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# OXYGEN CONTAMINANT DETECTION: PROCEDURES FOR FIELD ANALYSIS OF AVIATOR'S BREATHING OXYGEN

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Until recently, no instrument displayed the sensitivity, stability, and portability necessary for on-site field analysis of trace contaminants in aviator's breathing oxygen (ABO). A solid-state portable infrared gas analyzer became commercially available in 1971, which led to development of an instrument package capable of analyzing ABO at the base level. Procedures for field analysis of ABO are given as a guide for Air Force personnel using the ABO contaminant detector system developed by USAFSAM.

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# OXYGEN CONTAMINANT DETECTION: PROCEDURES FOR FIELD ANALYSIS OF AVIATOR'S BREATHING OXYGEN

## INTRODUCTION

Regardless of whether aviator's breathing oxygen (ABO) is stored aboard aircraft as liquid (LOX) or gas (GOX), there has always been a dire need to look for trace contaminants that could prove dangerously toxic, especially while in flight. Such contaminants in ABO need to be found before they are breathed. Ideally, each aircraft oxygen system should be checked prior to flight to insure delivery of "pure," uncontaminated oxygen. Until recently, fulfilling such a requirement would have been overwhelmingly difficult and perhaps inaccurate.

Practical developments and considerations led to the present ABO surveillance method, which is the periodic submission of LOX samples to various U.S. Air Force Logistics Command Laboratories. In the event of physiological incidents, LOX samples from aircraft, service carts, and bulk storage are submitted to USAF Environmental Health Laboratories for analysis. In either case, oxygen surveillance has not been totally effective; its prime shortcomings are slowness, inconvenience, and actually not determining the quality of oxygen received by the pilot. The present surveillance is particularly cumbersome and dilatory following physiological incidents in which ABO is suspected of having been contaminated, especially when less than one liter of LOX remains in the aircraft.

To circumvent delay, the Bioenvironmental Analysis Branch, USAFSAM, developed technics and instrumentation[a] for analyzing ABO at the base level. These technics will provide rapid and accurate analysis of ABO whether taken from the aircraft, service carts, or bulk storage.

## INSTRUMENTATION

In the latter part of 1971, a portable infrared (IR) analyzer became commercially available (Wilks Scientific Corp., South Norwalk, Conn.). While not specifically designed for oxygen contaminant analysis, the instrument can be adapted for this purpose; it is a single-beam scanning spectrophotometer with solid-state electronics and a variable-pathlength gas cell (0.75 to 20.25 meters). The gas cell can be pressurized to 150 psia (pounds per square inch, absolute) for increased sensitivity. The usable IR range for the instrument is from 2.5 to

[a] Ikels, K. G., W. L. Crow, and H. J. Kilian. Aviator's breathing oxygen contaminant detector. SAM-TR-74-2, February 1974.

14.5 microns (4000 to 690 $cm^{-1}$), which can be scanned automatically or manually in three segments. The instrument's output can be observed on a meter incorporated in the instrument or plotted on a strip-chart recorder. The entire ABO contaminant detector (ABOCD) system (Fig. 1) consists of spectrometer, recorder readout, vacuum/pressure pump, and stainless steel flex hoses and connectors.

### Spectrometer

The basic part of the ABOCD is the Wilks Miran I infrared spectrometer with variable-pathlength gas cell (Fig. 2). The spectrometer itself can be divided into three sections:

(1) The electronics portion contains the necessary power, filters, amplifiers, controls, and readout devices.

(2) The valving arrangements control the gases that are sampled by the instrument.

(3) The gas cell contains the gases to be analyzed and necessary reflecting surfaces that can be adjusted to vary the cell pathlength in order to obtain the desired sensitivity.

### Recorder

The recorder used as a readout for the ABOCD is a 115-V 60-Hz Laboratory Data Control Model 320. This potentiometric strip-chart recorder provides an accurate analog record of the oxygen analyzed.

### Pump

The ABOCD system uses a Thomas Model 4907 CA-18, 115-V 60-Hz 4-stage diaphragm vacuum/pressure pump (Fig. 3). This pump can render pressures in excess of 135 psia and a vacuum of 23 mm Hg.

## INSTALLATION AND CALIBRATION

1. Plug power cord into input plug in rear of spectrometer (Fig. 4D-4) and into a 115-V AC receptacle.

2. Set Time Constant at 0.6 sec (Fig. 4B-3).

3. Set Scale Expansion at X1 (Fig. 4B-4).

4. Set Slit width selector wheel at 0 mm, and Wavelength selector wheel between wavelength segments (Fig. 4A-2 and -3).

5. Plug recorder power cord (Fig. 5B-4) into 115-V AC receptacle.

6. With cable provided, connect recorder input terminals (Fig. 5B-1) to spectrometer output terminals (Fig. 4D-1); observe polarity, Red (+) Black (-).

7. Set recorder Mode switch (Fig. 5A-7) at POTENTIOMETRIC.

8. Turn both spectrometer and recorder Power switches to ON and allow 15 minutes for warmup (Figs. 4C-2 and 5A-4).

9. Using the spectrometer Zero control knob (Fig. 4B-2), adjust spectrometer galvanometer (Fig. 4A-1) to read 0% transmission.

10. Uncap and rotate felt-tip pen (Fig. 5A-1) so that tip rests on the paper; secure between holder prongs. NOTE: Keep pen capped when not in use.

11. Using the recorder Zero adjustment knob (Fig. 5A-9), set recorder pen to 0% transmission on the strip chart.

12. Advance spectrometer Wavelength selector wheel (Fig. 4A-2) to 3.5 microns and Slit width selector wheel (Fig. 4A-3) to 0.5 mm.

13. Using Gain control knob (Fig. 4B-1), adjust spectrometer galvanometer (Fig. 4A-1) to read 100% transmission.

14. Rotating recorder Full-Scale screw (Fig. 5A-5), adjust pen to read 100% transmission on the chart paper.

15. Return spectrometer Slit width selector wheel (Fig. 4A-3) to 0 mm. NOTE: Spectrometer and recorder are now calibrated and ready for use.

## ADJUSTMENT OF VARIABLE-PATHLENGTH GAS CELL

The variable-pathlength gas cell can be adjusted for 0.75- to 20.25-meter pathlength. However, only two pathlengths will be used; 2.25 meters for carbon dioxide analysis and 20.25 meters for all other subsequent contaminant analyses. The variable-pathlength cell is adjusted in the following manner:

1. With the spectrometer and recorder adjusted as outlined in "Installation and Calibration," rotate the variable-pathlength adjustment knob (Fig. 4E-2) fully counterclockwise.

