DETERMINATION OF FACEPIECE CARBON-DIOXIDE AND OXYGEN CONCENTRATION LEVELS OF TIGHT FITTING, POWERED AIR-PURIFYING RESPIRATORS, WITH THE BLOWER UNIT OFF OR NON-POWERED RESPIRATORS STANDARD TESTING PROCEDURE (STP)

1. PURPOSE

1.1. This test establishes the procedure for ensuring that the level of protection provided by the facepiece against carbon-dioxide build up and maintaining the oxygen concentration level requirements on tight fitting, powered air-purifying respirators (PAPR), with the blower unit off, or non-powered respirators, with a neck seal designed to offer personal protection against particulate and gas/vapor hazards, including CBRN Air Purifying Escape Respirators (APER), submitted for Approval, Extension of Approval, or examined during Certified Product Audits, meet the minimum certification standards set forth in 42 CFR, Part 84, Subpart G, Section 84.63(a)(c)(d); Volume 60, Number 110, June 8, 1995.

1.2. While wearing this type of device, the user exhales approximately 5% carbon dioxide into the facepiece. Most of this CO_2 exits through an exhalation valve to the external environment. The residual exhaled portion that remains in the facepiece and is rebreathed during inhalation is the portion of prime concern and is the object of the test requirement and this test procedure. A small amount of CO_2 is physiologically required in order to stimulate respiration; but once concentration levels increase beyond approximately 2% CO_2, there is a sharp rise in a person's respiratory minute-volume and breathing rate. Based on the maximum allowable average CO_2 concentration level for SCBA as acceptable under CE standards - the maximum acceptable CO_2 concentration level for a PAPR with the blower off and non-powered gas masks with a tight fitting neck seal, including CBRN APERs, used for escape purposes will be 2%.

2. GENERAL

2.1. This procedure describes the Determination of Facepiece Carbon-Dioxide and Oxygen Concentration Levels of Tight Fitting, Powered Air-Purifying Respirators, With the Blower Unit Off or Non-Powered Respirators test in sufficient detail that a person in the appropriate technical field can conduct the test and determine whether or not the product passes testing.

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 CO_2.

3.4. Instrument grade air.

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

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

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

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

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

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

3.11. 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

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

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

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

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

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

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

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

4. TESTING REQIREMENTS AND CONDITIONS

4.1. 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 measuring equipment utilized for this testing must have been calibrated using a method traceable to recognized international standards when available.

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 20.93% 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 20.93%, 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 Fig. 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 is critical since the response time must correlate closely with the pressure measurement for a simultaneous readout). This length of tubing has a 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 dummy head 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. 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 Figure 2) using the data monitoring/recording software application. Analysis of the recorded test parameters provides the average CO_2 concentration contributed by the facepiece being tested.

5.3.8. 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. The 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 Fig. 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 forward 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 Fig. 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 Fig. 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.

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

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.

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

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 in 42 CFR, Part 84, Subpart G, Section 84.63(a)(c)(d); 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.

6.3. The maximum allowable average carbon dioxide concentration for each sample tested shall not exceed 2.0% and the measured oxygen levels at the end of inspiration shall not fall below 19.5% (during the same measurement periods for carbon dioxide assessment) with the respirator operating with the blower off for escape purposes (including CBRN PAPRs) or non-powered respirator and CBRN APERs.

7. RECORDS/TEST SHEETS

7.1 Record test data in a format that shall be stored and retrievable. Data to be reported as shown in attached data sheet.

