American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

A Summary of the NIOSH evaluation program of portable direct-reading meters

CHARLES S. McCAMMON

To cite this article: CHARLES S. McCAMMON (1976) A Summary of the NIOSH evaluation program of portable direct-reading meters, American Industrial Hygiene Association Journal, 37:5, 289-295, DOI: 10.1080/0002889768507457

To link to this article: https://doi.org/10.1080/0002889768507457

The National Institute for Occupation Safety and Health (NIOSH) has developed a program to evaluate portable, direct-reading instruments. The results of these evaluations for CO, SO_2, combustible gas, and NO_2 instruments are reported. Realistic performance specifications have been developed for each of these types of instruments.

A Summary of the NIOSH evaluation program of portable direct-reading meters

CHARLES S. McCAMMON, Jr.
United States Department of Health, Education and Welfare, Public Health Service, National Institute for Occupational Safety and Health, Cincinnati, Ohio 45202.

Background and purpose

Under the Occupational Safety and Health Act of 1970, The National Institute for Occupational Safety and Health (NIOSH) has the responsibility of recommending sampling and analytical methods of suitable accuracy for making measurements of worker's exposure to toxic contaminants. In an attempt to meet this responsibility, NIOSH has included the use of portable direct-reading instruments as part of the methodology used to measure contaminants.

The usability of portable instruments is determined through a formal evaluation program. This program is initiated through a literature search for all portable direct-reading instruments sold in the U.S. for the measurement of a specific contaminant, e.g., carbon monoxide. Once these instruments have been found, the distributor or manufacturer is invited to submit their instrument for inclusion in the evaluation program. The instruments are all tested against the same 23 criteria and the results are tabulated and summarized. Once the testing is completed, specific design and performance specifications are drafted, taking into account NIOSH's ideal specifications for a portable instrument and also the state-of-the-art in detecting the specific contaminant as determined by the evaluation program.

There are numerous reasons why NIOSH is conducting these evaluation programs for portable instruments:

1. To encourage equipment manufacturers to improve the performance of instruments.
2. To ascertain the performance capabilities and limitations so that realistic performance standards can be set as the basis for an equipment testing and certification program.
3. To determine which instruments are best suited for NIOSH and OSHA use:
   a. To determine the best techniques for using such instruments.
   b. To determine the limits of accuracy and reliability for consideration in using instrument readings as measurements of contaminant concentrations for possible use as compliance tools.

This report has been reviewed by NIOSH and has been approved for publication. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of NIOSH. Mention of company or product names is not to be considered as an endorsement by NIOSH.

Charles McCammon received a B.S. degree in Chemical Engineering from Arizona State University in 1972. He has worked for NIOSH in the Division of Laboratories and Criteria Development, Engineering Branch since 1972.

TABLE I
Portable CO Meters Tested

METER	MANUFACTURER
Bullard Portable CO Monitor	E. D. Bullard Company Sausalito, California
CO-Dackel	Dortmund, W. Germany Dist. By: Daco Products, Inc. Monticlair, New Jersey
Ecolyzer Model 2800	Energetic Sciences, Inc. New York, New York
EnMet Model PTM (Prototype)	Environmental Metrology Corp. Ann Arbor, Michigan
Portable Carbon Monoxide Indicator Model D	Mine Safety Appliances, Co. Pittsburgh, Pennsylvania
Miran I Variable Path Infrared Analyzer	Wilks Scientific Corporation South Norwalk, Connecticut

4. To inform the public of commercial instrument performance.

Portable direct-reading meter criteria

As defined in this paper, a truly portable direct-reading instrument meets the following criteria:

1. Size—occupies one cubic foot or less in volume.
2. Power requirements—battery operated for 8 hours of continuous use and also able to run directly off AC power if desired.
3. Weight—weighs less than 10 pounds.
4. Direct-reading capabilities—should measure the contaminant of interest directly in ppm or some other useful unit of measurement for the contaminant of interest.
5. Range of concentrations—should measure the contaminant of interest over the range 1/5 to 5 times the 8-hour time-weighed average concentration.
6. Specificity—should be specific for the contaminant of interest and be free from interference from commonly occurring substances.
7. Cost—should be in relation to other instruments available for measuring the same contaminant.
8. Accuracy—should be accurate to within ±5% at the 8-hr TWA concentration. There are other requirements which will be explained in the specifications for specific types of instruments. Obviously, some of the above criteria are idealistic and do not reflect the state-of-the-art in specific contaminant measurement.

