DETERMINATION OF FACEPIECE CARBON DIOXIDE CONCENTRATION LEVELS - SELF-CONTAINED BREATHING APPARATUS STANDARD TESTING PROCEDURE (STP)

1. PURPOSE

This document establishes the standard procedure for ensuring that Self-Contained Breathing Apparatus (SCBA) submitted for Approval, Extension of Approval, or examined during Certified Product Audits, meet the minimum certification standards for carbon dioxide concentration as allowed for at 42 CFR, Part 84, Subpart G, Section 84.63(a)(c)(d), and Subpart H, Section 84.97(a)(b)(c); Volume 60, Number 110, June 8, 1995.

2. GENERAL

This STP describes the Determination of Facepiece Carbon Dioxide Concentration Levels - Self-Contained Breathing Apparatus test in sufficient detail that a person knowledgeable in the appropriate technical field can select equipment with the necessary resolution, conduct the test, and determine whether or not the product passes the test.

3. EQUIPMENT/MATERIALS

3.1. Scott Aviation mechanical breather with sedentary cam and solenoid valves attached

3.2. Thin-walled flexible plastic reservoir with a low-resistance relief valve (less than 1-inch water column)

3.3. Instrument-grade carbon dioxide (CO_2)

3.4. Instrument-grade air

3.5. Two-stage regulator with control valve for CO_2 cylinder (first stage gauge with 3000 psig capacity; second stage gauge with 0 - 100 psig capacity)

3.6. Specialty calibration gas mixture containing 5.00% CO_2 with the balance air

3.7. AEI Technologies CD-3A CO_2 gas analyzer, 0 – 15%, or equivalent

3.8. AEI Technologies Model P-61B CO_2 gas sensor, or equivalent

3.9. AEI Technologies S-3A/I Oxygen (O_2) gas analyzer, 0 – 100%, or equivalent

3.10. AEI Technologies Model N-22M O_2 gas sensor or equivalent

3.11. AEI Technologies Model R-1 Flow Control unit or vacuum pump for gas sample system, or equivalent

3.12. MKS Instruments Model No. 1179A618CS1BV Mass Flow Controller (MFC) for gas sample system flow control with a 5% CO_2/95% air mixture flow control range of 0 to 715 sccm, or equivalent

3.13. MKS Instruments Mass Flow Controller Model No. 1179A13CS1BV, or equivalent, with a Carbon Dioxide flow control range of 0 to 1000 sccm

3.14. MKS Instruments Mass Flow Controller Model No. 1179A24CS1BV-S, or equivalent, with an air flow control range of 0 to 15,000 sccm

3.15. MKS Instruments Type 247 4-Channel Power Supply Readout, or equivalent

3.16. Validyne Engineering Corporation Single-Channel Digital Transducer Indicator/Power Supply, Model No. CD-23-A-2-A-1-C, or equivalent

3.17. Validyne Engineering Corporation DP45-16 4516A3S4D Pressure Transducer, +/- 1.4 inches H_2O column measurement range, or equivalent

3.18. Acuity AR700-4 Laser Distance Gauge, Part No. AP7010040 or equivalent, 0 – 3.5 inches linear displacement

3.19. Lee LIF Series 2-Way micro-solenoid control valve, part no. LFAA1206018H

3.20. Multiple outlet box with 6 receptacles

3.21. Two adjustable jack stands

4. TESTING REQUIREMENTS AND CONDITIONS

Prior to beginning any testing, confirm that all measuring equipment employed has been calibrated in accordance with the testing laboratory’s calibration procedure and schedule. All measurement equipment utilized for this testing shall have been calibrated using a method traceable to recognized international standards when available. Except where specifically instructed, refer to the manufacturers’ operation and maintenance manuals for operation and calibration instructions.

5. PROCEDURE

5.1. Calibration of the AEI Technologies CD-3A CO_2 and S-3A/I O_2 gas analyzers will be performed as follows:

5.1.1. Turn on gas sample system vacuum pump. Set the gas sample system flow rate to 450 sccm as controlled by this system’s mass flow controller.

5.1.2. Adjust the zero potentiometer to 0.04% for the CO_2 gas analyzer and 20.95% for the O_2 gas analyzer, as necessary.

