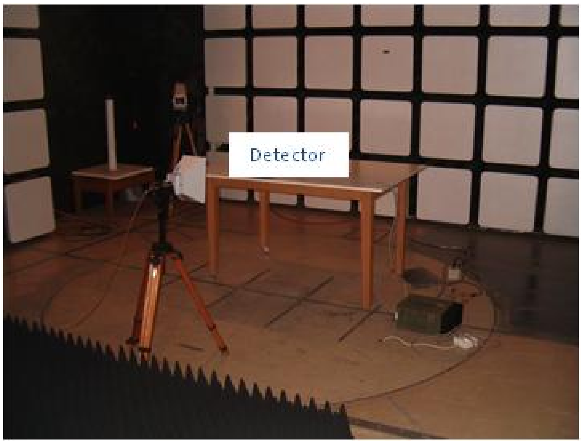
4.1.2 EMC TESTS

Flame detectors were tested according to IEC 61326-3-1:2008 requirements applying to safety-related systems and equipment intended to be used in safety-related systems.

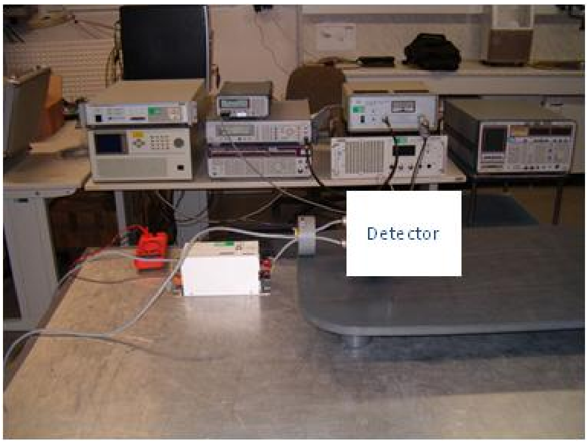
EMC tests were performed according to relevant European standards as described in the following table.

Immunity test	Level of disturbance (IEC 61326-3-1)	Test standard
Electrostatic discharge	± 6 kV in contact ± 8 kV in air	EN 61000-4-2
Radiated EM fields	20 V/m : 0.8-1 GHz 10 V/m : 1.4-2 GHz 3 V/m : 2-2.7 GHz	EN 61000-4-2
Fast transients	± 3 kV	EN 61000-4-4
Injected EM fields	10 V : 150 kHz-80 MHz	EN 61000-4-6
Surge	± 1 kV MD ± 2 kV MC	EN 61000-4-5

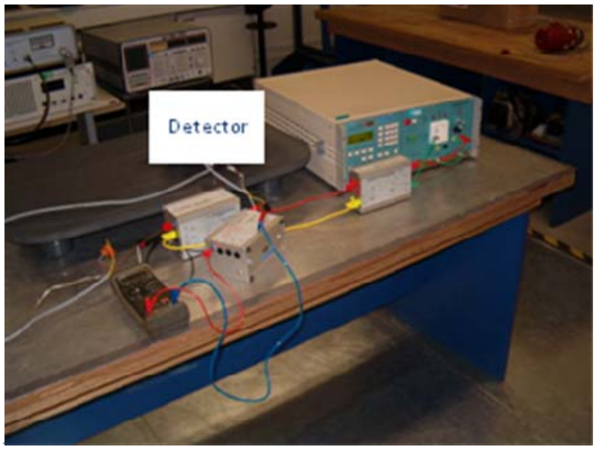
Tests were performed at INERIS/CETIM's EMC lab in Senlis - France. Some views of the different EMC testing equipment are presented hereafter.



Picture 4: Radiated field in anechoic chamber



Picture 5: Injected Radiated field arrangement

	
Picture 6: Electrical fast transients arrangement	*Picture 7: Surge arrangement*

Functions monitored during tests were the following:

- Output relay in closed position
- 4 mA current without presence of flame

4.2 TEST RESULTS

Over 2000 individual tests were performed during the indoor bench test phase.

A representative selection of detectors' technologies was tested regarding sensitivity, directional and voltage dependence (see tables 2 and 3).

Several detectors showed a permanent malfunction and were not tested. This was the case for the detectors from manufacturer 5.

	Arc Welding	Camera flasher	Incandescent bulb	Xenon lamp	Halogen lamp	Grindstone	Electrostatic sparks
Detector 1							
Detector 2							
Detector 3							
Detector 4							
Detector 5							
Detector 6							
Detector 7							
Detector 8							
Detector 9							
Detector 10							
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Detector 29							
Detector 30							
Detector 31							
Detector 32							
Detector 33							
Detector 34							
Detector 35							
Detector 36							

	Tested
	Not tested
	Malfunction

Table 2: Test matrix for immunity to false alarm testing

	ESD	Radiated EM-field	Fast transients	Surge	Injected EM-field	Dry heat	Damp heat	Cold
Detector 1								
Detector 2								
Detector 3								
Detector 4								
Detector 5								
Detector 6								
Detector 7								
Detector 8								
Detector 9								
Detector 10								
Detector 11								
Detector 12								
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Detector 33								
Detector 34								
Detector 35								
Detector 36								

	Tested
	Not tested
	Malfunction

Table 3: Test matrix for immunity to electromagnetic disturbances and climatic variations

4.2.1 FLAME RESPONSE SENSITIVITY

Detection distances and corresponding response times averaged over 10 tests are presented per technology and per manufacturer in table 4.

		Methane		Propane		Hydrogen	
Manufacturer 1	*Technology*	*Detection distance*	*Time of response*	*Detection distance*	*Time of response*	*Detection distance*	*Time of response*
1	IR3_CO2	1.3 m	8.5 s	1 m	8 s	-	-
5	IR3_CO2	1.3 m	8 s	1 m	8.3 s	-	-
36	IR3_CO2	1.3 m	7.7 s	1 m	8.1 s	-	-
6	IR3_CO2_LD	1.4 m	7.7 s	1.1 m	7.8 s	-	-
33	IR3_CO2_LD	2.9 m	9.3 s	2.4 m	8.8 s	-	-
34	IR3_CO2_LD	2.4 m	8 s	1.8 m	8.9 s	-	-
3	UV/IR_CO2	0.5 m	5 s	0.6 m	5.5 s	-	-
32	UV/IR_CO2	0.6 m	5.1 s	0.8 m	4.6 s	-	-
35	UV/IR_CO2	0.5 m	4.9 s	0.8 m	5.3 s	-	-
Manufacturer 2	*Technology*	*Detection distance*	*Time of response*	*Detection distance*	*Time of response*	*Detection distance*	*Time of response*
2	IR3_CO2	1.6 m	14.5 s	1.3 m	15.4 s	-	-
4	IR4_H2O+CO2	1.5 m	13.1 s	1.2 m	12.9 s	0.7 m	13.1 s
27	IR4_H2O+CO2	1.6 m	13.8 s	1.2 m	12.3 s	0.7 m	12 s
28	IR4_H2O+CO2	1.5 m	12.3 s	1.2 m	13.1 s	0.7 m	12.5 s
11	UV/IR_H2O	-	-	-	-	-	-
30	UV/IR_H2O	-	-	-	-	-	-
Manufacturer 3	*Technology*	*Detection distance*	*Time of response*	*Detection distance*	*Time of response*	*Detection distance*	*Time of response*
10	IR3_CO2	0.5 m / 4.4 m	5 s / 11.2 s	2.6 m	7.5 s / 12 s	-	-
19	IR3_CO2	4.3 m	11.3 s	2.6 m / 3.3 m	7.7 s / 11.5 s	-	-
20	IR3_CO2	4.3 m	11.7 s	2.6 m	7.5 s / 10.7 s	-	-
17	IR3_H2O	1.9 m	4.1 s	1.3 m	3.4 s	1.7 m	3.7 s
8	IR3_H2O	1.9 m	3.0 s	1.3 m	2.9 s	1.7 m	3.2 s
21	IR3_H2O	1.9 m	3.3 s	1.3 m	2.9 s	1.7 m	3.1 s
7	UV/IR_CO2	0.4 m	9.9 s	0.5 m	9.8 s	-	-
18	UV/IR_CO2	0.7 m	7.7 s	-	-	-	-
22	UV/IR_CO2	0.9 m	6.6 s	0.7 m	6.5 s	-	-
Manufacturer 4	*Technology*	*Detection distance*	*Time of response*	*Detection distance*	*Time of response*	*Detection distance*	*Time of response*
9	IR3_CO2	-	-	-	-	-	-
12	IR3_CO2	-	-	1.5 m	25.4 s	-	-
13	IR3_CO2	1 m	5.2 s	-	-	-	-
14	IR3_CO2	1.5 m	20.9 s	-	-	-	-
16	IR3_CO2	1 m	11.1 s	-	-	-	-