Tests completed

So far, NIOSH has completed four instrument laboratory evaluations, two under contract and two in-house. Evaluations for combustible gas,[1] and NO_2[2] instruments have been completed in-house, while evaluations for carbon monoxide[3] and sulfur dioxide[4] were completed under a task order contract with Research Triangle Institute.

Carbon monoxide meters

Six carbon monoxide instruments were obtained for an evaluation program. Listed in Table I are the instruments and their respective manufacturers. The last instrument listed, the Wilks IR, is not a portable meter by NIOSH definition, but it was included because industry considers it to be a portable IR. This work was completed by Research Triangle Institute and copies of their final report which summarizes their entire effort is available from NIOSH, through this author.

Very briefly, the conclusions reached by RTI concerning performance standards are as follows:

Physical characteristics

Portable CO meters shall have the following physical characteristics.

1. *Portability:* Meters including all required parts and accessories shall weigh 12 lbs. or less, have a volume of 1 ft^3 or less with no single dimension in excess of 2 ft, and be capable of operating within specifications from internal, rechargeable batteries for a period of eight hours of continuous use. It shall include a battery condition indicator and be operational

during the recharge cycle. Compatible chargers shall be available, capable of recharging the batteries within sixteen hours without damaging the batteries when left in the continuously charging mode.

2. *Readout:* Meters shall have either a direct readout of CO concentration in parts per million (ppm) or a readout that is easily interpreted in ppm without requiring additional equipment.
3. *Recorder output:* Meters shall have a recorder output to indicate the CO concentration in the sample. The full-scale recorder output shall be greater than 100 mV when terminated in an impedance of 2kΩ. The recorder output shall either be referenced to the ground potential or floating such that grounding either side of the output will not affect the meter.
4. *Simple to operate:* Meters shall be simple to operate so that operators without scientific backgrounds or formal training in the use of the instrument, other than reading the operators manual, can obtain measurements that reflect the instrument's capabilities.
5. *Instructional manuals:* Instruction manuals for each instrument shall include, as a minimum, complete operating instructions including procedures for turn-on, warm-up, zero and calibration checks, sample collection, maintenance, recalibration and performance checks. The manuals shall include flow diagrams and wiring and schematic diagrams, and an estimate of the lifetime of consumable reagents. The manuals shall include parts list suitable for identifying parts and sources of parts for use for replacement orders.
6. *Intrinsic safety:* Meters shall conform to the intrinsic safety specifications of the U. S. Bureau of Mines or approved by Factory Mutual as intrinsically safe for use in hazardous locations, Class 1, Division 1, Group D; and non-incendive for use in Class 1, Division 2, Groups A, B, C and D.
7. *Ruggedness:* Meters shall be sufficiently rugged to withstand routine transporting, handling and use in the field environment by the operator.
8. *Sample conditioning:* Any sample conditioning equipment required shall be an integral part of the meter.
9. *Ease of zero and span adjustments:* Zero and span adjustments shall be readily accessible for field adjustment, and the meter design shall include provisions to introduce zero and calibration gases in non-laboratory environments. The meter shall be capable of being zeroed in a contaminated atmosphere to within 5 ppm of a true zero. If accessories are required for this capability, they shall be considered a physical part of the meter and included as part of its total weight and volume.

Performance characteristics

Portable CO meters shall conform to the following performance requirements:

1. *Useful range:* Meters shall have a useful range which includes values from 1/5 to 6 times the OSHA 8 hour time-weighted-average allowable exposure concentration (TWA limit).
2. *Accuracy:* Meters shall read the true concentration of a sample within a greater of ±10% of reading of ±10% of the TWA limit.
3. *Zero drift:* A meter's zero drift shall not exceed ±10% of the TWA limit during an eight hour period of continuous use while operating from batteries or during an 8 hour period of continuous use while operating from line current.
4. *Span drift:* A meter's response to a CO concentration of approximately 80% of the maximum range shall remain within ±20% of the true value during a period of two weeks of intermittent use.
5. *Minimum detectable change:* Meters shall be able to detect changes of ±10% of reading over the Useful Range of the meter as defined in subsection 1.
6. *Warm-up time.* The meter shall meet all performance specifications after a warm-up time of 15 minutes.
7. *Response time (90%):* The time interval between a step increase or decrease in the CO concentration at the meter's input of at least 70% of its maximum range and the time the meter settles within ±10% of its final readout shall not exceed 2 minutes.

