

GAS SEQUENCES FOR CALIBRATION AND CALIBRATION CHECK TESTING OF THE MULTIRAE INSTRUMENT FAMILY



Figure 1. The MultiRAE family.

The MultiRAE is a family of multi-gas and multi-threat monitors that combines continuous monitoring capabilities for volatile organic compounds (VOCs), toxic and combustible gases, and radiation, with Man Down Alarm functionality, in one highly portable, wireless instrument. MultiRAE monitors offer an industry-leading selection of interchangeable, field-replaceable electrochemical, combustible, infrared, PID (photoionization detector), and gamma radiation sensors to fit a wide variety of applications. The MultiRAE monitors are highly customizable with over 20 field-interchangeable intelligent sensor options for a total of up to six threats monitoring at a time. RAE Systems Technical Note TN-114: Sensor Specifications and Cross-Sensitivities (available for free download from www.raesystems.com/downloads/tech-notes) give the information on sensor specifications, cross-sensitivities, and calibration information to assure the proper instrument exploitation.

PURPOSE OF THIS TECHNICAL NOTE

The variety of sensor combinations, including corrosive, chemically active and highly adsorptive do not always address the proper calibration gas sequences and the calibration check tests that could potentially lead to actual gases. This can create misleading data in the field and cause possible threats to workers/responders' personal health and safety. The aim of this technical note is to experimentally confirm the calibration sequences for the most often-used gas combinations.

CALIBRATION

Calibration refers to an instrument's measuring accuracy relative to a known traceable concentration of test gas. Direct Reading Portable Gas Monitors (DRPGMs) compare the sensor's response to a known concentration of the test gas. The instrument's response to the calibration gas serves as the reference point¹ (see <https://www.osha.gov/dts/shib/shib093013.html>).

Instrument inaccuracy due to improper or irregular maintenance and calibration can lead to exposure to hazardous levels of toxic gases or an oxygen-deficient atmosphere. This exposure can cause workers/responders to suffer serious injuries or illness, and even death. Flammable gas explosions can be catastrophic.

The best way to verify that a DRPGM detects gas accurately and reliably is to test it with a known concentration of gas. This procedure verifies whether the sensors in the instrument respond accurately and whether the alarms function properly.

The International Safety Equipment Association (ISEA) in its statement² makes clear the definition of the full calibration, bump test and calibration check procedures:

http://www.safetysystem.org/userfiles/file/calibration_statement-2010-mar4.pdf

- a. **Bump Test (Function Check)** – A *qualitative* function check where a challenge gas is passed over the sensor(s) at a concentration and exposure time sufficient to activate all alarm indicators to present at least their lower alarm setting. The purpose of this check is to confirm that gas can get to the sensor(s) and that all the alarms present are functional.
- b. **Calibration Check** – A *quantitative* test utilizing a known traceable concentration of test gas to demonstrate that the sensor(s) and alarms respond to the gas within manufacturer's acceptable limits. This is typically $\pm 10\%$ to 20% of the test gas (unless otherwise specified by the manufacturer, internal company policy, or a regulatory agency).

c. Full calibration – The *adjustment* of the sensor(s) response to match the desired value, compared to a known traceable concentration of test gas. This should be done in accordance with the manufacturer’s instructions.

CALIBRATION METHODS

RAE Systems recommends two calibration methods:

- Manual
- Automated

Manual. A manual procedure includes a source of calibrating gas, a gas regulator (GR), a Teflon-type connecting tubing for gas delivery to the instrument, and the instrument itself. Manual calibration suggests two procedures: Full Calibration and Calibration Check. Instrument functionality (alarms) is checked during the latter one. To perform the calibration, attach a Gas Delivery System (GDS) to the instrument either through the T-type connection (left image in Figure 2) or through the Calibration adapter (right image), and follow the instructions in the user’s guide, available at <http://www.raesystems.com/>

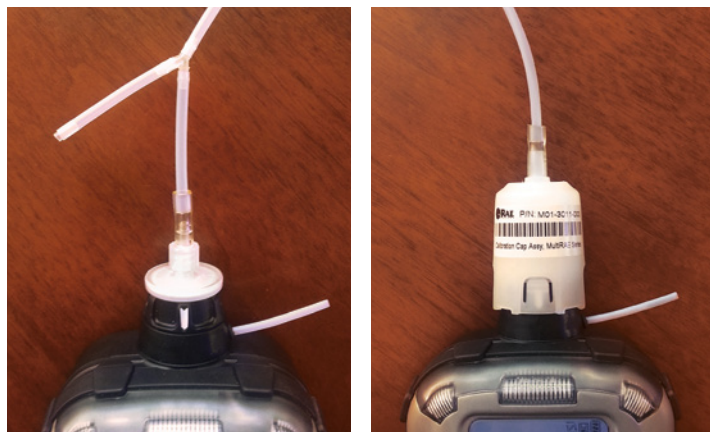


Figure 2. The T-type and the Calibration Adapter connection for gas delivery to the instrument.