5.1.3. Administer span gas to the gas sample tube sample point via a tube that is at least three times the diameter of the gas sample tube. Use a span gas flow of at least 500 sccm. The excess span gas will flow around the inlet to the sampling point to the atmosphere in the test lab. The gas sample tube sampling point shall be inserted at least several inches into the span gas delivery tube and remain in that position throughout the CO_2 gas analyzer span check and adjustment.

5.1.4. Adjust the CO_2 gas analyzer span potentiometer to the span gas concentration (normally 5.00%), as necessary.

5.1.5. Remove the span gas delivery tube to allow the CO_2 and O_2 gas analyzers' outputs to decrease to and stabilize near the zero gas concentrations of 0.04% and 20.95%, respectively.

5.1.6. Adequate ventilation must be present in the test area to prevent the build-up of CO_2 gas near the gas sampling point.

5.1.7. Repeat steps 5.1.2 through 5.1.5 until the zero and span gas concentrations for the CO_2 gas analyzer and the zero concentration for the O_2 gas analyzer are reproducible without further adjustments being necessary.

5.2. Determination of the CO_2 gas analyzer/gas sample system response time will be performed as follows:

5.2.1. Administer calibration gas to the gas sample tubing sampling point as controlled by the gas sample system delay solenoid valve.

5.2.1.1. Operate the data recording system while activating and deactivating the gas sample system delay solenoid valve to detect the times at which the calibration gas flow is started/stopped.

5.2.1.2. The time required to reach 90% of the CO_2 gas analyzer span gas concentration after activation of the gas sample system delay solenoid valve is the CO_2 gas analyzer/gas sample system response time (gas sample transit time plus gas CO_2 gas analyzer response time).

5.2.1.3. The gas sample system response time that is determined will be used when performing test data analysis.

5.3. CO_2 and O_2 concentration levels in the facepiece will be determined for the largest size of a multiple-size device or for a single-size device as follows:

5.3.1. Assemble the CO_2 Deadspace Test apparatus as shown in Attachment 8.1. The CO_2 pickup, O_2 pickup, and pressure transducer shall be mounted where shock and vibration are minimal. Use exactly 20 inches of 3/4 inch I.D. tubing between the headform mouth and the breathing machine "T". This length of tubing has an internal volume of approximately 145 cm^3.

5.3.2. All test instruments, including the CO_2 and O_2 gas analyzers, pressure transducer, and mass flow controllers should remain powered at all times. If this is not the case, allow at least 18 hours for these instruments to reach steady state after they are powered before starting testing.

5.3.3. Set the air flow rate to 10.45 liters/min and the CO_2 flow rate to 550 cm^3/min using these streams' respective mass flow controllers. These flow rates will provide a 5% CO_2 air mixture at the headform mouth during exhalation. The flexible bag will be kept filled with slightly more than 10.5 liters/min flow (11.0 liters/min) and minimize back pressure in the system. To maintain a 5% CO_2 concentration in the exhaled breathing gas, some slight readjustment of air and CO_2 flow rates may be necessary.

5.3.4. Turn on the breathing machine and let it warm-up for one minute. Set the potentiometer for 14.5 rpm on the sedentary cam. This will give a flow rate of 10.5 lpm.

5.3.5. A LabVIEW-based software application (or equivalent) shall be used to monitor all test parameters during testing and to record all test data needed to assess the inspired CO_2 levels of the respirator being tested.

5.3.6. Run a blank test, operating the equipment to produce the correct CO_2 pattern at the dummy head mouth. Record the CO_2 concentration at the mouth of the headform and all other required test parameters for at least three complete respiratory cycles using the data monitoring/recording software application. Analysis of the recorded test parameters provides the average CO_2 concentration contributed by the headform. This is a blank value which must be subtracted from the total inspired CO_2 of all facepiece and breathing apparatus tested.

5.3.7. Mount the facepiece to be tested on the headform. For open-circuit apparatus, connect the entire apparatus to the facepiece, place the regulator in the desired mode of operation, and open the compressed-air cylinder valve on SCBA. On the closed-circuit apparatus, only those parts contributing to dead air space are tested. Exhaled CO_2 must be released and not permitted to re-enter the closed-circuit apparatus during inhalation. Record the CO_2 concentration at the mouth of the headform and all other required test parameters for at least three complete respiratory cycles (see Attachment 8.2.) using the data monitoring/recording software application. Analysis of the recorded test parameters provides the average CO_2 concentration contributed by the apparatus and/or facepiece being tested.