2. Set recorder Chart speed-selector switch (Fig. 5A-3 at 2 in./min).

3. Manually set Wavelength wheel (Fig. 4A-2) at 3.5 microns, and Slit width wheel (Fig. 4A-3) at .5 mm.

4. Slowly turn the variable-pathlength adjustment knob (Fig. 4E-2) clockwise. The recorder pen will traverse up scale until a maximum peak is reached then traverse down again. Continued rotation of the adjustment knob will generate 16 peaks on the strip-chart, as shown in Figure 6.

NOTE: If the recorder pen traverses off scale when the variable-pathlength adjustment knob is rotated, turn the spectrometer Gain knob (Fig. 4B-1) counterclockwise until all peaks are kept on scale.

5. Set and lock the variable-pathlength adjustment knob on the 2d peak maximum (2.25 meters) for carbon dioxide analysis, and on the 14th peak maximum (20.25 meters) for all other subsequent contaminant analyses.

6. Set recorder Chart speed switch (Fig. 5A-3) back to zero.

7. Return Slit width wheel (Fig. 4A-3) to 0 mm and position the Wavelength wheel (Fig. 4A-2) between wavelength segments.

## GAS CELL EVACUATION

1. Connect power cord from 4-stage vacuum/pressure pump to 115-V AC receptacle.

2. Using stainless steel flex line, connect vacuum and inlet quick-connect (Fig. 7A-1) to gas cell inlet quick-connect (Fig. 7A-3).

3. Make sure that the exhaust and filling valve located on the pump (Fig. 7A-2) is in the EXHAUST position.

4. Turn pump power switch to ON (Fig. 7A-8).

5. Make sure gas exit valve (Fig. 7A-6) is closed, full clockwise.

6. Turn gas cell exhaust valve (Fig. 7A-4) and gas cell inlet and exhaust valve (Fig. 7A-5) to OPEN position. NOTE: All valve positions should be identical to those in Figure 7A.

7. Evacuate cell until pressure gauge (Fig. 7A-7) reads approximately 30 inches vacuum.

8. Rotate gas cell inlet and exhaust valve (Fig. 7A-5) clockwise 90°, to CLOSE position.

9. Disconnect flex line to gas cell inlet quick-connect (Fig. 7A-3).

10. Turn power switch on pump to OFF.

## GAS SAMPLING

### Sampling from an Aviator's Breathing Oxygen Cylinder

NOTE: Potential hazards exist when working with any oxygen system; therefore, certain precautionary measures must be observed and practiced when handling oxygen to insure the safety and well-being of each individual. Personnel responsible for conducting or assisting in on-site field evaluation of suspected contaminated oxygen must be familiar with T.O. 42B6-1-1, especially sections I, IV, and VI.

1. Connect a two-stage high-pressure oxygen regulator (Fig. 8) to a cylinder of ABO (220 cu ft).

2. Turn low-pressure adjustment valve (Fig. 8-1) on regulator fully counterclockwise, and make sure the oxygen outlet valve (Fig. 8-2) is closed.

3. Open cylinder valve (Fig. 8-3) by rotating it counter-clockwise. High-pressure gauge (Fig. 8-5) should read above 150 psig.

4. Adjust low-pressure gauge (Fig. 8-4) on regulator to 150 psi by turning the low-pressure adjustment valve clockwise. Thoroughly purge all stainless steel sample lines. NOTE: To eliminate the chance of residual contaminants being introduced into the system, all lines must be thoroughly purged prior to introducing ABO samples into the gas cell.

5. Using a stainless steel flex line, connect outlet quick-connect on regulator (Fig. 8-6) to gas cell inlet quick-connect (Fig. 7B-3).

6. Turn gas cell exhaust valve (Fig. 7B-4) and gas cell inlet and exhaust valve (Fig. 7B-5) to OPEN.

7. Slowly pressurize gas cell to 120 psig. (Fig. 7B-7) by opening the oxygen outlet valve (Fig. 8-2) on the oxygen regulator.

8. When the gas cell maintains a pressure of 120 psig, close the oxygen outlet valve (Fig. 8-2) on the oxygen regulator.

9. Close gas cell inlet and exhaust valve (Fig. 7B-5) by rotating handle clockwise 90°.

10. Disconnect stainless steel flex line from gas cell inlet quick-connect (Fig. 7B-3).

11. See "Sample Analysis" procedures for details.

12. When sample analysis is complete, slowly bleed cell down to zero pressure by opening the gas cell exit valve (Fig. 7B-6).

13. When the gas cell is depressurized, close exit valve (Fig. 7B-6) and follow outline in "Gas Cell Evacuation."

## Sampling from Aircraft

1. Before sampling oxygen from the aircraft, groundcrew maintenance personnel must be notified so that internal power to aircraft can be supplied. This must be done to accurately ascertain the volume of LOX remaining in the converter.

2. Once internal power has been supplied to aircraft, record the LOX volume of the aircraft from the LOX volume indicator located inside cockpit.

3. Free the mask end of the oxygen regulator hose (Fig. 9-2) and place it outside the cockpit.

4. Attach stainless steel flex line with oxygen hose adapter (Fig. 9-1) to the oxygen regulator hose (Fig. 9-2), and other end of flex line to a second stainless steel flex line equipped with male attachment.

5. Attach other end of second stainless steel flex line to the vacuum and inlet quick-connect located on 4-stage pump (Fig. 7B-1).

6. Attach stainless steel filling line (Fig. 3-4) from pump to gas cell inlet quick-connect (Fig. 7B-3).

7. Set oxygen Supply switch on the oxygen regulator (Fig. 10-5) in cockpit to ON.

8. Set oxygen mode selector (Fig. 10-4) to 100%.

9. Set oxygen delivery selector (Fig. 10-3) to EMERGENCY.

10. Turn pump exhaust and filling valve (Fig. 7A-2) to EXHAUST.

11. Turn gas cell inlet and exhaust valve (Fig. 7B-5) to OPEN, and make sure gas cell exhaust valve (Fig. 7B-4) is also at OPEN.

12. Turn pump to ON (Fig. 7B-8) and thoroughly purge all lines for 2 minutes.

13. After 2-minute purge, place pump exhaust and filling valve (Fig. 7B-2) in FILLING position. (NOTE: Valve settings should now be identical to those in Fig. 7B).