Table 4: Results for detection distances and times of response

Comment: Detector 6 was in fact a standard version given the results obtained. The sensitivity of this detector is effectively halved in comparison to the one of its counterparts 33 and 34. Moreover this fact could be verified in large tests. A setting error is probably the cause of the problem.

The test results on the optical bench highlighted the following points:

- a greater sensitivity of the multi-IR technology with respect to UV/IR technology
- a greater sensitivity to hydrocarbon flames of CO2 based detectors with respect to H2O based detectors
- a sensitivity to the hydrogen flame for H2O based detectors similar to the one measured with the flames of hydrocarbons. The mixed version - H2O-CO2 - has a lower sensitivity under the same conditions of comparison
- response times significantly below the normative threshold of 30 seconds
- a better response of multi-IR detectors to the flame of methane than to the flame of propane[2]
- an absence of influence of power supply of devices in their specified operating range

4.2.2 INFLUENCE OF THE ORIENTATION

The results of the measurement of α angle are presented by technology and manufacturer in table 5.

The results for β angles are not presented in detail. In 50 % of cases, the devices correctly detected the flame for all the angles tested. For the remaining cases, the devices were influenced by their orientation on the optical axis, especially when β angles tested were 90 ° and 270 °.

[2] This is probably due to a difference in the intensity of the emitted IR radiation flux between the two flames; knowing that at equal intensity, the sensitivity should be greater with the propane flame.

Manufacturer 1	*Technology*	*Methane*	*Propane*	*Hydrogen*
1	IR3_CO2	50 °	50°	-
5	IR3_CO2	50 °	55°	-
36	IR3_CO2	50 °	59°	-
6	IR3_CO2_LD	50 °	50°	-
33	IR3_CO2_LD	50 °	50°	-
34	IR3_CO2_LD	50 °	50°	-
3	UV/IR_CO2	45°	45°	-
32	UV/IR_CO2	45°	45°	-
35	UV/IR_CO2	45°	45°	-
Manufacturer 2	*Technology*	*Methane*	*Propane*	*Hydrogen*
2	IR3_CO2	20°	20°	-
4	IR4_H2O+CO2	30°	35°	20°
27	IR4_H2O+CO2	30°	30°	20°
28	IR4_H2O+CO2	30°	30°	20°
11	UV/IR_H2O	-	-	-
30	UV/IR_H2O	-	-	-
Manufacturer 3	*Technology*	*Methane*	*Propane*	*Hydrogen*
10	IR3_CO2	35°	35°	-
19	IR3_CO2	45°	45°	-
20	IR3_CO2	55°	45°	-
17	IR3_H2O	20°	25°	55°
8	IR3_H2O	25°	25°	50°
21	IR3_H2O	30°	30°	50°
7	UV/IR_CO2	35°	40°	-
18	UV/IR_CO2	45°	-	-
22	UV/IR_CO2	35°	35°	-
Manufacturer 4	*Technology*	*Methane*	*Propane*	*Hydrogen*
9	IR3_CO2	-	-	-
12	IR3_CO2	-	30°	-
13	IR3_CO2	40°	-	-
14	IR3_CO2	25°	-	-
16	IR3_CO2	40°	-	-

Table 5: Overview of α-angle results

4.2.3 FALSE ALARM SOURCES

Results related to detectors' immunity in case of the presence of a false alarm source are presented in table 6.

			Arc Weld.	Camera	Incandes.	Xenon	Halogen	Grindstone	ESD
M1	**Det 1**	**IR3_CO2**	**-**	-	-	-	-	No Alarm	-
M2	**Det 2**	**IR3_CO2**	**Alarm**	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm
M1	**Det 3**	**UV/IR_CO2**	**-**	-	-	-	-	-	No Alarm
M1	**Det 5**	**IR3_CO2**	**Alarm**	No Alarm	No Alarm	No Alarm	**Alarm**	No Alarm	No Alarm
M1	**Det 6**	**IR3_CO2_LD**	**-**	-	-	-	-	No Alarm	No Alarm
M3	**Det 7**	**UV/IR_CO2**	**Alarm**	No Alarm	**Alarm**	No Alarm	**Alarm**	**Alarm**	**Alarm**
M4	**Det 9**	**IR3_CO2**	**-**	-	-	-	-	-	No Alarm
M4	**Det 12**	**IR3_CO2**	**Alarm**	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm
M4	**Det 14**	**IR3_CO2**	**Alarm**	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm
M3	**Det 17**	**IR3_H2O**	**Alarm**	No Alarm	**Alarm**	No Alarm	**Alarm**	No Alarm	No Alarm
M3	**Det 18**	**UV/IR_CO2**	**-**	-	-	-	-	-	-
M3	**Det 19**	**IR3_CO2**	**Alarm**	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm
M2	**Det 28**	**IR4_H2O+CO2**	**Alarm**	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm
M1	**Det 32**	**UV/IR_CO2**	**-**	-	-	-	-	**Alarm**	-
M1	**Det 33**	**IR3_CO2_LD**	**-**	-	-	-	-	-	No Alarm
M1	**Det 34**	**IR3_CO2_LD**	**Alarm**	No Alarm	No Alarm	No Alarm	**Alarm**	-	-
M1	**Det 35**	**UV/IR_CO2**	**Alarm**	No Alarm	No Alarm	No Alarm	No Alarm	-	-
M1	**Det 36**	**IR3_CO2**	**Alarm**	No Alarm	No Alarm	No Alarm	**Alarm**	-	-

Table 6: Immunity against different false alarm sources

Test results show that arc welding is a source of systematic false alarm when it is present at the close proximity of detectors. This is why manufacturers recommend moving away the devices from such an interfering source and do not guarantee total immunity of the devices.

It should be noted that the most sensitive devices to false alarm sources are those with the shortest response times.

4.2.4 EMC AND CLIMATIC DISTURBANCES

A selection of detectors was tested according to IEC 61326-3-1 EMC requirements and under different climatic conditions. Results are presented in table 7.