5.3.8. Disconnect the entire apparatus from the facepiece, if applicable. Remove the facepiece from the headform. Repeat the actions outlined in Section 5.3.7 two additional times, for a total of three dons.

5.4. Data is to be analyzed as follows:

5.4.1. Test data is recorded at 40 Hz (every 0.025 second) by the LabVIEW software application and includes CO_2 and O_2 volume % measured at the headform mouth, facepiece resistance, and linear piston displacement. This data is downloaded into an Excel spreadsheet and plots with the three traces shown in Attachment 8.2. are simultaneously produced.

5.4.2. Prior to analyzing the test data and determining test results, the CO_2 and O_2 volume % data must be shifted back in time by the time equivalent to the gas sample system response time. This is necessary to synchronize the CO_2 and O_2 volume % data with the facepiece resistance and linear piston displacement data.

5.4.3. The start of the inhalation phase of a breathing cycle is determined as the point in time at which the facepiece resistance (green trace in Attachment 8.2.) begins to drop rapidly after the piston resting phase that follows the forward piston stroke.

5.4.4. The start of the inhalation phase is corroborated by the piston displacement (red trace in Attachment 8.2.). The beginning of the inhalation phase is signified as the time at which the piston begins to retract (increase in displacement) after the preceding piston resting phase. The end of the inhalation phase is signified by the start of the piston resting phase that precedes the forward piston stroke.

5.4.5. The duration of the inhalation phase must correspond to the time between the start and end of piston retraction. With a breathing rate of 14.5 breaths per minute, the inhalation phase is 1.70 seconds.

5.4.6. The inspired CO_2 level for a facepiece mounted on the headform is determined from the recorded test data as follows:

Sum the measured CO_2 volume % measurements at 0.025-second increments during the inhalation phase and divide by the number of CO_2 volume % data points (n) measured. Based on the 1.70-second inhalation phase duration, n = 68.

$$\text{Avg. Inspired } CO_2 \text{ for facepiece} = \frac{(\Sigma\ CO_2 \text{ volume \%})}{n}$$

5.4.7. The inhalation phase for a blank CO_2 level determination starts at the last peak CO_2 volume % just prior to the rapid decrease in the CO_2 volume %.

5.4.8. The blank CO_2 level is determined from the recorded test data as follows:

Sum the measured CO_2 volume % measurements at 0.025-second increments during the inhalation phase and divide by the number of CO_2 volume % data points (n) measured.

$$\text{Avg. Blank } CO_2 = \frac{(\Sigma\ CO_2 \text{ volume \%})}{n}$$

5.4.9. The inspired CO_2 level for each don of the respirator being tested is the difference between the inspired CO_2 for the facepiece and the blank CO_2 level that was measured.

$$\text{Inspired } CO_2 = \text{Avg. Inspired } CO_2 \text{ (facepiece)} - \text{Avg. Blank } CO_2$$

5.4.10. The reported inspired CO_2 level for each respirator is the minimum measured inspired CO_2 concentration level of the three dons. The reported O_2 level for each respirator is the minimum O_2 level measured during the inhalation phase (the period over which the inspired CO_2 level is assessed) of the chosen don.

6. PASS/FAIL CRITERIA

6.1. The criterion for passing this test is set forth according to 42 CFR, Part 84, Subpart G, Section 84.63(a)(c)(d), and Subpart H, Section 84.97(a)(b)(c); Volume 60, Number 110, June 8, 1995.

6.2. This test establishes the standard procedure for ensuring that:

84.63. Test requirements; general –

(a) Each respirator and respirator component shall when tested by the applicant and by the Institute, meet the applicable requirements set forth in subparts H through L of this part.

(c) In addition to the minimum requirements set forth in subparts H through L of this part, the Institute reserves the right to require, as a further condition of approval, any additional requirements deemed necessary to establish the quality, effectiveness, and safety of any respirator used as protection against hazardous atmospheres.