14. Pressurize gas cell to 125 psig (Fig. 7B-7).

15. When gas cell maintains a pressure of 125 psig, return pump exhaust and filling valve (Fig. 7B-2) to EXHAUST.

16. Close gas cell inlet and exhaust valve (Fig. 7B-5) by turning handle clockwise 90°.

17. Disconnect stainless steel filling line from gas cell inlet quick-connect (Fig. 7B-3).

18. Adjust cell pressure to 120 psig by slowly bleeding the oxygen through the gas cell exit valve (Fig. 7B-6).

19. See "Sample Analysis" for details.

20. When sample analysis is complete, slowly bleed gas cell down to 0.00 psig by opening the gas cell exit valve (Fig 7B-6).

21. When gas cell is depressurized, close exit valve (Fig. 7B-6) and follow outline in "Gas Cell Evacuation."

22. Return aircraft oxygen regulator supply switch to OFF and oxygen delivery and mode to NORMAL (Fig. 10).

## Sampling from Liquid Oxygen Sampler (Cryogenic)

1. Request that a LOX sample be obtained from the bulk supply or service cart via liquid oxygen sampler FSN 6695-85-1348 or equal (Fig. 11).

2. Upon receiving the LOX sampler, make sure its pressure gauge (Fig. 11-3) reads at least 300 psig.

3. Attach sampler-to-analyzer adapter (Fig. 11-1) to sampler outlet valve.

4. Attach stainless steel flex hose to adapter.

5. Purge sampler-to-analyzer adapter and steel flex hose.

6. Attach other end of stainless steel flex hose to spectrometer inlet quick-connect (Fig. 7B-3).

7. Set spectrometer gas inlet and exhaust valve (Fig. 7B-5) at OPEN.

8. Slowly pressurize gas cell to 120 psig by opening outlet valve (Fig. 11-2) on LOX sampler.

9. Close sampler outlet valve (Fig. 11-2) and gas cell inlet and exhaust valve (Fig. 7B-5).

10. Analyze sample as described in "Sample Analysis."

11. When analysis is completed, slowly bleed oxygen from the gas cell via gas exit valve (Fig. 7A-6) until gauge (Fig. 7A-7) indicates zero pressure.

12. Close gas exit valve (Fig. 7A-6) and follow outline in "Gas Cell Evacuation" procedure.

## SAMPLE ANALYSIS

The portable IR spectrometer is equipped with a circular variable filter divided into three concise wavelength segments; 2.5-4.5 microns, 4.5-8.0 microns, and 8.0-14.5 microns (Fig. 12). Because of the possible quantity of contaminants present in oxygen, two cell-pathlength settings must be used for oxygen contaminant analysis. In the 2.5- to 4.5-micron wavelength segment, ethane and methane are analyzed at a 20.25-m cell pathlength, and carbon dioxide at a 2.25-m pathlength. In the 4.5- to 8.0-micron wavelength segment, nitrous oxide, carbon monoxide, and water vapor are analyzed at a 20.25-m pathlength. In the 8.0- to 14.5-micron wavelength segment, freons, solvents, acetylene, and ethylene are analyzed at a 20.25-m pathlength. A 4-part strip-chart record is made from each oxygen sample analyzed. After the previously discussed calibration and gas sampling procedures are completed, each oxygen sample will be analyzed.

### Analysis at 20.25-Meter Pathlength

1. Adjust cell pathlength to 20.25 meters, as outlined in "Adjustment of Variable-Pathlength Gas Cell."

2. Set Wavelength selector (Fig. 4A-2) at 2.5 microns; recorder pen should read zero on the chart paper.

3. Set Slit width selector (Fig. 4A-3) at .5 mm.

4. Manually rotate Wavelength selector (Fig. 4A-2) through 2.5- to 4.5-micron segment until recorder pen makes a maximum upscale deflection around 3.5 microns. Set Wavelength selector at this point.

5. Adjust spectrometer Gain control knob (Fig. 4B-1) to 100% transmission on recorder chart.

6. Make sure recorder reading coincides with galvanometer reading (Fig. 4A-1). Refer to "Installation and Calibration," step 14, if adjustment is needed.

7. Manually return Wavelength selector (Fig. 4A-2) to 2.5 microns.

8. Set recorder Chart speed selector (Fig. 5A-3) at 2 in./min.

9. Depress Scan switch (Fig. 4C-1) and record the 2.5-4.5 micron segment.

10. Return Scan switch (Fig. 4C-1) to original position at the conclusion of the wavelength segment.

11. Set recorder Chart speed selector (Fig. 5A-3) at 0 in./min.

12. Advance Wavelength selector (Fig. 4A-2) to the next wavelength segment, repeating steps 2 through 11, for the 4.5-8.0 and 8.0-14.5 micron segments. Continue scanning until all three wavelength segments are recorded at the 20.25-m pathlength.

### Analysis at 2.25-Meter Pathlength

1. Adjust cell pathlength to 2.25 meters, as outlined in "Adjustment of Variable-Pathlength Gas Cell."

2. Return Wavelength selector (Fig. 4A-2) to 2.5 microns, and repeat steps 2-11 as outlined in "Analysis at 20.25-Meter Pathlength" for 2.5-4.5 micron segments.

## INTERPRETATION OF DATA

The completed analysis of an oxygen sample consists of a 4-part strip-chart record and forms the basis for the rapid assessment of oxygen quality. The actual assessment is accomplished by superimposing the appropriate clear plastic overlay over the corresponding wavelength strip-chart segments. Each calibrated overlay consists of an infrared absorption spectra of frequently occurring oxygen contaminants, analyzed at known use-limit concentrations as indicated in Table 1. Therefore, an estimate of the concentration of each contaminant can be made by a visual comparison of the calibrated overlay to an oxygen spectra of unknown contaminant concentration. This semiquantitative method allows the operator to bracket the concentration ranges of the suspected oxygen contaminants in such a manner that the overall quality of the oxygen can be determined easily and accurately.

Most contaminants found in ABO exhibit relatively simple infrared spectra and absorb at frequencies generally free from interference by other contaminants. Tables 1 and 2 list the analytical wavelengths at which the most common oxygen contaminants absorb infrared energy.