[redacted]

Table 7: Immunity against EMC & climatic disturbances

** Results obtained before changing detectors*

Most detectors were not disturbed during tests, except the ones of M1 manufacturer when EMC tested. These detectors have since been modified and laboratory tests attest of their compliance with all EMC requirements of IEC 61326-3-1standard.

5. OUTDOOR TESTS

Outdoor tests on flame detectors were performed between October 27th and December 5th 2010 in Borås, Sweden by the *department of Fire Technology of SP Technical Research Institute of Sweden*.

5.1 LOCATION

The tests were performed on a fire fighters training field near SP in Borås, Sweden. This location was chosen as it offered a relatively flat and opened surface of 80 m long. Also, it allowed the realization of open fires and had all the necessary utilities.

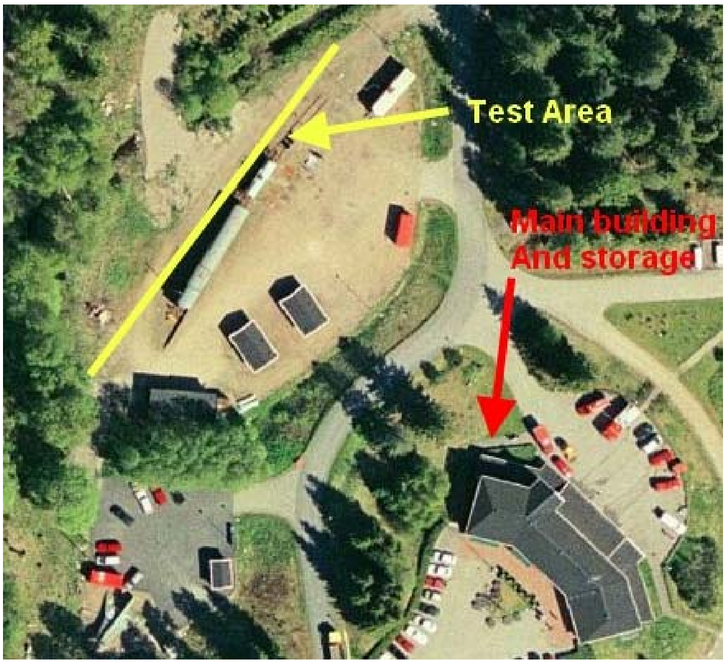


Photo 7: Overview of the test site

5.2 TEST METHOD

Test method and test parameters were jointly developed by SP Technical Research Institute of Sweden and INERIS.

Five different fuels were used for testing response sensitivity to the flame and determining the horizontal field of view of detectors.

5.2.1 FUELS

The five fuels were selected for their representativeness of the three physical states (solid, liquid and gas) and to reflect the usual specifications of manufacturers. Note that heptane is the reference fire for flammable liquid fuels, while methane is the reference fire for gaseous fuels under the EN 54-10 standard.

Heptane

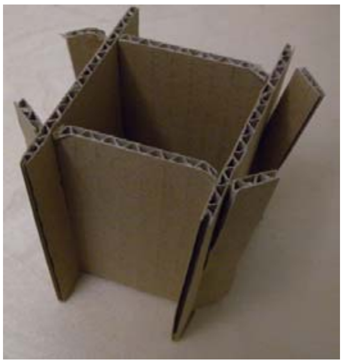
Heptane was poured into a 0.3 x 0.3 x 0,08 m (L x W x H) steel tray filled with water at a level of about 20 cm, and ignited for 1 minute. After each test, the fire was extinguished by placing a non-combustible plate of calcium silicate above the tray. Between each test, the tray was re-filled with heptane.

Ethanol

Ethanol was poured into a 0.3 x 0.3 x 0.08 m (L x W x H) steel tray, filled with water at a level of about 20 cm, and ignited for 1 minute. After each test, the fire was extinguished by placing a non-combustible plate of calcium silicate above the tray. Between each test, the tray was re-filled with ethanol.

Cardboard

Twelve 0.3 x 0.3 m cardboard sheets, vertically standing in two stacks of six sheets each were arranged. Stacks were then set in a supportive box made of steel mesh in the middle of which four sheets of 0, 08 x 0, 08 m cardboard were placed for the ignition. The measurement was started when the detectors could see the flames over the stacks.



Methane

A sand burner of 0.17 x 0.17 x 0.17 m was used to produce a flame of about 0.8 m high. The detectors were exposed after stabilization of burning conditions.

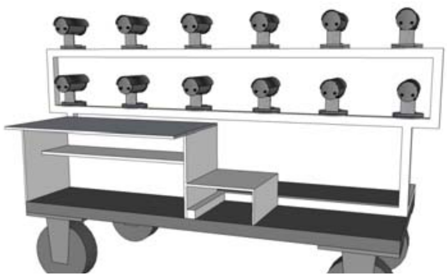
Hydrogen

The hydrogen flame was produced under the same conditions as those of methane. The flame height was approximately 0, 6 m. Detectors were exposed after stabilization of burning conditions.

5.2.2 TESTING RAMP

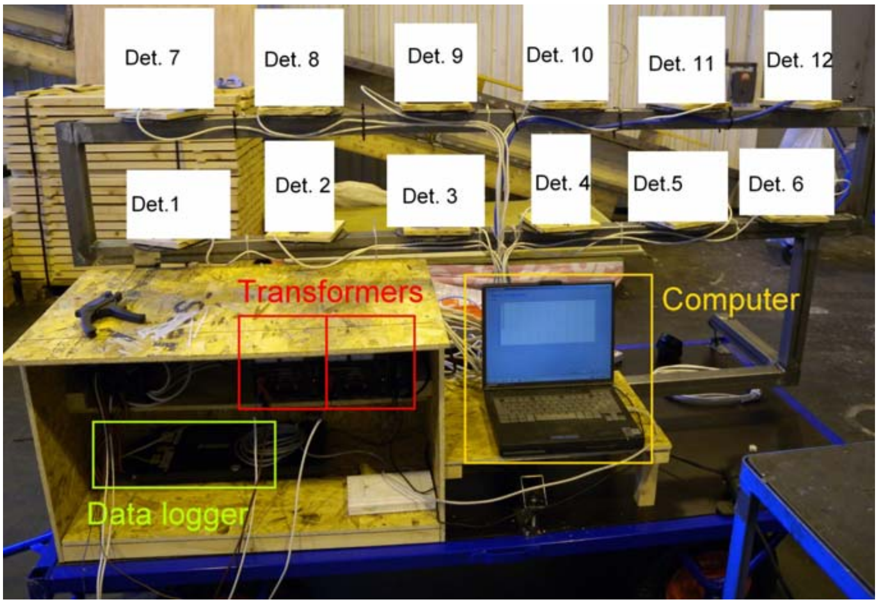
A metal ramp mounted on a trolley was made to support up to 12 detectors. The detectors could be oriented horizontally. A vertical adjustment was also possible to compensate ground irregularities.

The detectors were placed on the ramp at a distance of 0.3 m apart, on two levels and at ground height between 1 m and 1.5 m.



The following equipment was used as power supply and data acquisition system :

- 2 DC power transformers (output 24 V, < 1 Ampere)
- 1 data logger
- 1 Computer



5.2.3 MONITORING OF WEATHER CONDITIONS DURING TESTS

Environmental conditions (temperature, humidity, wind speed and direction, etc.) were recorded with a weather station every 5 minutes. Records of manual observations have complemented this information.