(d) Where it is determined after receipt of an application that additional requirements will be required for approval, the Institute will notify the applicant in writing of these additional requirements, and necessary examinations, inspections, or tests, stating generally the reasons for such requirements, examinations, inspections, or tests.

84.97 Test for carbon dioxide in inspired gas; open- and closed-circuit apparatus; maximum allowable limits –

(a) Open-circuit apparatus:

(1) The concentration of carbon dioxide in inspired gas in open-circuit apparatus will be measured at the mouth while the apparatus mounted on a dummy head is operated by a breathing machine. An acceptable method for measuring the concentration of carbon dioxide is described in Bureau of Mines Report of Investigations 6865, A Machine-Test Method for Measuring Carbon Dioxide in the Inspired Air of Self-Contained Breathing Apparatus, 1966. Copies of Report of Investigations 6865 may be inspected or obtained

from the NIOSH, Technology Evaluation Branch, 626 Cochrans Mill Road, Pittsburgh, Pennsylvania 15236.

(2) The breathing rate will be 14.5 respirations per minute with a minute-volume of 10.5 liters.

(3) A sedentary breathing machine cam will be used.

(4) The apparatus will be tested at a temperature of 27° ±2°C. (80° ±5°F).

(5) A concentration of 5 percent carbon dioxide in air will be exhaled into the facepiece.

(b) Closed-circuit apparatus. The concentration of carbon dioxide in inspired gas in closed-circuit apparatus will be measured at the mouth while the parts of the apparatus contributing to dead-air space are mounted on a dummy head and operated by the breathing machine as in paragraphs (a)(1) through (5) of this section.

(c) During the testing required by paragraphs (a) and (b) of this section, the concentration of carbon dioxide in inspired gas at the mouth will be continuously recorded, and the maximum average concentration during the inhalation portion of the breathing cycle shall not exceed the following limits.

Maximum Average Concentration of Carbon Dioxide in Inspired Air

Where the service time is -	CO_2 percent by volume
Not more than 30 minutes......	2.5
1 hour......................	2.0
2 hours.....................	1.5
3 hours.....................	1.0
4 hours.....................	1.0