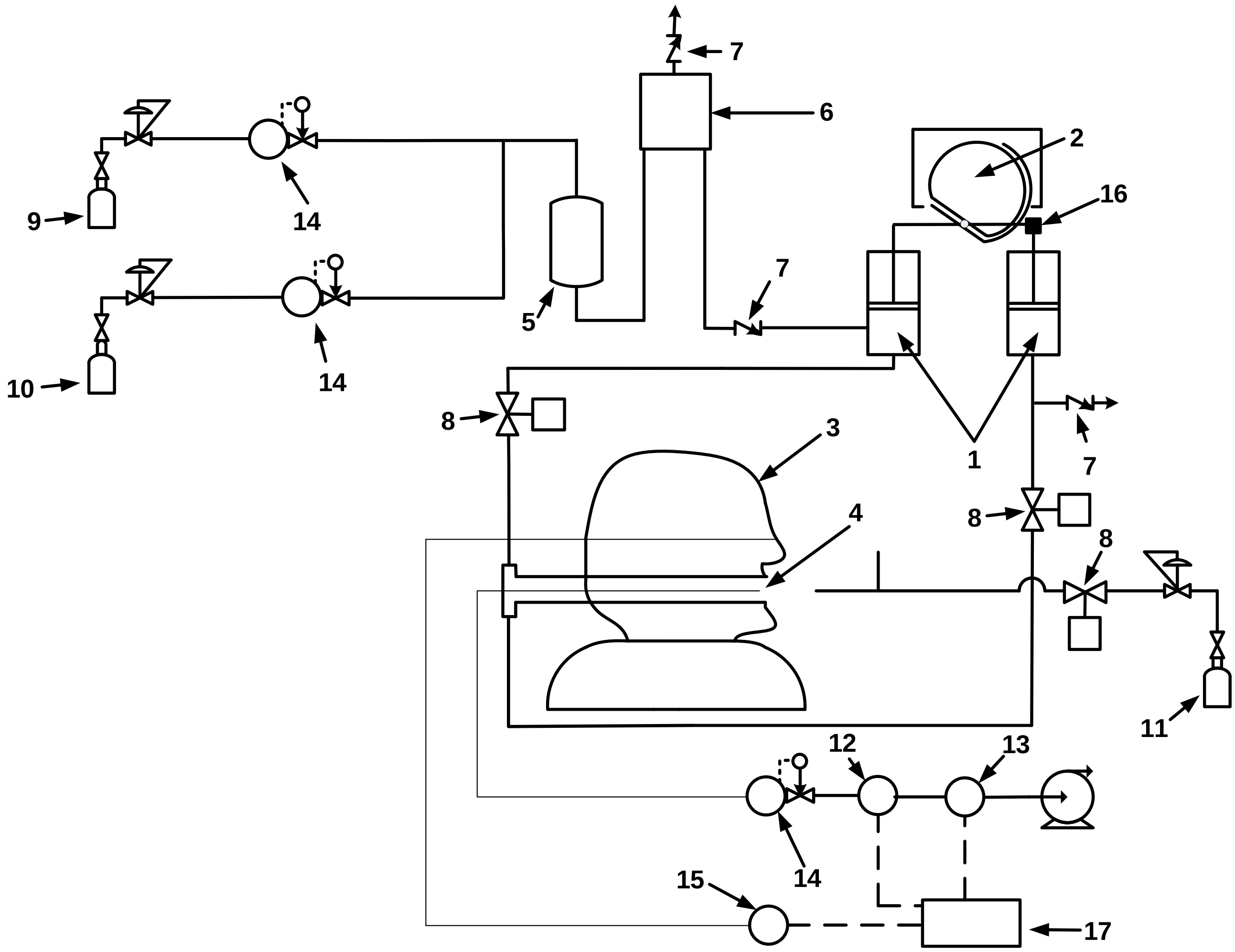

Figure 1. NIOSH CO_2 Deadspace Test System Schematic

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**

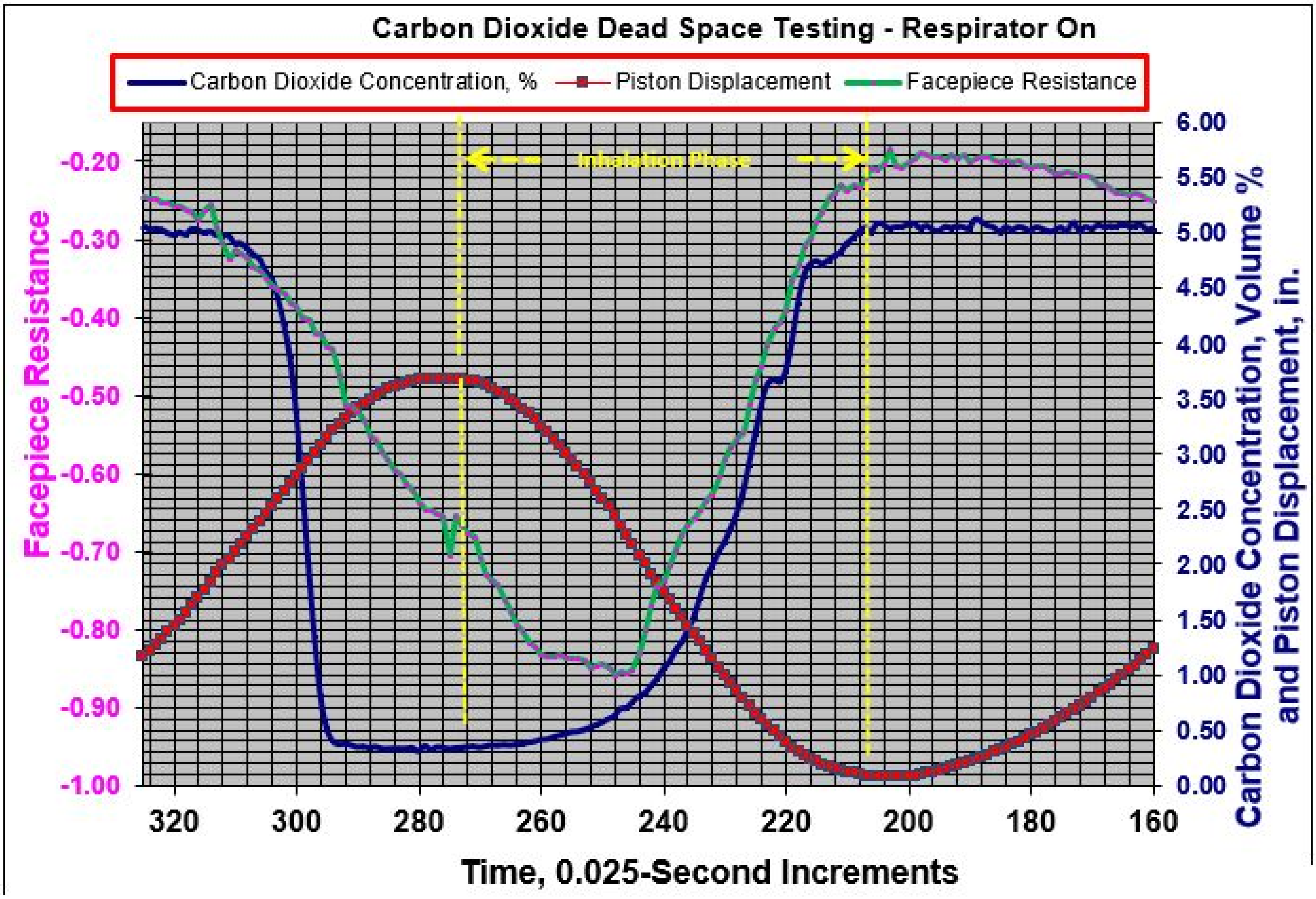

Figure 2. NIOSH CO_2 Deadspace Test Data Plot

Table 1. Facepiece Carbon Dioxide or Oxygen Concentration Levels of Tight-Fitting Powered Air-Purifying Respirators with the Blower Unit Off or Tight-Fitting Non-Powered Gas Masks with a Tight-Fitting Seal Test Data Sheet

Determination of Facepiece CO2/O2 Concentration

RPD Part Nos.:

Comment(s):

Manufacturer Name (MFR) TN-XXXXX STP-YYY DON ZZ

TEST DATA

Test Time, 0.025-second time increments	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

# Events						
Totals						
Average						

Average 3 Cycles - ______ - ______ = ______ *CO2 Dead Space Level*

New Data Acquisition System Method

PASS or FAIL: PASS

Tested by: Date: **ETB-1223 Rev 0**

Revision History

Revision	Date	Reason for Revision
1.0	10 December 2001	Historic document
1.1	12 September 2005	Update header and format to reflect lab move from Morgantown, WV No changes to method
1.2	24 July 2020	General update to include LabVIEW-based data monitoring, data recording and data analysis methods