5.2.4 GENERAL TEST PROCEDURE

The tests were conducted as follows:

1. Cleaning of the lenses of detectors with a suitable cleaning agent
2. Transportation of equipment from the storage to the test area
3. Equipment connections and verification of operational status
4. Warm-up of equipment and installation of the weather station
5. Functional testing of devices and sight adjustment
6. Tests to determine performance parameters
7. Shut off and logout of detectors
8. Transportation of equipment from the test area to the storage

5.2.4.1 DETERMINATION OF D10 AND D30 DISTANCES

The sensitivity of detectors was evaluated from the measurement of D10 and D30 distances:

- **D10**: Maximum distance at which the detectors gives an alarm signal within 10 s after exposure.
- **D30**: Maximum distance at which the detectors gives an alarm signal within 30 s after exposure.

Detectors were moved away from the source, step by step, in accordance to the following distances of test:

7 m	35 m
9 m	40 m
11 m	45 m
13 m	50 m
15 m	55 m
17 m	60 m
19 m	65 m
21 m	70 m
24 m	75 m
27 m	80 m
30 m	

Two series of tests were conducted to determine D10 and D30 distances. In the first series, measurements were made at each test distance and until all the devices no longer detected the flame. In the second series, measurements started at the distance, determined in the first series, at which all the devices detected the flame.

5.2.4.2 MAXIMUM HORIZONTAL DETECTION ANGLE

The maximum horizontal viewing angle was determined from the measurement of angle α. The maximum horizontal viewing angle is equal to twice the angle α. The angle α was measured at the maximum distance D30 obtained during testing of the previous chapter. It was only measured in one direction but symmetry of both sides of the optical axis was assumed. All detectors were first tested at 0 °. In case of no detection, the distance was reduced until the outbreak of the fire alarm is achieved. The detectors were then tested at 12.5 °. Depending on the answer at 12.5 °, the angle could be increased or decreased to determine the maximum value.

5.2.5 LIMITATION OF THE METHOD

The test method has the following limitations:

- Slight differences in distance to the flame existed given the positioning of detectors on the ramp
- The measurements of distances and angles were made manually using uncalibrated tools
- The data acquisition system had an accuracy of ± 1 s

5.3 TEST RESULTS

In total, over 250 individual tests were performed during the outdoor test phase to determine D10, D30 and α parameters for the different detectors and with the different fuels. An overview of the different tests performed and a simplified description of the weather conditions at the time of tests is given in table 8.

[redacted]

Table 8: Overview of performed tests during the outdoor test phase

The explanation of the conditions during the tests is detailed below.

[redacted]

5.3.1 DETECTION DISTANCES

Detection distances measured are reported in table 9. Measurement results of the first and second series of tests are included. Tables 10 to 14 provide details.

[redacted]

Table 9: Flame distances D10 and D30

Fuel: Heptane

Distance	Det. 1	Det.2	Det. 3	Det. 4	Det. 5	Det. 6	Det. 7	Det. 8	Det. 9	Det. 10	Det. 11	Det. 12
5 m	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	y	x, y
7 m	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	y	x, y
9 m	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	y	y
11 m	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	y	y
13 m	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	y	x, y
15 m	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	**Y**	**Y**
17 m	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	**Y**	**X**,y,**Y**
19 m	x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		y
21 m	**X**,y,**Y**	y,**Y**	x, y,**Y**	y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	y	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		y
24 m	y,**Y**		**X**,y,**Y**	**Y**	**X**,y,**Y**	**X**,y,**Y**	**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		**Y**
27 m	y,**Y**		y,**Y**		x, y,**Y**	y,**Y**		**X**, **Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		
30 m	**Y**				y,**Y**	y,**Y**		x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		
35 m			y					x, y	x, y,**Y**	**X**, **Y**		
40 m									y,**Y**	x,**X**,y,**Y**		
45 m									y,**Y**	x,**X**,y,**Y**		
50 m									y,**Y**	x,**X**,y,**Y**		
55 m									**Y**	**X**,y,**Y**		
60 m									y,**Y**	x,**X**,y,**Y**		
65 m										x, y,**Y**		
70 m										**Y**		
75 m										**Y**		
80 m												

x =Within 10s first series
X =Within 10s validation series
y =Within 30s first series
Y =Within 30s validation series

Two tests performed
One test performed (first series)
One test performed (validation series)
Not tested
Detector malfunction

Table 10: Results from the distance tests performed with Heptane as fuel

Fuel: Ethanol

Distance	Det. 1	Det.2	Det. 3	Det. 4	Det. 5	Det. 6	Det. 7	Det. 8	Det. 9	Det. 10	Det. 11	Det. 12
5 m	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	
7 m	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	y
9 m	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	x, y	y	x, y
11 m	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**		
13 m	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		**Y**
15 m	**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		y,**Y**
17 m	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		
19 m	y,**Y**		x, y,**Y**	**Y**	**X**,y,**Y**	**X**,y,**Y**		x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**		**Y**
21 m	**X**,y,**Y**		x, y,**Y**	**Y**	**X**,y,**Y**	x,**X**,y,**Y**		x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**		
24 m	y		y		y,**Y**	y,**Y**		x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**		
27 m								**Y**		x,**X**,y,**Y**		
30 m								**X**, **Y**	**X**,y,**Y**	x,**X**,y,**Y**		
35 m								**X**, **Y**		x,**X**,y,**Y**		
40 m									**Y**	**X**,y,**Y**		
45 m								**X**, **Y**		x,**X**,y,**Y**		
50 m										y,**Y**		
55 m										y,**Y**		
60 m										y		
65 m												
70 m												
75 m												
80 m												

x =Within 10s first series
X =Within 10s validation series
y =Within 30s first series
Y =Within 30s validation series

Two tests performed
One test performed (first series)
One test performed (validation series)
Not tested
Detector malfunction

Table 11: Results from the distance tests performed with Ethanol as fuel

Fuel: Cardboard

Distance	Det. 1	Det.2	Det. 3	Det. 4	Det. 5	Det. 6	Det. 7	Det. 8	Det. 9	Det. 10	Det. 11	Det. 12
5 m												
7 m												
9 m	x, y	x, y	x, y	x, y	x, y		x, y	x, y	x, y	x, y		x, y
11 m	**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**	**X**,y,**Y**	x, y	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		x,**X**,y,**Y**
13 m	x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	**X**, **Y**	**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		
15 m	**X**,y,**Y**	**Y**	x,**X**,y,**Y**	**Y**	**X**,y,**Y**	**X**,y,**Y**	y,**Y**	y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		
17 m	y	y	x, y,**Y**	y	y			y	x, y,**Y**	x,**X**,y,**Y**		
19 m			y,**Y**						x,**X**,y,**Y**	x,**X**,y,**Y**		
21 m			y						x, y	x,**X**,y,**Y**		
24 m									**Y**	x,**X**,y,**Y**		
27 m									y	x,**X**,y,**Y**		
30 m									y	x,**X**,y,**Y**		
35 m										**X**,y,**Y**		
40 m										x,**X**,y,**Y**		
45 m										x,**X**,y,**Y**		
50 m										**Y**		
55 m												
60 m												
65 m												
70 m												
75 m												
80 m												

x =Within 10s first series
X =Within 10s validation series
y =Within 30s first series
Y =Within 30s validation series