TABLE II
Portable Combustible Gas Meters Tested

METER	MANUFACTURER
J-W Model SS-P Combustible Gas Indicator	Bacharach Instrument Company Pittsburgh, Pennsylvania
J-W Model CSS-P Combustible Gas Indicator	Bacharach Instrument Company Pittsburgh, Pennsylvania
J-M TLV Sniffer Combustible Gas Indicator	Bacharach Instrument Company Pittsburgh, Pennsylvania
MSA Model 40 Combustible Gas Indicator	Mine Safety Appliance, Company Pittsburgh, Pennsylvania
Gastech Model 1031 PPM-Range Gas Indicator	Johnson Instrument Division Gastech Inc. Mountain View, California
General Monitors Model 1100E Portable Gas Detector	Genreal Monitors, Inc. Costa Mesa, California
ERDCO Model 05HCS TOX-EX Combustible Gas Detector	ERDCO Engineering Corp. Addison, Illinois
Davis D-16 Vapotester	Scott-ATO Davis Instruments Charlottesville, Virginia
Welsh Gasotrans G.70-0065 Combustible Gas Indicator	Dist. By Welsh Company Providence, Rhode Island

TABLE III
Portable NO_2 Meters Tested

METER	MANUFACTURER
CEA Model PM-102 NO_2 Analyzer	Combustion Equipment Associates, Inc. New York, New York
EnviroMetrics Model N-46 NO_2 Analyzer	EnviroMetrics, Inc. Marina DelRay, California
Mast Model 724-21 NO_2 (Ozone) Meter	Mast Development Company Davenport, Iowa
ML Model 8102A NO_2 Analyzer	Monitor Labs, Inc. San Diego, California

8. *Operating humidity range:* The meter shall meet all performance specifications within an ambient relative humidity range of from 10 to 90% while continuously sampling for 4 hours without maintenance.
9. *Operating temperature range:* The meter shall meet all performance specifications within an ambient temperature range of from 0 to 40°C.
10. *Interferences:* Interference equivalents for carbon dioxide, nitrogen oxide, nitrogen dioxide, methane, hydrogen sulfide and other significant interferences shall be specified.

Combustible Gas Meters

Nine meters were tested on a variety of combustible gases. All the instruments were very portable, but they did not meet all the desired specifications. Listed in Table II are the meters and their manufacturers. The recommended standards for combustible gas meters are as follows:

Physical characteristics

These characteristics are basically the same as those listed for CO meters except the weight requirement is 10 pounds or less rather than 12.

Performance characteristics

Portable combustible gas meters shall conform to the following performance requirements:

1. *Useful range:* Meters shall have a useful range which reads 0-100% of the Lower Explosive Limit (LEL) or 0-10,000 ppm hexane and corresponding response curves should be provided to correlate per cent LEL to ppm for hexane and other contaminants.

2. *Accuracy:* Meters shall read the true hexane concentration of a sample within the greater of ±5% of reading or ±1% LEL of hexane. The instrument should have this accuracy when received from the manufacturer.
3. *Span drift:* A meter's response to a hexane concentration of 70% LEL shall remain within ±5% of the true value during a period of two weeks of intermittent use.
4. *Zero drift:* A meter's zero drift shall not exceed ±1% LEL of hexane during an eight hour period of continuous use while operating from batteries or during an 8 hour period of continuous use while operating from line current.
5. *Minimum detectable change:* Meters shall be able to detect changes of ±1% LEL over the useful range of the meter as previously defined.
6. *Warm-up time:* The meter shall meet all performance specifications after a warm-up time of 15 minutes.
7. *Response time (90%):* The time interval between a step increase or decrease in a hexane concentration at the meter's input of at least 70% of its maximum range and the time the meter settles within ±10% of its final readout shall not exceed 20 seconds.
8. *Operating humidity range:* The meter shall meet all performance specifications within an ambient relative humidity range of 10-90% while continuously sampling for 8 hours without maintenance.
9. *Operating temperature range:* The meter shall meet all performance specifications within an ambient temperature range of from 0 to 40°C.
10. *Response curves:* The instrument shall be calibrated on hexane and response curves should be provided showing relative responses to methane, pentane, benzene, and five other contaminants.