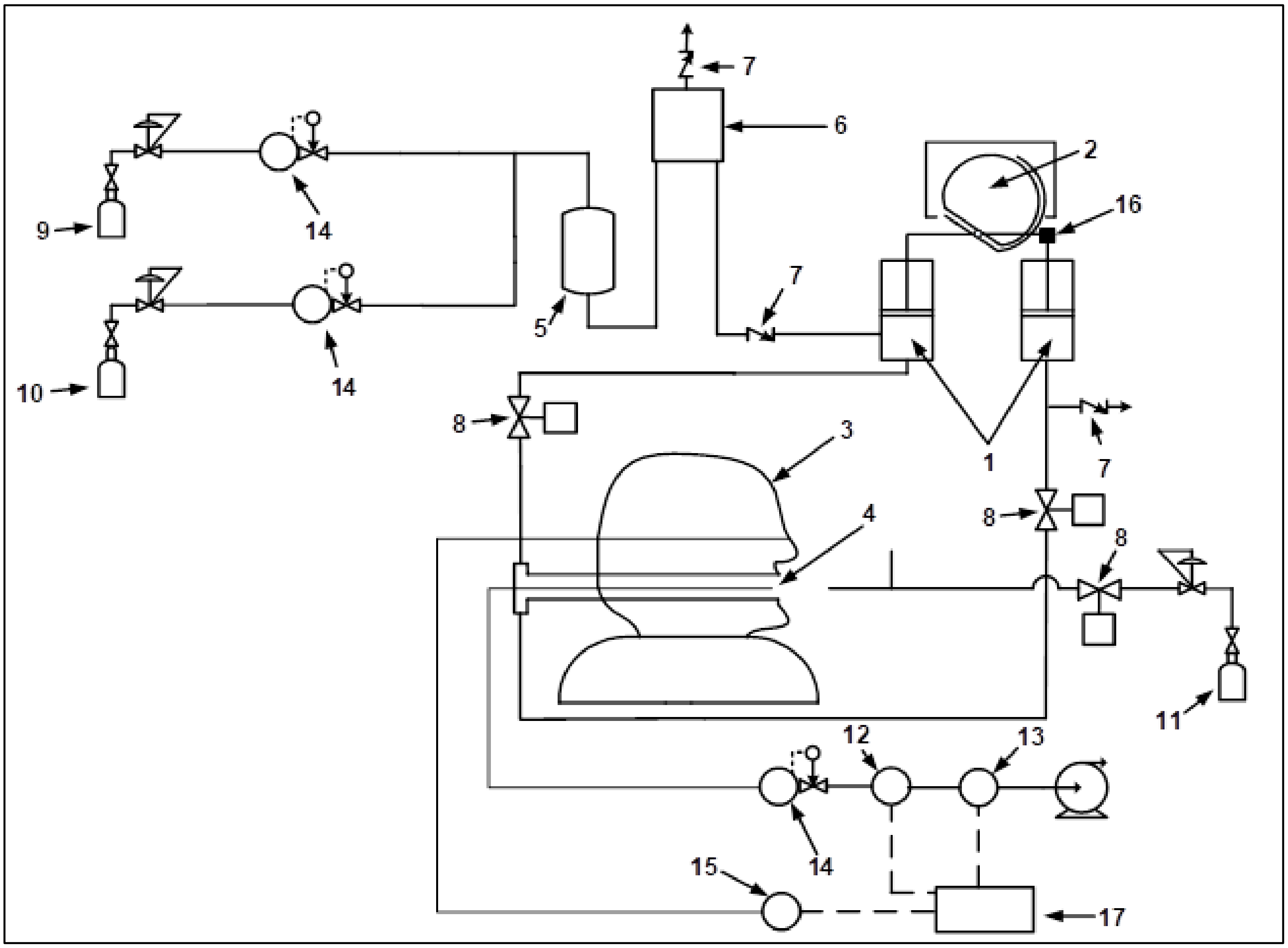
7. RECORDS/TEST SHEETS

7.1. Record test data in a format that shall be stored and retrievable. Data to be recorded and reported as shown in the attached data sheet (Attachment 8.3.).

8. ATTACHMENTS

8.1. NIOSH CO_2 Deadspace Test System Schematic with Description of Components
8.2. NIOSH CO_2 Deadspace Test Data Plot
8.3. Facepiece Carbon Dioxide of Self-Contained Breathing Apparatus Test Data Sheet