TABLE 1. LOWER DETECTION LIMITS OF THE PORTABLE IR SYSTEM

| Contaminant | Use limit[a] (ppm) | Analytical wavelength (microns) | P-IR (ppm) |
|---|---|---|---|
| $CO_2$ | 10 | 4.25 | 2 |
| $N_2O$ | 2 | 4.50 | 0.5 |
| $CH_4$ | 50 | 3.24 | 5 |
| $C_2^+$ Hydrocarbons | 6 | 3.35 | 1 |
| $C_2H_2$ | 0.1 | 13.75 | 0.2 |
| $C_2H_4$ | 0.4 | 10.58 | 0.4 |
| Refrigerants (total) (individual) | 2 | See Table 2 | 0.1 |
| Solvent (total) (individual) | 0.2 | See Table 2 | 0.1 |
| Other | 0.2 | Varies | |
| CO | | 4.60 | 2.0 |

[a] T.O. 42B6-1-1 (Nov 1966)

TABLE 2. LOWER DETECTION LIMITS OF COMPOUNDS DETERMINED WITH THE PORTABLE IR SYSTEM

| Compound | Analytical wavelength (microns) | Lower detection limits[a] (ppm) |
|---|---|---|
| R-11 | 9.30 | 0.1 |
| R-12 | 9.15 | 0.1 |
| R-13 | 9.05 | 0.1 |
| R-22 | 9.05 | 0.1 |
| R-113 | 8.50 | 0.2 |
| R-114 | 8.50 | 0.2 |
| R-115 | 10.25 | 0.2 |
| Trichloroethylene | 10.70 | 0.1 |
| Carbon tetrachloride | 12.60 | 0.1 |
| Methyl chloroform | 9.25 | 0.1 |
| Chloroform | 13.00 | 0.1 |
| 2-propanol | 10.56 | 1.0 |

[a]Limits determined with the pathlength at 20 meters and the cell pressurized to 135 psia.

The infrared absorption spectra of ABO is provided by the recorder as a scaled output in linear percent transmission from 0 to 100%. A reading of 0 transmission at a specified frequency indicates that a given contaminant or contaminants exist in a concentration range large enough to absorb the entire detectable quantity of transmitted infrared energy. Conversely, a reading of 100% transmission at the same specified frequency indicates that a contaminant or contaminants do not exist in a concentration range large enough to absorb any detectable quantity of infrared energy. Therefore, a decrease in the percent of transmitted infrared energy at a specified frequency indicates a corresponding logarithmic increase in contaminant concentration.

Figure 13 represents a 4-part strip-chart record of ABO of unknown contaminant concentration. The infrared spectra shown is divided into three concise wavelength segments. However, due to the concentration of carbon dioxide absorbed at 4.25 microns in Figure 13(A), it is necessary to reduce the pathlength from 20.25 meters to 2.25 meters, as indicated in Figure 13(B). This action results in the composite 4-part strip-chart record.

Examples of the oxygen spectra contained in the calibrated plastic overlays appear in Figure 14. The concentration of each contaminant corresponds with its use-limit value given in Table 1. Only examples of contaminants that occur most frequently in ABO appear in the figure.

The spectra containing ABO of undetermined contaminant concentration (Fig. 13) may be assessed by visually comparing each corresponding wavelength segment to that of the ABO spectra of calibrated contaminant concentration (Fig. 14). Any deviation from specific points marked on the calibrated ABO spectra which results in an increase in the percent of transmitted infrared energy, indicates that the level of contaminant concentration falls within the prescribed use-limit value. Conversely, any deviation resulting in a decrease in the percent of transmitted infrared energy, indicates that the level of contaminant concentration is above the prescribed use-limit value and is, therefore, of unacceptable quality, as outlined in T.O. 42B6-1-1 (Nov. 1966).

For example, carbon dioxide absorbs infrared energy in the 2.5-4.5 micron segment. A comparison of Figures 13(B) and 14(B) reveals that the percent of transmitted infrared energy in the uncalibrated ABO spectra measured at 4.25 microns is greater than that of the calibrated ABO spectra (44% vs. 30% T). Thus, the level of carbon dioxide contamination is well within its indicated use-limit value specified in Table 1. Had the percent of transmitted infrared energy been less than that recorded in the calibrated ABO spectra (less than 30% T), the level of carbon dioxide contamination would have been higher than the specified use-limit value, and therefore unacceptable.

This overlay method of quantification works extremely well for all compounds listed in Table 1. However, notable exceptions occur with

solvents and refrigerants. Since these compounds exhibit spectra containing several absorption bands in the 8.0-14.5 micron segment, identification and quantification is sometimes difficult because of overlapping spectral absorbance. Therefore, unless positive identification can be made, any measurable absorbance in the 8.0-14.5 micron segment should be considered questionable, and appropriate action taken.

Absorptions between 5.5 and 7.5 microns (water vapor band) and between 2.6 and 2.9 microns (composite carbon dioxide and water vapor band) are usually disregarded and can be expected to fluctuate from sample to sample. This fluctuation is due to changes in atmospheric conditions and the incomplete purging of all sample lines. For this reason, periodic fluctuations may also be expected to occur at 4.25 microns, the analytical wavelength of carbon dioxide. Therefore, extreme care should be taken to insure that the gas cell is thoroughly evacuated and all sample lines are properly purged prior to sampling.

Table 1 does not list a use-limit value for carbon monoxide, which appears as a double absorption peak in the same region as nitrous oxide at 4.7 microns. Since the minimum detectable concentration of carbon monoxide is between 1 and 2 parts per million at a scale expansion factor of X1, any appearance of carbon monoxide would constitute contaminated oxygen. The occurrence of carbon monoxide in oxygen is rare and is usually due to insufficient purging of the oxygen hose and sampling lines. If carbon monoxide does appear during sampling, the system should be thoroughly purged and resampled.