Two tests performed
One test performed (first series)
One test performed (validation series)
Not tested
Detector malfunction

Table12: Results from the distance tests performed with Cardboard as fuel

Fuel: Methane

Distance	Det. 1	Det.2	Det. 3	Det. 4	Det. 5	Det. 6	Det. 7	Det. 8	Det. 9	Det. 10	Det. 11	Det. 12
5 m												
7 m	x, y	x, y	x, y	x, y	x, y		x, y	x, y	x, y	x, y	x, y	x, y
9 m	x, y	x, y	x, y	x, y	x, y		x, y	x, y	x, y	x, y	x, y	x, y
11 m	x, y	x, y	x, y	x, y	y		x, y	x, y	x, y	x, y	x, y	x, y
13 m	x, y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		**X**,y,**Y**	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**
15 m	**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		x,**X**,y,**Y**	x,**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**
17 m	x, y,**Y**	x, y,**Y**	x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**		x, y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**	y	x, y,**Y**
19 m	y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	**X**,y,**Y**	y,**Y**		y,**Y**	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**	**Y**	y,**Y**
21 m	y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**	y,**Y**	**X**,y,**Y**		y,**Y**	**X**,y,**Y**	**X**,y,**Y**	x,**X**,y,**Y**		**Y**
24 m	y,**Y**	y	y,**Y**	y,**Y**	**X**,y,**Y**		y	x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**		y,**Y**
27 m	y,**Y**	y	x,**X**,y,**Y**	y,**Y**	x,**X**,y,**Y**			x,**X**,y,**Y**	x, y,**Y**	x,**X**,y,**Y**		**Y**
30 m	y		x,**X**,y,**Y**	y	x, y,**Y**			x,**X**,y,**Y**	x, y	x,**X**,y,**Y**		
35 m	y		**X**,y,**Y**		y			x,**X**,y,**Y**	x,**X**,y,**Y**	x,**X**,y,**Y**		
40 m			y					x,**X**,y,**Y**	x, y,**Y**	**X**,y,**Y**		
45 m								x,**X**,y,**Y**	y	x,**X**,y,**Y**		
50 m								**X**,y,**Y**	y	x,**X**,y,**Y**		
55 m										x,**X**,y,**Y**		
60 m										**X**,y,**Y**		
65 m										**X**, **Y**		
70 m												
75 m										**Y**		
80 m										y,**Y**		

x =Within 10s first series
X =Within 10s validation series
y =Within 30s first series
Y =Within 30s validation series

Two tests performed
One test performed (first series)
One test performed (validation series)
Not tested
Detector malfunction

Table 13: Results from the distance tests performed with Methane as fuel

Fuel: Hydrogen

Distance	Det. 1	Det.2	Det. 3	Det. 4	Det. 5	Det. 6	Det. 7	Det. 8	Det. 9	Det. 10	Det. 11	Det. 12
5 m												
7 m			x, y	x, y				x, y		x, y	x, y	
9 m				y				x, y		x, y	x, y	

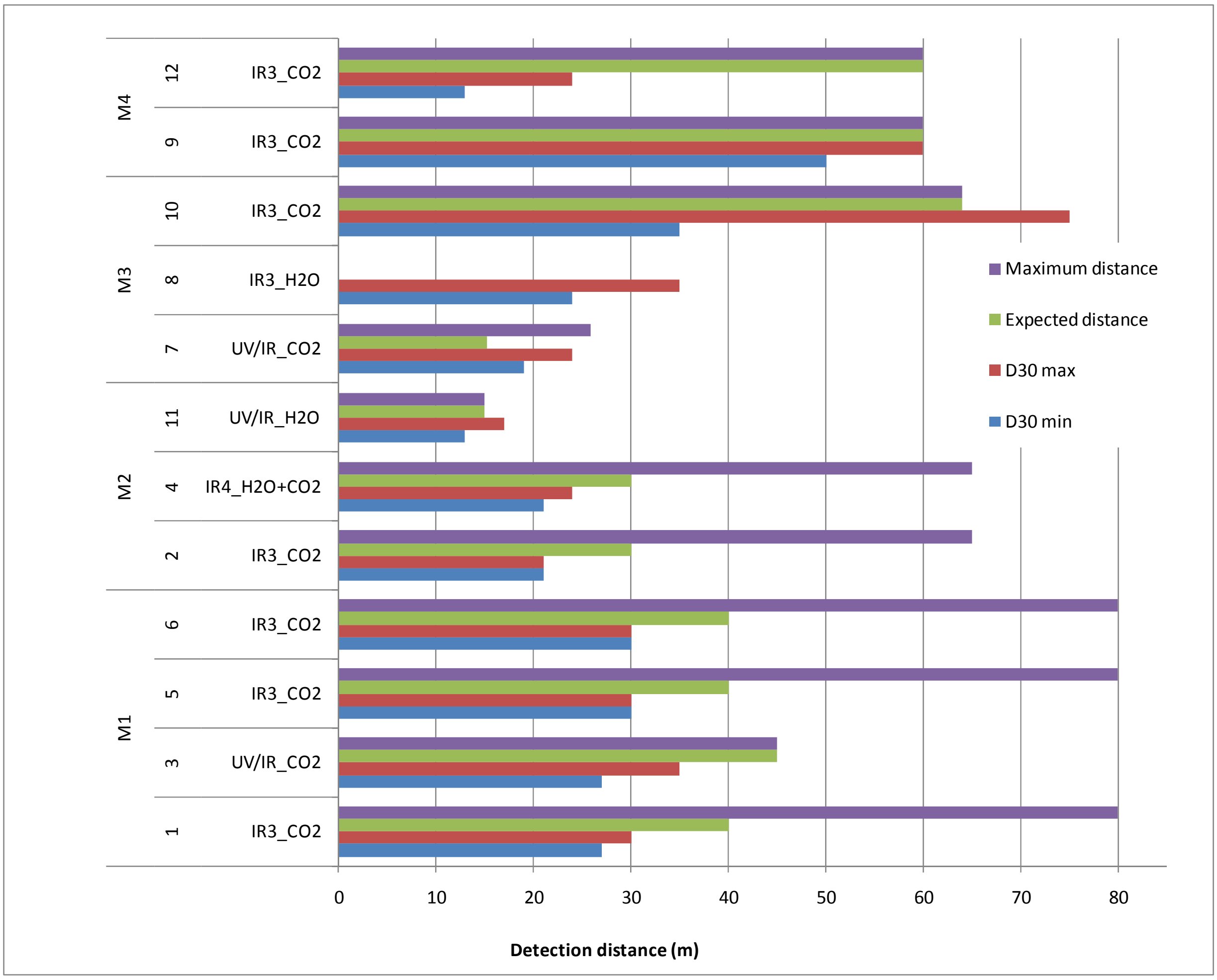
x =Within 10s first series
X =Within 10s validation series
y =Within 30s first series
Y =Within 30s validation series

Two tests performed
One test performed (first series)
One test performed (validation series)
Not tested
Detector malfunction