It is possible that separate specifications may be drafted for a different class of combustible gas meters. These meters would be much smaller, i.e., one or two pounds, less accurate, and less sophisticated than those mentioned above. Special provisions might also be provided to encourage multiple scale instruments.

Nitrogen dioxide meters

Those instruments tested in the NO_2 evaluation test are listed in Table III. The criteria for portability was relaxed somewhat on NO_2 instruments in order to have a sufficient number of instruments to test. Only one of the instruments was battery operated and the weight of two instruments exceeded the 15 pounds specifications. The following specifications are based on these meters and their performance.

Physical characteristics

1. *Portability:* Meters including all required parts and accessories shall weigh 20 lbs or less and have a total volume of 1 ft^3 or less. The instrument shall be able to operate off a power source not greater than 120 vac and off a portable battery supply for at least 8 hours of continuous operation without charging.

2.-9. *See carbon monoxide meters.*

Performance characteristics

1. *Useful range:* Meters shall have a useful range which includes values from 1/5 to 2 times the OSHA 8 hour time-weighted-average allowable exposure concentration (TWA limit).
2. *Accuracy:* Meters shall read the true NO_2 concentration of a sample within the greater of ±5% of reading or ±5% of the TWA limit. The instrument shall be calibrated to this accuracy by the manufacturer before shipment of the meter.
3. *Zero drift:* A meter's zero drift shall not exceed ±5% of the TWA limit during an eight hour period of continuous use while operating from batteries or during an 8 hour period of continuous use while operating from line current.
4. *Span drift:* A meter's response to a NO_2 concentration of approximately 80% of the maximum range shall remain within ±5% of the true value during a period of two weeks of intermittent use.
5. *Minimum detectable change:* Meters shall be able to detect changes of 0.1 ppm over the useful range of the meter.
6. *Warm-up time:* The meter shall meet all performance specifications after a warm-up-time of 15 minutes.

TABLE IV
Portable SO_2 Meters Tested

METER	MANUFACTURER
Casella SO_2 Sampler Model T1400	CF Casella & Company Ltd. London, England Dist. By: BGI Incorporated Waltham, Massachusetts
SO_2 Ultra Portable Analyzer	CEA Instruments New York, New York
Sulfur Dioxide Analyzer Model S-364	EnviroMetrics, Inc. Marina DelRay, California
Microcoulomb Detector Model 724-21MS	Mast Development Company Davenport, Iowa
Titrilog IIII	Process Analyzer, Inc. Houston, Texas
Miran I Variable Path Infrared Analyzer	Wilks Scientific Corp. South Norwalk, Connecticut

7. *Response time (90%):* The time interval between a step increase or decrease in the NO_2 concentration at the meter's input of at least 70% of its maximum range and the time the meter settles within ±10% of its final readout shall not exceed one minute.
8. *Operating humidity and temperature range:* The meter shall be capable of meeting all performance specifications over a range of 10 to 90% relative humidity and 0 to 40°C.
9. *Interferences:* Interference Equivalents for nitric oxide, ozone, carbon monoxide, sulfur dioxide and other significant interferences shall be specified.

Sulfur dioxide meters

Those instruments included in the SO_2 evaluation test are listed in Table IV. Again the criteria for portability was greatly relaxed to include a sufficient number of instruments in the test. The CEA meter was the only battery operated instrument in the test, but several of the other meters had the potential for battery operation. The following are standards based on the performance of these instruments and their capabilities:

Physical characteristics

1. *Portability:* Meters including all required parts and accessories shall weigh 15 lbs or less and have a total volume of 1 ft^3 or less. The instrument shall be able to operate off a power source not greater than 120 vac and off a portable battery supply for at least 8 hours of continuous operation without charging.

2.-9. See *carbon monoxide meters*.