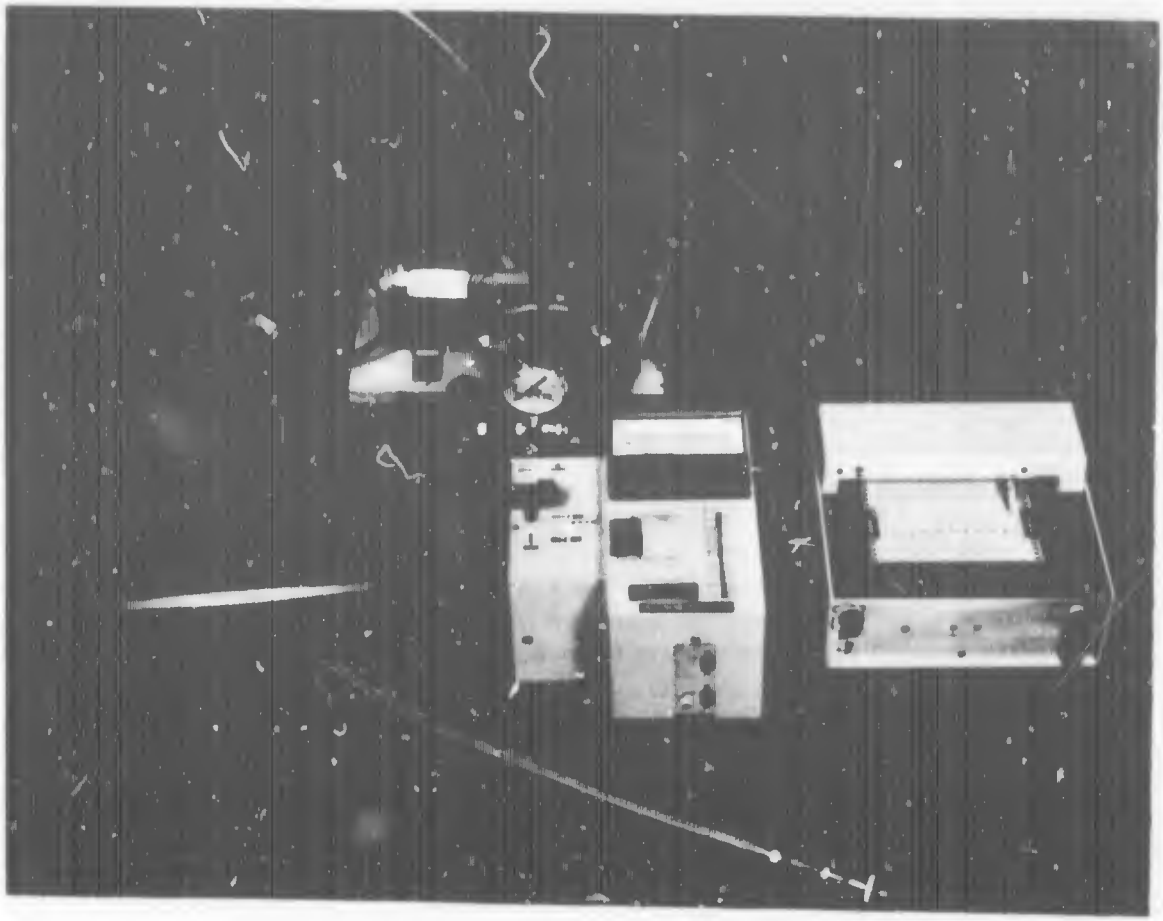


Figure 1. Aviator's breathing oxygen contaminant detector (ABOCD).

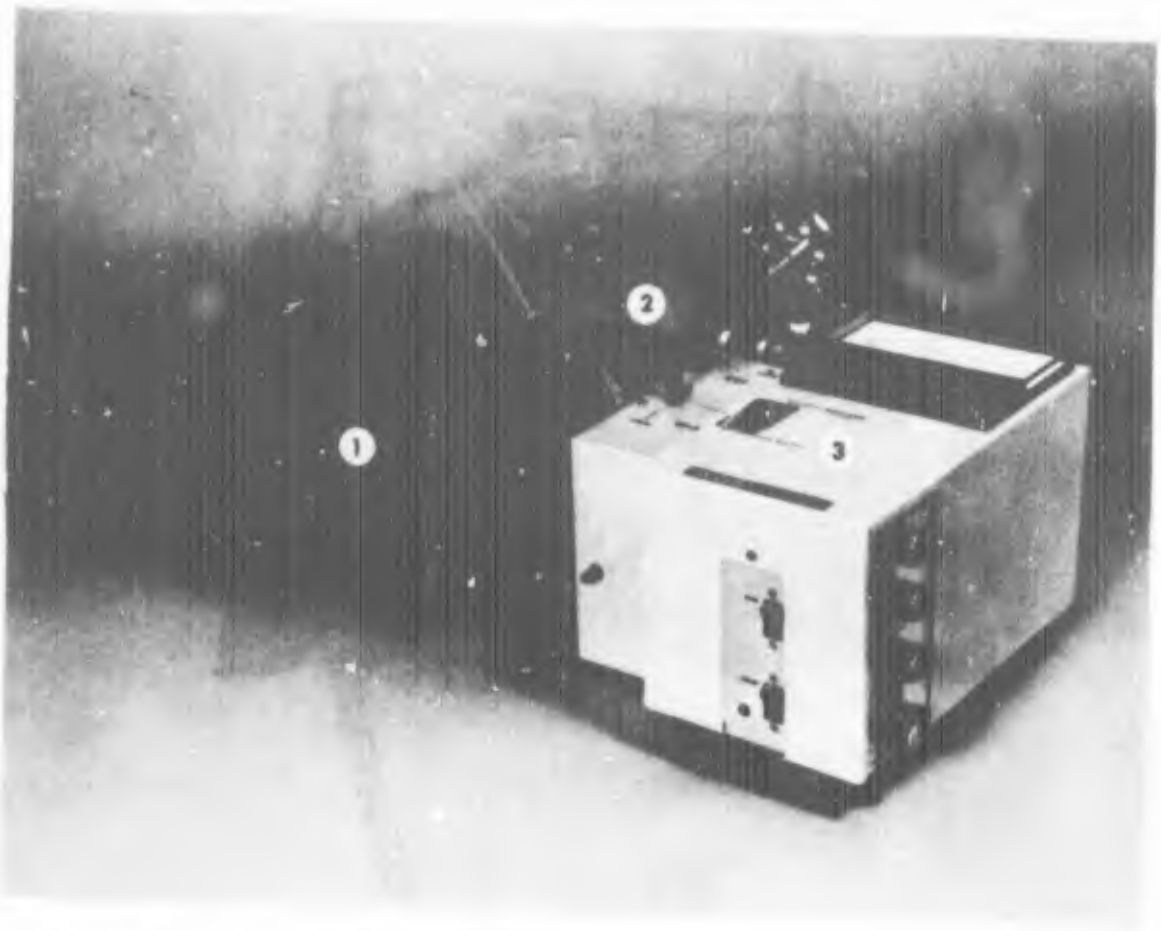



Figure 2. Infrared spectrometer:

1. Variable pathlength gas cell
2. Valving
3. Infrared spectrometer electronics

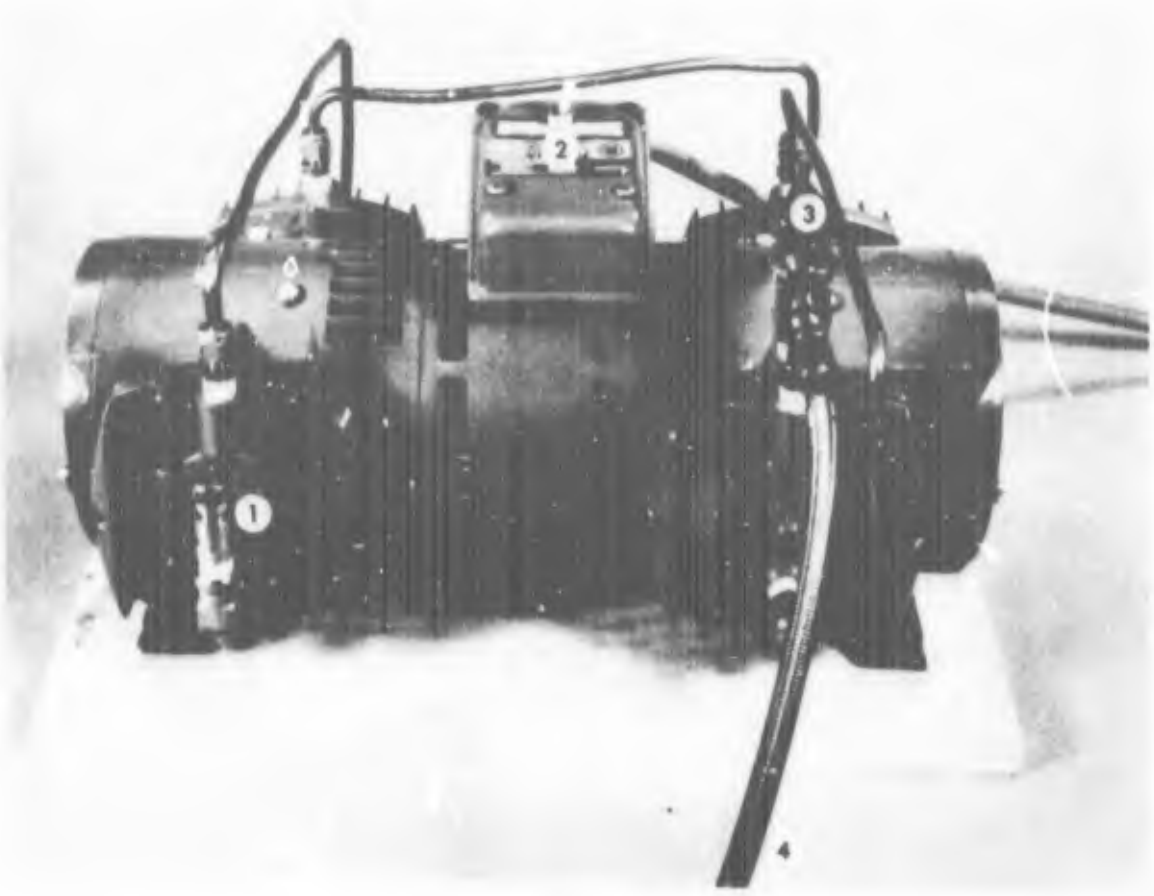



Figure 3. Four-stage vacuum and compression pump:

1. Vacuum and inlet quick-connect
2. Power switch
3. Exhaust and filling valve
4. Filling line

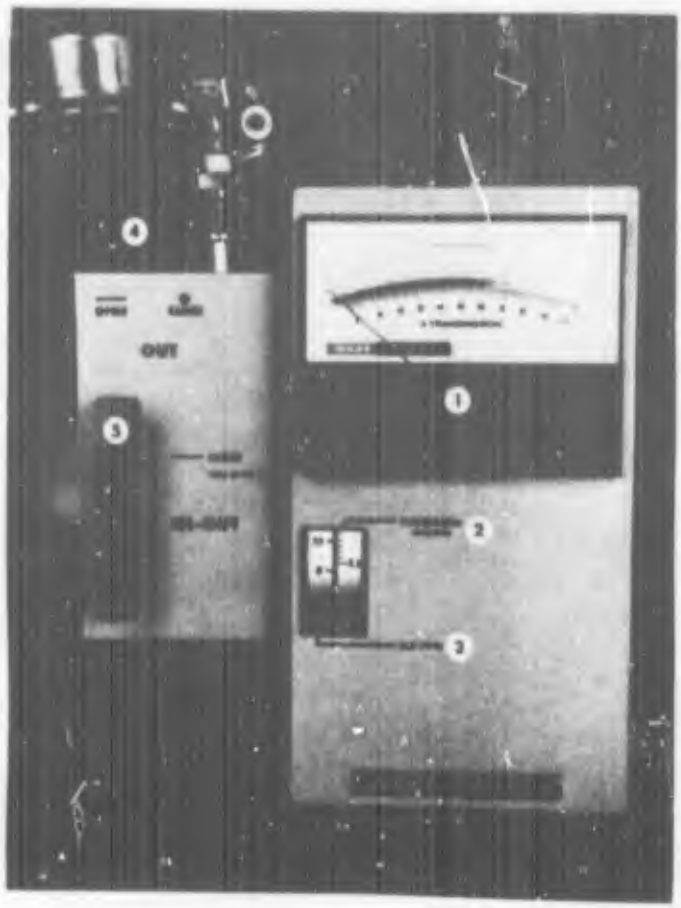



Figure 4A. Top view of infrared spectrometer:

1. Galvanometer
2. Wavelength selector wheel (μ)
3. Slit width selector wheel (mm)
4. Gas cell exhaust valve (OPEN)
5. Gas cell inlet and exhaust valve (OPEN)