Both GDSs are working well and provide equal gas delivery to the instrument, as shown in Figure 3. T-type tubing connection does not ship with the MultiRAE instruments family, but can be ordered separately, p/n M02-3008-000.

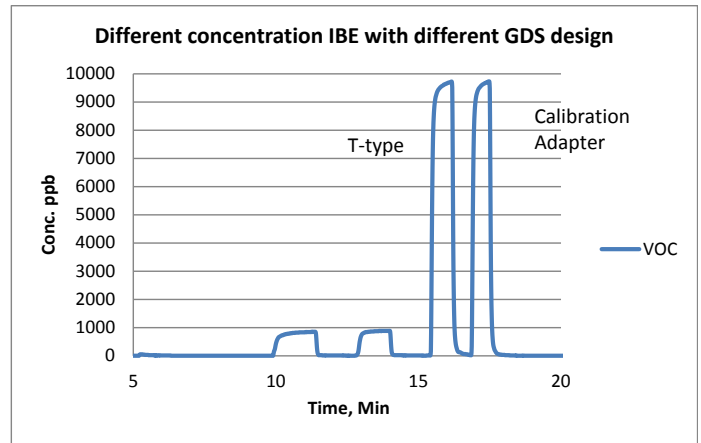


Figure 3. Instrument response to the different IBE (isobutylene) concentrations with the T-type and the calibration adapter connection.

Automated. Automated calibration comprises a gas source with a gas regulator and tubing, an AutoRAE 2 Automatic Test and Calibration System, which includes a controller and cradles with built-in tubing system, pump, and valves (refer to the user’s guide, available at <http://www.raesystems.com/>) and the instrument. Automated calibration includes performing a full calibration and a bump test. For the quantitative verification, a calibration check procedure is still required, and it needs to be performed manually.



Figure 4. AutoRAE 2. Controller and two cradles.

Since the calibration procedure can be done in the field (manual) or in stationary conditions like a special room or laboratory (either method could be used), further manual calibration checking is required, and it should give the same reading for both calibration methods, regardless of the place and method for full calibration, to ensure the proper instrument reading in the field.

CALIBRATION SEQUENCE, CALIBRATION CHECK, AND MUTUAL SENSOR CROSS-SENSITIVITY

Eleven main sensor configurations for the new MultiRAE instruments family (MultiRAE Lite, MultiRAE, and MultiRAE Pro) were tested. The data from the tests and verifications are presented in this section. The full calibration conditions are mostly the same for the manual process and the AutoRAE 2 calibration. Verification of the test sequence results are done by manual calibration check in the same gas order (sequence) as the full calibration with the constant-flow regulator (GR) designed to deliver a 0.5 L/min gas flow, and the special calibration adapter (or the T-type tubing connection).

Note. The AutoRAE 2 System can support up to 10 instruments. A video is available at: <http://www.youtube.com/watch?v=uBTvaxCmJuc>.

While setting purge and soak time are selected, make sure that they provide the same gas concentration to the first and the following instruments in the cradles during a full calibration. Otherwise, the instrument in the first cradle will be calibrated differently from the others, and it may lead to a different measurement reading in between the instruments for the same gas concentration in the field.

CO-H₂S-O₂-LEL-PID

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	1	CO	50	ppm	20	20
2	2	H ₂ S	10	ppm	20	20
3	16	O ₂	18	%	20	20
4	22	CH ₄	50	%LEL	20	20
5	19	IBE	10	ppm	20	20

Manual full calibration performed without special precautions, using the same calibration gas, constant flow regulator (GR) with a 0.5 L/min. gas flow, calibration adapter (or T-type tubing connection), and the same gases sequence as at Full Calibration in AutoRAE 2.