Table 14: Results from the distance tests performed with Hydrogen as fuel

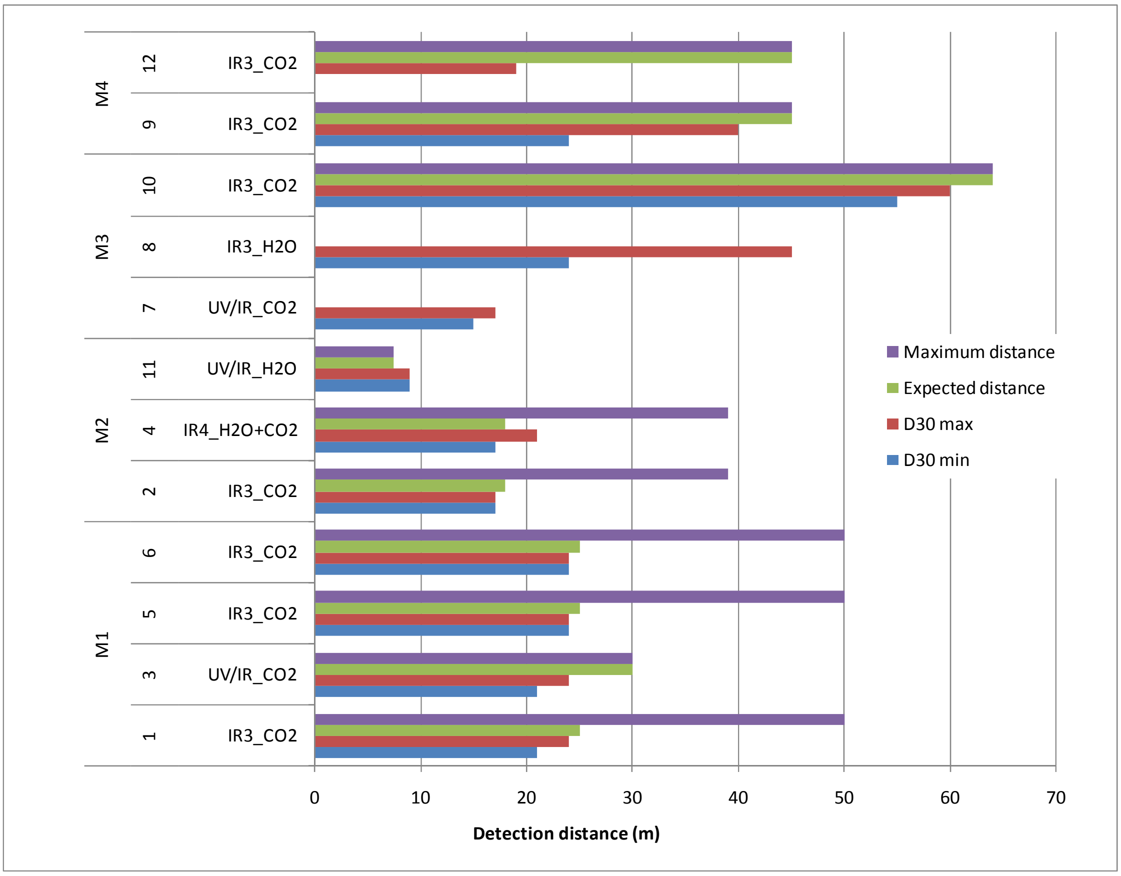
Notes:
Difficulties of handling and transportation of hydrogen on the test site did not allow the achievement of all specified tests.

Figures 1 to 4 show the minimum and maximum detection distances measured in relation to the ones specified by the manufacturer (if any) for standard fires[3]. The "maximum distance" is the specified distance for the highest sensitivity setting level, while the "expected distance" is the specified distance to the default sensitivity setting (factory setting). **Note that the maximum distances specified are those measured within the limit of 30s (D30), while response times specified are usually below 10s.**