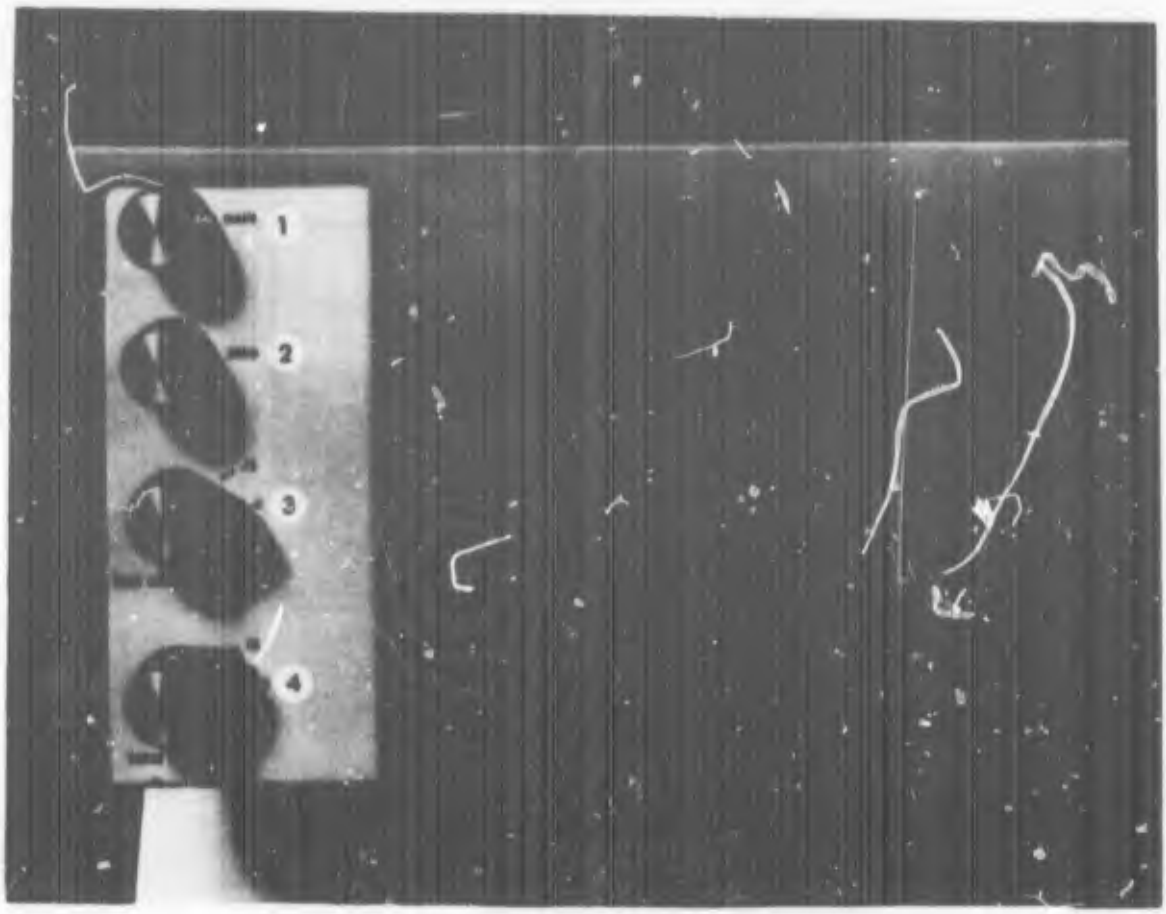



Figure 4B. Side view of infrared spectrometer:

1. Gain control knob
2. Zero control knob
3. Time Constant switch
4. Scale Expansion switch

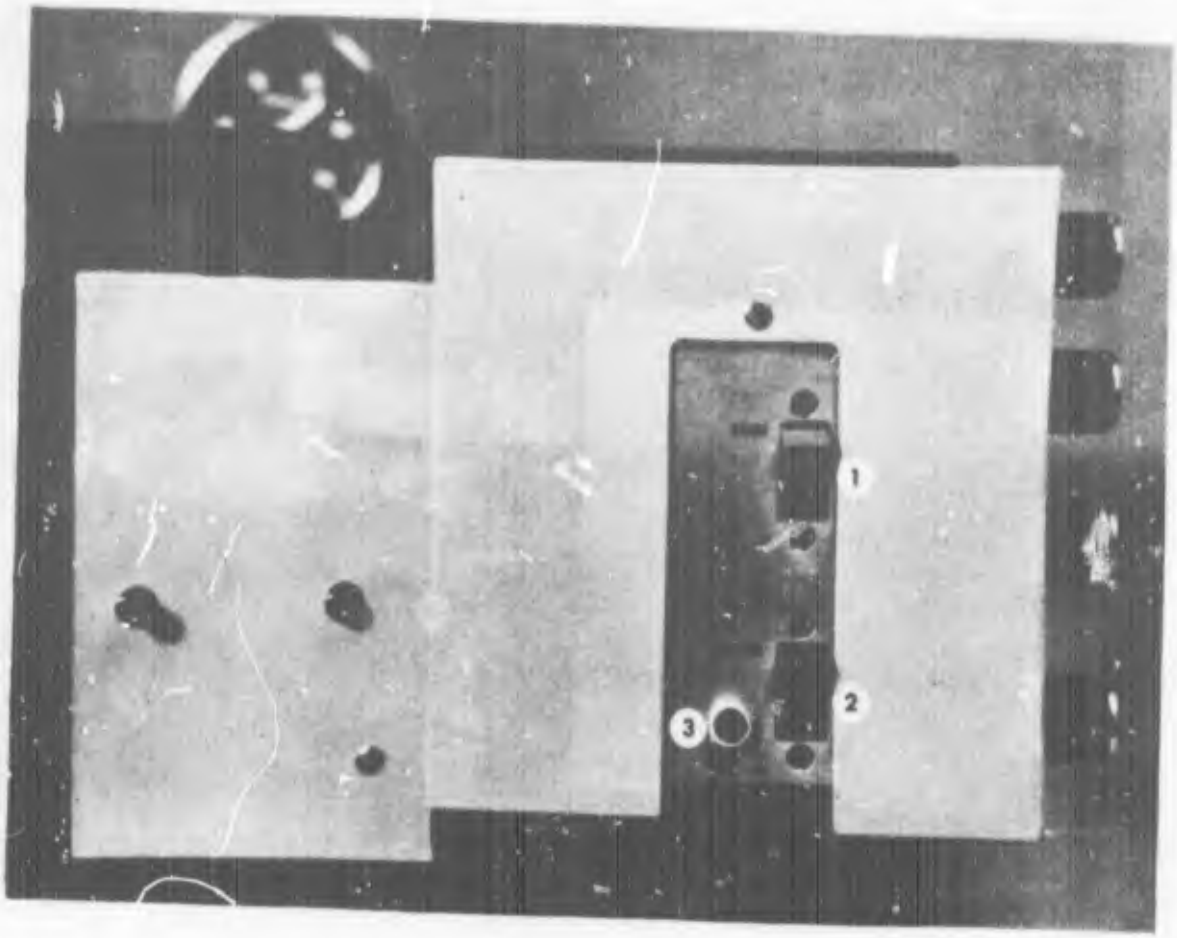



Figure 4C. Front view of infrared spectrometer.