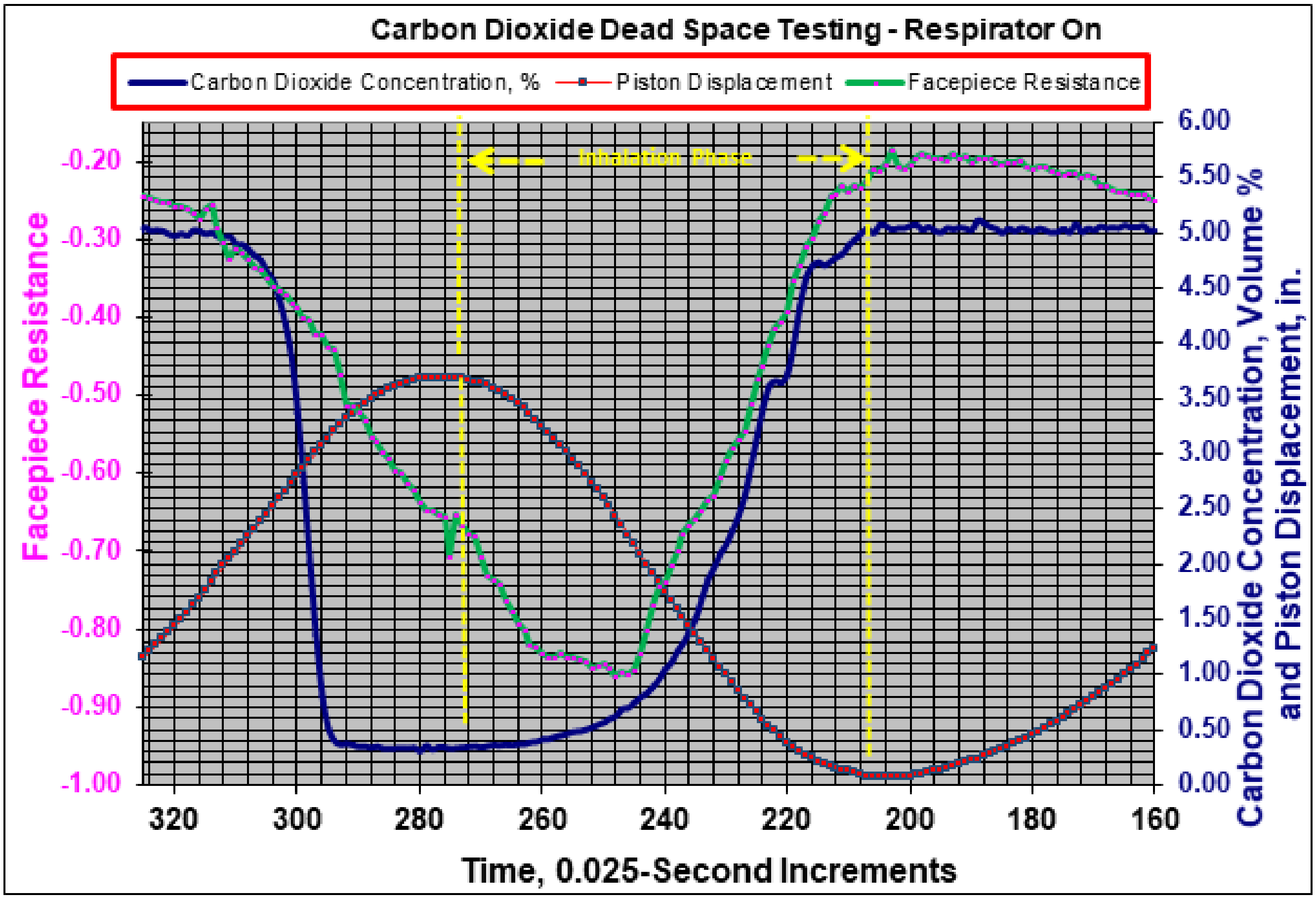
Attachment 8.1. NIOSH CO_2 Deadspace Test System Schematic



Key

1 **Breathing machine**
2 **Sedentary cam**
3 **Headform**
4 **Airway opening/sampling point**
5 **Rigid mixing vessel**
6 **Flexible reservoir**
7 **Non-return valve**
8 **Solenoid valve**
9 **CO_2 supply**
10 **Air supply**
11 **Calibration gas supply**
12 **CO_2 analyzer**
13 **O_2 analyzer**
14 **Mass flow controller**
15 **Pressure transducer**
16 **Linear displacement transducer**
17 **Computer**

Attachment 8.2. NIOSH CO_2 Deadspace Test Data Plot



Attachment 8.3. Facepiece Carbon Dioxide of Self-Contained Breathing Apparatus Test Data Sheet

TN -			Manufacturer:				
Open-Circuit or Closed-Circuit		Facepiece P/N:		Model No.:			
Date:			Test Technician:				
Test Data							
Event		Resp On - 1st Three Cycles			Best Three Blank Cycles		
		Trace 1	Trace 2	Trace 3	Trace 1	Trace 2	Trace 3
4							
8							
12							
16							
20							
24							
28							
32							
36							
40							
44							
48							
52							
56							
60							
64							
68							
72							
76							
80							
	# Events						
	Totals						
	Average						
	Average 3 Cycles -		-		=		
						CO2 Dead Space Level	
Existing NIOSH Certification Test Method (Summary)							
	# Events						
	Totals						
	Average						
	Average 3 Cycles -		-		=		
						CO2 Dead Space Level	
New Data Acquisition System Method (Reported)							

Revision History

Revision	Date	Reason for Revision
1.0	15 February 2001	Historic document
1.1	21 September 2005	Update header and format to reflect lab move from Morgantown, WV No changes to method
2.0	22 April 2019	Edited to current style and format. The underlying procedure is largely unchanged, but the data analysis method is updated to rely upon a digital transformation of the transducer signals rather than graphic analysis of a strip chart. Changes to the list of equipment, Section 3, and changes to the procedure, Section 5, support the updated method of analyzing the data.