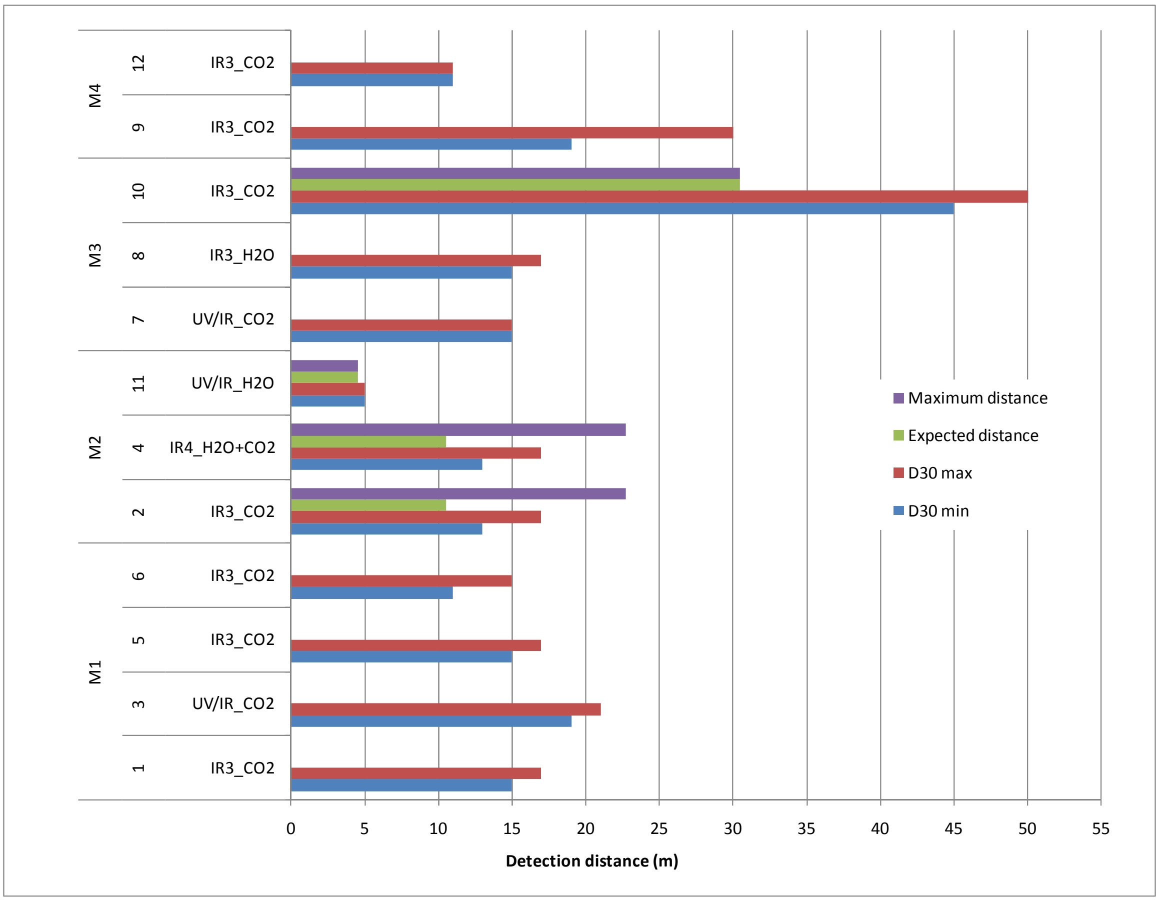


Graph 1: Measured detection distances vs. specified distances – Heptane fuel

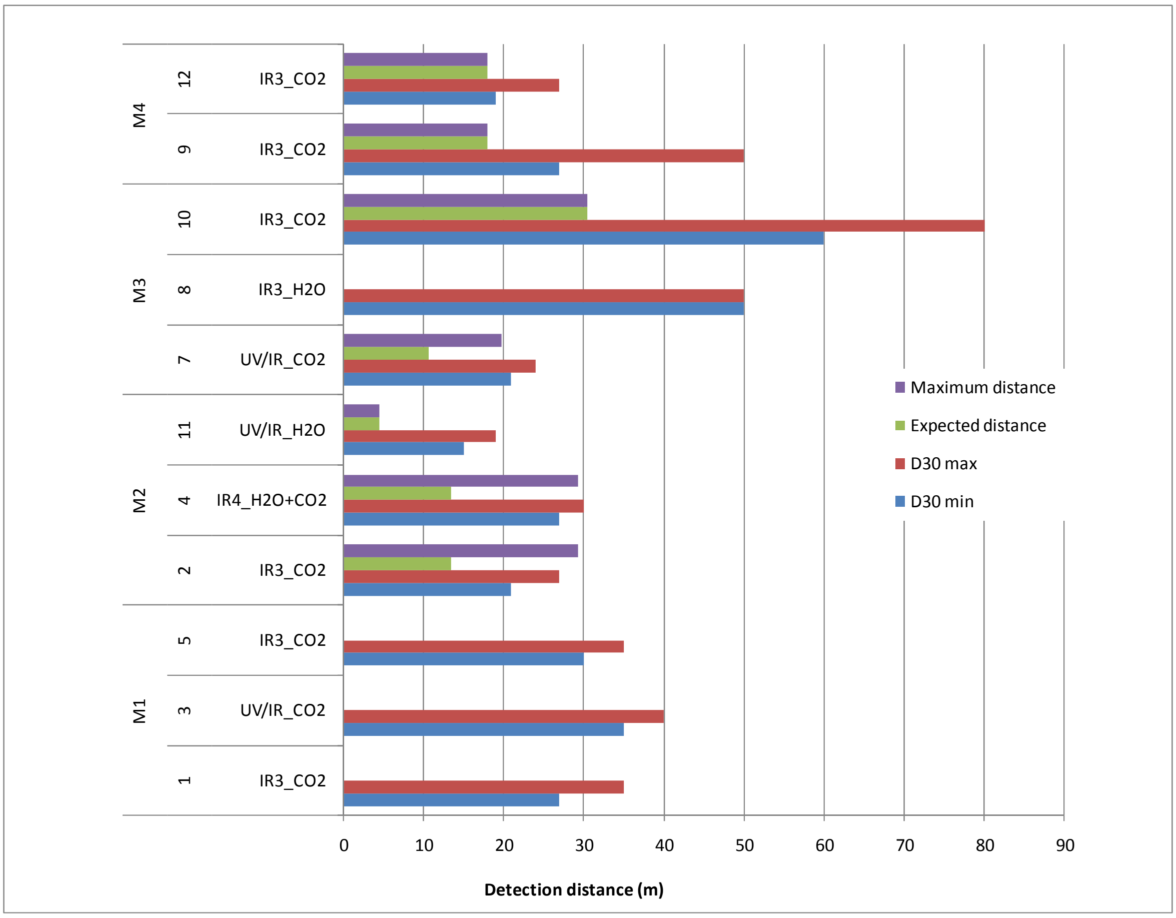
[3] Heptane and ethanol fires 30 cm x 30 cm



Graph 2: Measured detection distances vs. specified distances – Ethanol fuel



Graph 3: Measured detection distances vs. specified distances – Cardboard fuel



Graph 4: Measured detection distances vs. specified distances – Methane fuel

The results obtained highlight the following points:

- the maximum D30 detection distances measured are generally 20 to 30 % lower than the values specified by the manufacturers, when the fires used are comparable to standard fires[4] (see graph 1 and 2),
- the measured detection distances are well above the values specified by the manufacturers, for fires of methane and cardboard[5] (see figures 3 and 4),
- the measured detection distances with a single detector are generally comparable from one test to another, but differences of 40 to 70 % were observed in some cases (8, 9, 10 in particular),
- an average deviation of about 30 % is observed between the maximum D10 and D30 distances measured (cf. table 9),
- a correct detection of the hydrogen flame for "H_2O" detectors (detectors 4, 8 and 11) and an unexpected response of "CO_2" detectors is observed (detectors 3 and 10),
- detection distances are generally larger in the absence of precipitation,
- an earlier detection occurs in windy conditions,
- detectors are not hindered by temperature conditions in the range of 9°C to 11°C, as well as in the presence of snow or frost.

[4] Heptane and ethanol fires 30 cm x 30 cm

[5] For methane and cardboard fires, flames are not comparable to "normalized" flames

5.3.2 FIELD OF VIEW

α angles were measured at a single distance from the source and therefore do not fully characterize the horizontal field of view[6]. The results are summarized in the table below.

Detector	Manufacturer	Technology	Heptane [α-angle@distance]	Ethanol [α-angle@distance]	Cardboard [α-angle@distance]	Methane [α-angle@distance]
1	M1	IR3_CO2	20°@30m	25°@24m	45°@17m	15°@30m
2	M2	IR3_CO2	15°@24m	10°@19m	30°@17m	5°@27m
3	M1	UV/IR_CO2	30°@30m	30°@24m	20°@21m	35°@30m
4	M2	IR4_H2O+CO2	25°@24m	20°@19m	30°@17m	35°@27m
5	M1	IR3_CO2	15°@35m	5°@27m	45°@17m	15°@30m
6	M1	IR3_CO2	15°@35m	5°@27m	45°@17m	N/A
7	M3	UV/IR_CO2	15°@24m	12.5°@17m	25°@17m	20°@24m
8	M3	IR3_H2O	10°@35m	45°@27m	N/A	15°@45m
9	M4	IR3_CO2	15°@65m	25°@27m	12.5°@21m	12.5°@45m
10	M3	IR3_CO2	20°@80m	25°@65m	N/A	0°@80m
11	M2	UV/IR_H2O	12.5°@17m	20°@11m	12.5°@7m	15°@13m
12	M4	IR3_CO2	25°@24m	12.5°@17m	35°@11m	5°@27m

Table 15: Angle α measurement – results

Note: α angles of detectors 8 and 10 were not determined due to adverse weather conditions

For information, horizontal fields of view (or vertical ones) are represented in the operating instructions of manufacturers in the form of diagrams (see Figure 8). Viewing angles evolve according to the distance between detectors and the radiation source. This distance is expressed as a percentage of the maximum detection distance specified by the manufacturer. The specified value of the horizontal viewing angle is generally between 50 % and 70 % of the maximum range of detection. It corresponds to the maximum angle in the field of view.