Calibration check test of the gas sequence performed in the same way as manual or automated full calibration procedure and data of the sensor response in the instruments to the calibration gases exposure, as well as their cross-sensitivity, are presented in the table:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	O ₂ %	CO ppm	H ₂ S ppm	PID ppb
Air		0	20.9	0.0	0.0	0.0
4x*	*	48	18.0	50.0	9.8	1.2
IBE	10	0	21.2	0.0	0.0	9.6

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

LEL-H₂S-O₂-PID-SO₂

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	22	CH ₄	50	%LEL	20	20
2	2	H ₂ S	10	ppm	20	20
3	16	O ₂	18	%	20	20
4	19	IBE	10	ppm	20	20
5	3	SO ₂	5	ppm	20	60

Manual full calibration and the calibration check test done without special precautions, except tubing pre-soak within 60 seconds was done for an SO₂ sensor.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	O ₂ %	SO ₂ ppm	H ₂ S ppm	PID ppb
Air		0	20.9	0.0	0.0	0.0
4x*	*	48	18.0	0.3	9.7	1.2
IBE	10	0	21.2	0.1	0.0	9.6
SO ₂	5	0	1.5	4.9	0.7	0.2

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

Figure 5 provides a graph of the instrument's response to calibration gas exposure.

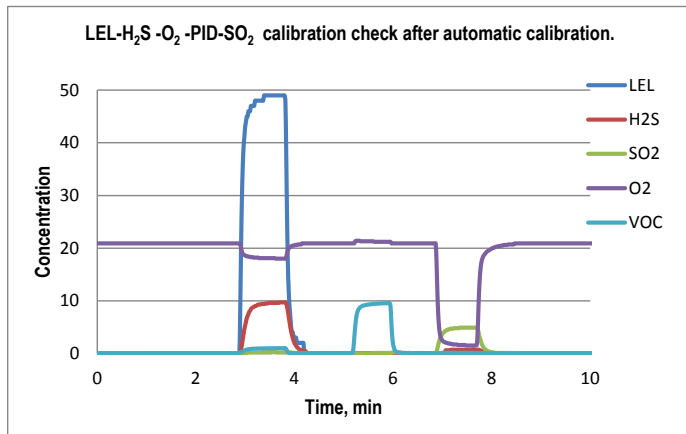


Figure 5. The calibration check test after the auto calibration in AutoRAE 2. (Note: LEL scale is %LEL, O₂ scale is vol. %, and EC sensors scale is ppm. Applied 4-gas mix: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

LEL-H₂S-O₂-CO-CO₂

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	22	CH ₄	50	%LEL	20	20
2	2	H ₂ S	10	ppm	20	20
3	16	O ₂	18	%	20	20
4	1	CO	50	ppm	20	20
5	18	CO ₂	2000	ppm	20	20

Manual full calibration and the calibration check test done without special precautions.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	O ₂ %	H ₂ S ppm	CO ppm	CO ₂ ppm
Air		0	20.7	0	0	50.0
4x*	*	49	18.0	9.9	48.5	0.0
CO ₂	2000	0	20.9	0	0	2000.0

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

Cl₂-LEL-O₂-PID-NH₃

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	11	Cl ₂	10	ppm	20	300
2	22	CH ₄	50	%LEL	20	20
3	16	O ₂	18	%	20	20
4	19	IBE	10	ppm	20	20
5	7	NH ₃	50	ppm	20	60

Manual full calibration and calibration check test done without special precautions, except GDS system pre-soak for a Cl₂ sensor according to RAE Systems Technical Note TN-201 and for an NH₃ sensor for 60 seconds before the calibration procedure.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	O ₂ %	H ₂ S ppm	CO ppm	CO ₂ ppm
Air		0	20.9	0	0	0
Cl ₂	10	0	1.5	9.8	0.0	0
4x*	*	51	18.4	0.0	0.0	1
IBE	10	0	21.2	0.0	0.0	10
NH ₃	5	0	1.0	0.1	46.5	1

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

PH₃-NH₃-LEL-PID-Cl₂

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	8	PH ₃	5	ppm	20	60
2	7	NH ₃	50	ppm	20	60
3	22	CH ₄	50	%LEL	20	20
4	19	IBE	10	ppm	20	20
5	11	Cl ₂	10	ppm	20	300

Manual full calibration and calibration check test done without special precautions, except GDS system pre-soak for a Cl₂ sensor according to RAE Systems Technical Note TN-201 and for NH₃ and PH₃ sensors for 60 seconds before calibration.