Performance characteristics

1. *Useful range:* Meters shall have a useful range which includes values from 1/5 to 10 times the OSHA 8 hour time-weighted-average concentration (TWA limit).
2. *Accuracy:* Meters shall measure the true SO_2 concentration of a sample within the greater of ±10% of reading or ±20% or the TWA limit.
3. *Zero drift:* A meter's zero drift shall not exceed ±20% of the TWA limit during a 24 hour period of continuous use.
4. *Span drift:* A meter's response to a SO_2 concentration of approximately 80% of the maximum range shall remain within ±20% or the true value during a period of two weeks of intermittent use.
5. *Minimum detectable change:* Meters shall be able to detect changes of ±20% of reading over the useful range of the meter as previously defined.
6. *Warm-up time:* The meter shall meet all performance specifications after a warm-up time of 30 minutes.
7. *Response time (90%):* The time interval between a step increase or decrease in the SO_2 concentration at the meter's input of at least 70% of its maximum range and the time the meter settles within ±10% of its final readout shall not exceed 2 minutes.
8. *Operating humidity and temperature range:* The meter shall meet all performance specifications within an ambient relative humidity range of from 10 to 90% and an ambient temperature range of from 0 to 40°C.

TABLE V
Summary of Performance Specifications

SPECIFICATION	CO METERS	COMBUSTIBLE GAS METERS	NO_2 METERS	SO_2 METERS
TWA	50 ppm	0-100% LEL	5 ppm	5 ppm
Weight	12 lbs	10 lbs	20 lbs	15
Useful Range	1/5 to 6 x TWA	0-100% LEL or 0-10,000 ppm	1/5 to 2 x TWA	1/5 to 2 x TWA
Accuracy	± 10% of reading or ± 10% of TWA	± 5% of reading or ± 1% LEL	± 5% of reading or ± 10% of TWA	± 10% of reading o ± 20% of TWA
Zero Drift	± 10% of TWA	± 1% LEL	± 5% of TWA	± 20% of TWA
Span Drift	± 20% of value	±5% of value	± 5% of value	± 20% of value
Minimum Detectable Change	± 10% of reading	± 1% LEL	0.1 ppm	± 10% of reading
Warm-up Time	15 minutes	15 minutes	15 minutes	30 minutes
Response Time (90%)	2 minutes	20 seconds	1 minute	2 minutes
Humidity Range	10-90% RH	10-90% RH	10-90% RH	10-90% RH
Temperature Range	0-40°C	0-40°C	0-40°C	0-40°C

9. *Interferences:* Interference equivalents for carbon monoxide, carbon dioxide, nitrogen oxide, nitrogen dioxide, hydrogen sulfide, ozone and other significant interferences shall be specified.

Table V shows a summary and comparison of the meters tested and the respective specifications of each class of meters.

Future development

After the performance specifications have been developed, compatible quality control standards are to be written. These quality control standards are to insure that the manufacturer's product is reproducible from one meter to another.

The next step is to take the meter performance and testing specifications and the quality control specifications and promulgate them as regulations as the basis for equipment certification. Once the regulations are adopted, the actual testing and certification will be administered by the NIOSH Testing and Certification Laboratory in Morgantown, West Virginia.

The specifications listed in this paper are a first draft based on the analysis of test data. The presence or absence of testing standards or other performance and design standards does not necessarily mean that these factors have been ignored. The specifications contained in this paper are but a base upon which NIOSH plans future instrument certification programs.

References

1. McCammon, Charles S. Jr.: *Evaluation of Portable, Direct-Reading Combustible Gas Meters.* HEW Publication No. (NIOSH) 74-107, April 1974.
2. Johnson, Bruce A: *Evaluation of Portable, Direct-Reading NO_2 Meters.* HEW Publication No. (NIOSH) 74-108, April 1974.
3. *Evaluation of Portable Carbon Monoxide Meters.* Final Report prepared under Contract No. HSM-99-73-1 (Task Order #1) by Research Triangle Institute, March 1974.
4. *Evaluation of Portable Sulfur Dioxide Meters.* Final Report prepared under Contract No. HSM-99-73-1 (Task Order #2) by Research Triangle Institute, March 1974.

Accepted October 24, 1975