[6] Reminder : angle α = half horizontal field of view

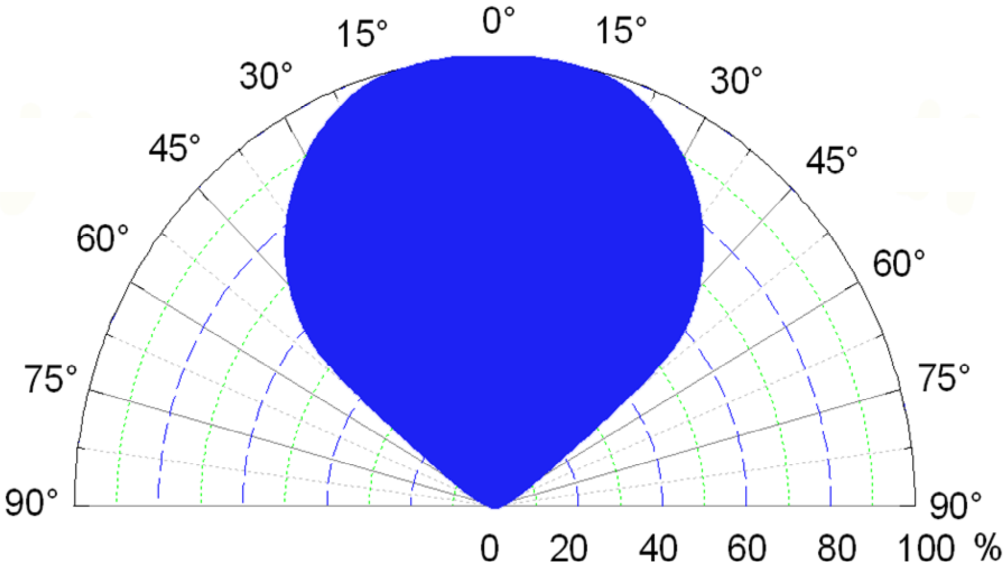


Figure 8: Horizontal or vertical field of view as a function of detection distance

The measured horizontal viewing angles are highly variable from one detector to another and from a fire to another. Knowing that weather conditions sometimes changed during the tests, the detectors were not necessarily placed at the maximum detection distance measured during the corresponding tests. Analysis of the results obtained for the same production and type7 showed that the viewing angle varies with the distance detection chosen for the measurement. It remains difficult to compare measured angles to angles determined from charts provided by manufacturers.

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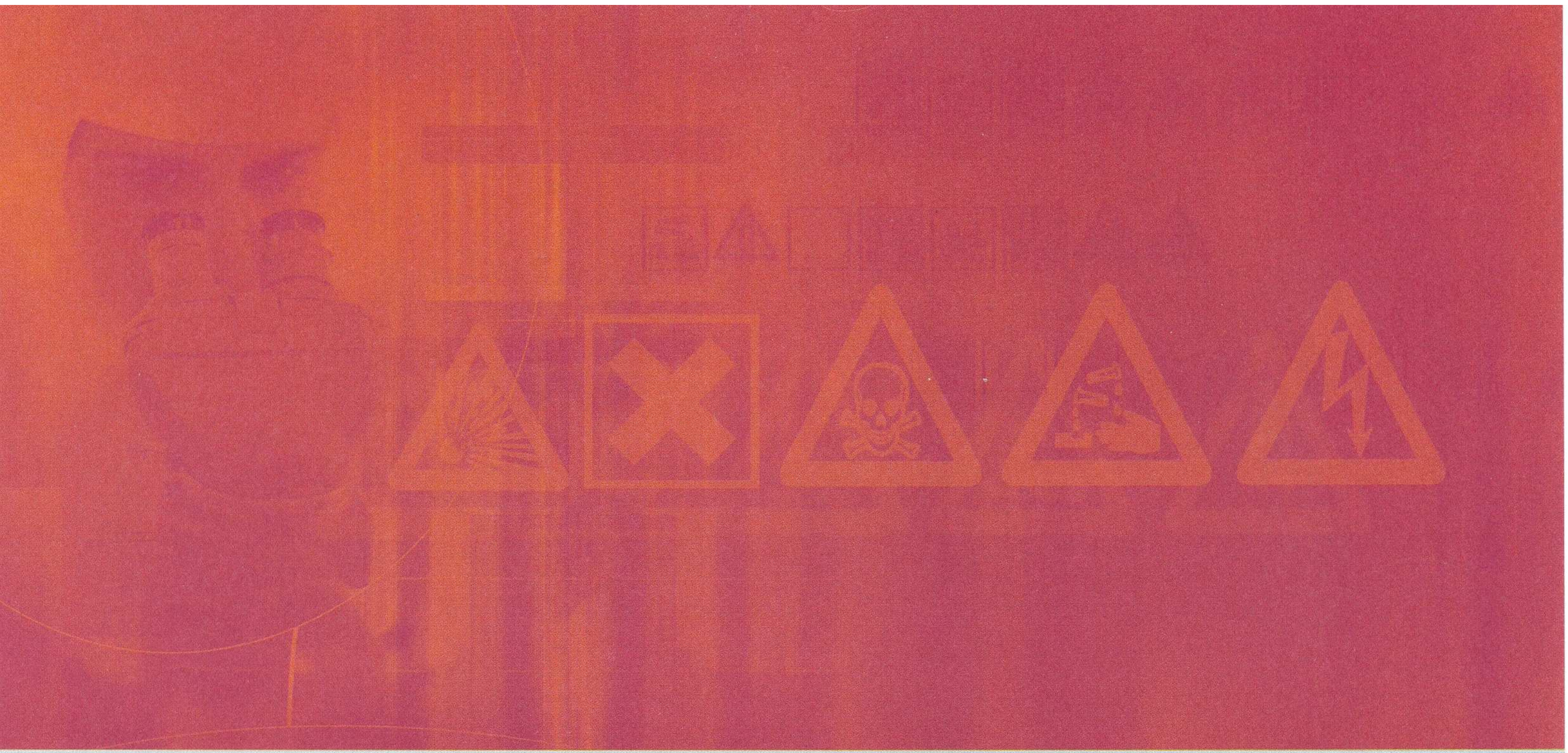
[7] *Detectors 1, 5 et 6 (manufacturer M1) and detectors 9 et 12 (manufacturer M4)*

6. CONCLUSIONS

The results of the test campaign show the main following key observations:

- the longest detection distances are obtained for the multi-IR detectors based on the characteristic emission peak of CO_2, while the UV/IR detectors are less sensitive,
- the maximum detection distance measured, in outdoor conditions, in a 30 s time are usually 20-30 % lower than the values specified by the manufacturers, when the fire used are similar to "normalized" fire (fires of heptane and ethanol),
- the detection distances measured, in outdoor conditions, are much higher than the distances specified by manufacturers, with methane and carboard fires,
- the detection distances measured in outdoor conditions, with a same detector, are generally comparable from one test to another, **but differences from 40 to 70 % are observed in some cases,**
- an average difference of about 30 % is observed between the maximum D10 and D30 measured distances, given that the detection distances are specified in D30 by the manufacturers while the response time advertised are generally lower than 10 seconds. *This observation is important because the response time requirements of flame detectors are set by those applicable to the safety function, which are dictated by the kinetics of the dangerous phenomenon to manage.*
- the orientation of the detectors on their optical axis influences their sensitivity in nearly 50 % of cases,
- the detectors have proved their **robustness against hard weather conditions or severe electromagnetic interferences and pretty good immunity against false alarm sources,**
- the horizontal viewing angles measured in outdoor conditions are below 60 degrees, although they can reach 90 degrees in some cases.

Variations of response observed during outdoor testing show the influence of environmental conditions on the detection distances of flame detectors. Ultimately, **compliance with a safety margin of 50 %** of the maximum distance specified by manufacturers may be recommended when using detectors outdoor. **This margin is the guarantee of an optimal probability of detection, response time and field of view**, particularly when the flame detectors are integrated into a chain carrying a function of control of major accident risks.



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