Calibration check test of the gas sequence and cross-sensitivity data:

Unit 6 Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	PH ₃ ppm	Cl ₂ ppm	NH ₃ ppm	PID ppm
Air		0	0	0	0	0
PH ₃	5	0	4.8	0.0	0.0	0.5
NH ₃	50	0	0.2	0.0	48.2	1.4
CH ₄	50%LEL	50	0.2	0.0	0.5	0.0
IBE	10	0	0.1	0.0	0.0	10.1
Cl ₂	10	0	0.0	10.3	0.0	0.1

HCN-PH₃-CO-H₂S-O₂-LEL

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	6	HCN	10	ppm	20	60
2	8	PH ₃	5	ppm	20	60
3	1	CO	50	ppm	20	20
4	2	H ₂ S	10	ppm	20	20
5	16	O ₂	18	%	20	20
6	22	CH ₄	50	%LEL	20	20

Manual full calibration and calibration check test done without special precautions, except GDS system HCN and PH₃ sensor pre-soak for 60 seconds before calibration.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	O ₂ %	H ₂ S ppm	CO ppm	PH ₃ ppm	HCN ppm
Air		0	20.9	0.0	0.0	0.0	0.5
HCN	10	0	1.0	0.0	0.0	0.0	9.5
PH ₃	5	0	1.1	2.9	3.5	4.9	50.0
4x*	*	47	17.9	9.1	48.5	10.2	50.0

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

NO-O₂-CO-H₂S-LEL-SO₂

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	4	NO	25	ppm	20	20
2	16	O ₂	18	%	20	20
3	1	CO	50	ppm	20	20
4	2	H ₂ S	10	ppm	20	20
5	22	CH ₄	50	%LEL	20	20
6	3	SO ₂	5	ppm	20	60

Manual full calibration and calibration check test done without special pre-cautions, except GDS system SO₂ sensor pre-soak for 60 seconds before calibration.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	O ₂ %	H ₂ S ppm	CO ppm	NO ppm	SO ₂ ppm
Air		0	20.9	0.0	0.0	0.0	0.0
NO	25	0	1.7	3.7	10.7	24.5	0.0
4x*	*	46	18.2	9.2	46.5	4.8	0.3
SO ₂	5	0	1.7	0.0	0.0	0.5	4.9

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

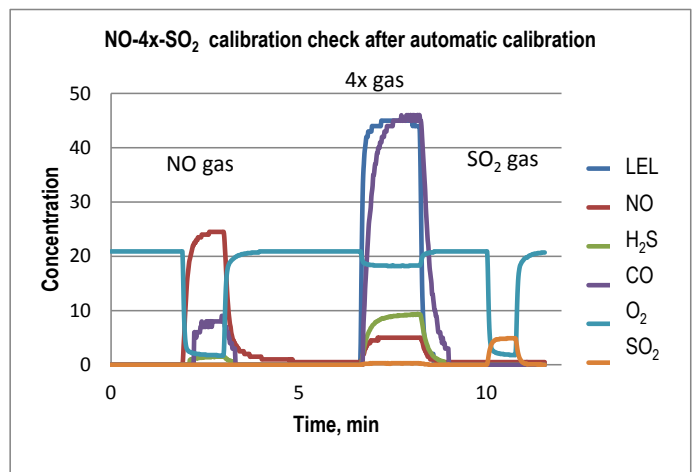


Figure 6. The Calibration check test after the auto calibration in AutoRAE 2, mutual cross-sensitivity. (Note: : LEL scale is %LEL, O₂ scale is vol. %, and EC sensors scale is ppm. Applied 4-gas mix: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

NH₃-NO₂-CO-H₂S-O₂-LEL

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	7	NH ₃	50	ppm	20	20
2	5	NO ₂	5	ppm	20	60
3	1	CO	50	ppm	20	20
4	2	H ₂ S	10	ppm	20	20
5	16	O ₂	18	%	20	20
6	22	CH ₄	50	%LEL	20	20

Manual full calibration and calibration check test done without special precautions, except GDS system NO₂ sensor pre-soak for 60 sec before calibration.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	NO ₂ ppm	H ₂ S ppm	CO ppm	O ₂ ppm	NH ₃ ppm
Air		0	0.0	0.0	0.0	20.9	0.0
NH ₃	50	0	0.0	0.0	0.0	2.0	48.5
NO ₂	5	0	4.9	0.0	0.0	20.9	0.0
4x*	*	48	0.0	10.1	48.0	18.0	1.0

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

HCN-O₂-CO-H₂S-LEL-PID

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	6	HCN	10	ppm	20	60
2	16	O ₂	18	%	20	20
3	1	CO	50	ppm	20	20
4	2	H ₂ S	10	ppm	120	20
5	22	CH ₄	50	%LEL	20	20
6	19	IBE	10	ppm	20	20

Manual full calibration and calibration check test done without special precautions, except GDS system HCN sensor pre-soak for 60 seconds before calibration.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	HCN ppm	H ₂ S ppm	CO ppm	O ₂ %	VOC ppm
Air		0	1.0	0.0	0.0	20.9	0
HCN	10	0	10.3	0.0	0.0	1.9	0
4x*	*	46	50.0	8.7	48.2	18.2	1
IBE	10	0	5.5	0.0	0.0	21.1	10

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

NO₂-NH₃-SO₂-LEL-H₂S

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	5	NO ₂	5	ppm	120	60
2	7	NH ₃	50	ppm	20	60
3	3	SO ₂	5	ppm	20	60
4	22	CH ₄	50	%LEL	20	20
5	2	H ₂ S	10	ppm	20	60

Manual full calibration and calibration check test done without special precautions, except GDS system NO₂, NH₃, H₂S, and SO₂ sensor pre-soak for 60 seconds before calibration.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	NO ₂ ppm	NH ₃ ppm	SO ₂ ppm	H ₂ S ppm
Air		0.0	0.0	0.0	0.0	0.0
NO ₂	5	0.0	5.0	0.0	0.0	0.0
NH ₃	50	0.0	0.0	48.0	0.0	0.0
SO ₂	5	0.0	0.0	0.0	5.2	1.0
LEL	50%LEL	48.0	50.0	0.0	0.0	0.0
H ₂ S	10	0.0	0.0	0.0	0.0	9.7

HCN-Cl₂-LEL-O₂-PID

AutoRAE 2 sequence:

Sequence	Gas Index	Gas	Conc.	Conc. Units	Purge Time Sec.	Soak Time Sec.
1	6	HCN	10	ppm	20	60
2	16	Cl ₂	10	ppm	20	300
3	22	CH ₄	50	%LEL	20	20
4	16	O ₂	18	ppm	20	20
5	19	IBE	10	ppm	20	20

Manual full calibration and calibration check test done without special precautions, except GDS system Cl₂ sensor pre-soak according to RAE Systems Technical Note TN-201 and pre-soak for HCN sensor for 60 seconds before calibration.

Calibration check test of the gas sequence and cross-sensitivity data:

Calibration check (average data)

Gas	Conc. ppm	LEL % LEL	HCN ppm	Cl ₂ ppm	O ₂ %	PID ppm
Air		0.0	ppm	ppm	%	ppm
HCN	10	0.0	9.0	0.0	1.8	0.0
Cl ₂	10	0.0	0.0	10.5	1.6	0.0
4x*	*	48.0	50.0	0.0	18.2	1.1
IBE	10	0.0	5.5	0.0	21.1	9.7

* 4x is the mixture of 4 gases: CO (50 ppm), H₂S (10 ppm), O₂ (18% vol.), CH₄ (50% LEL).

Consolidated table of the calibration gas sequences for the main MultiRAE instrument family configurations.

Calibration Sequence	Sensor configuration										
	CO	CH ₄	CH ₄	Cl ₂	PH ₃	HCN	NO	NH ₃	HCN	NO ₂	HCN
1	CO	CH ₄	CH ₄	Cl ₂	PH ₃	HCN	NO	NH ₃	HCN	NO ₂	HCN
2	H ₂ S	H ₂ S	H ₂ S	CH ₄	NH ₃	PH ₃	O ₂	NO ₂	O ₂	NH ₃	Cl ₂
3	O ₂	O ₂	O ₂	O ₂	CH ₄	CO	CO	CO	CO	SO ₂	CH ₄
4	CH ₄	IBE	CO	IBE	IBE	H ₂ S	H ₂ S	H ₂ S	H ₂ S	CH ₄	O ₂
5	IBE	SO ₂	CO ₂	NH ₃	Cl ₂	O ₂	CH ₄	O ₂	CH ₄	H ₂ S	IBE
6						CH ₄	SO ₂	CH ₄	IBE		

1. "Calibrating and Testing Direct-Reading Portable Gas Monitors," OSHA, SHIB 09-30-2013
2. "ISEA Statement on Validation of Operation For Direct Reading Portable Gas Monitors," ISEA, 03-05-2010