1. Scan drive switch
2. Power switch
3. Power light

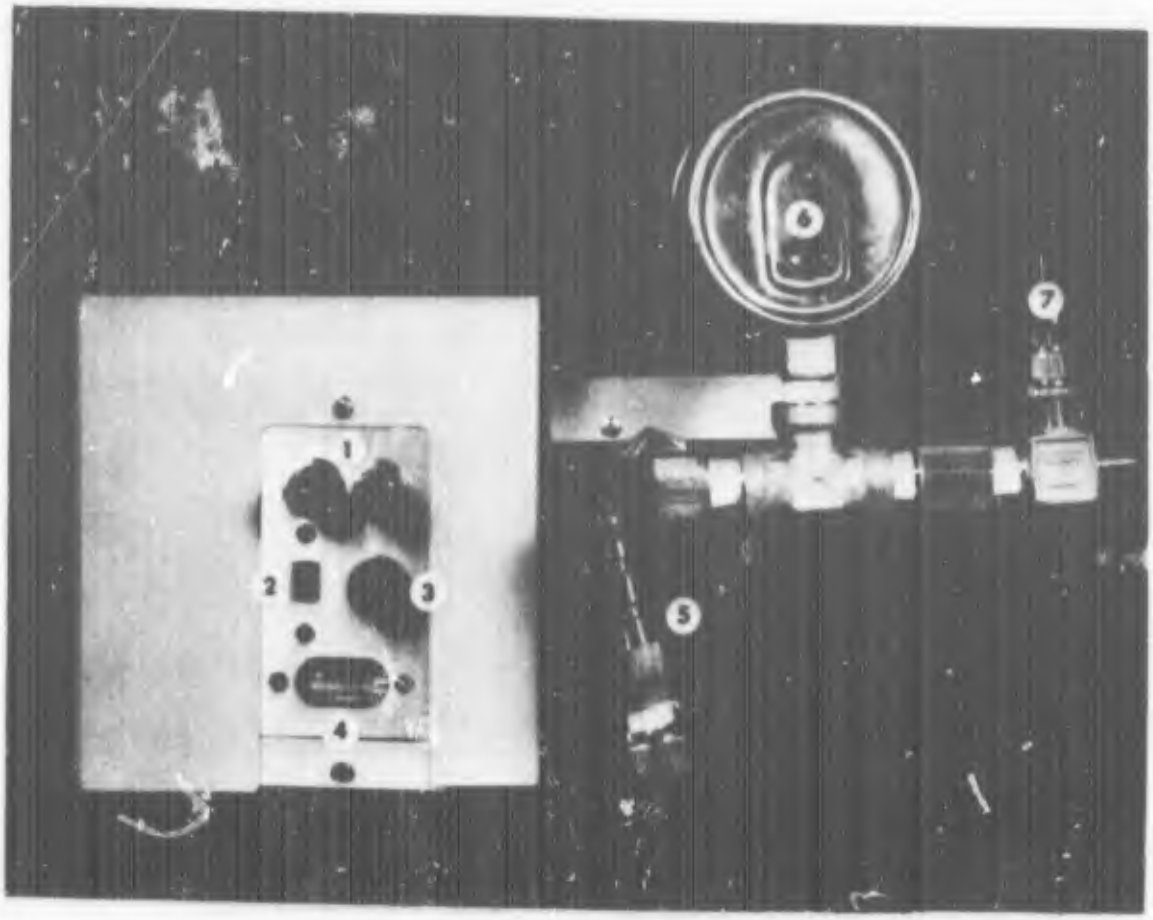



Figure 4D. Rear view of infrared spectrometer:

1. Spectrometer output terminals
2. Voltage selector switch
3. 1-amp fuse and fuse holder
4. Power input plug (115 V)
5. Inlet quick-connect
6. Pressure gauge
7. Exit valve

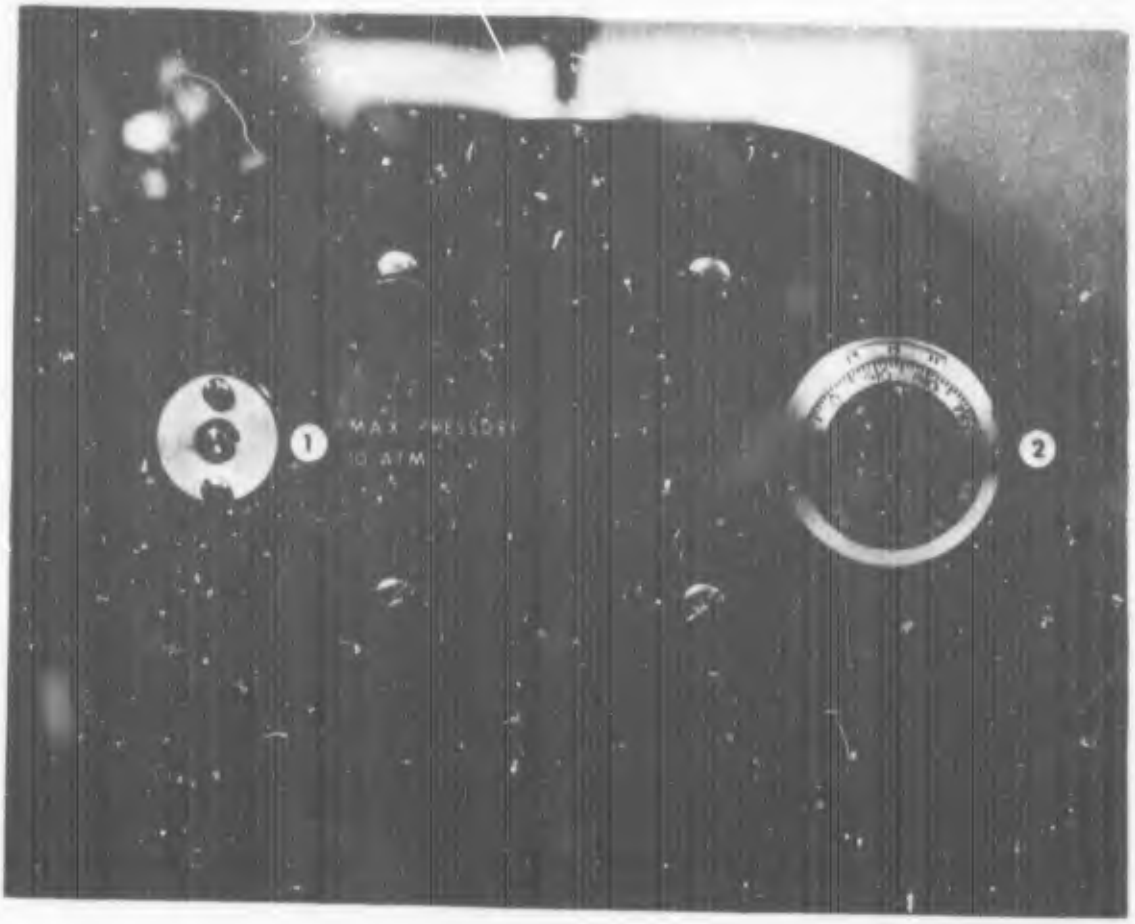



Figure 4E. Side view of variable-pathlength gas cell:

1. Pressure release valve (for safety purposes only)
2. Variable-pathlength adjustment knob

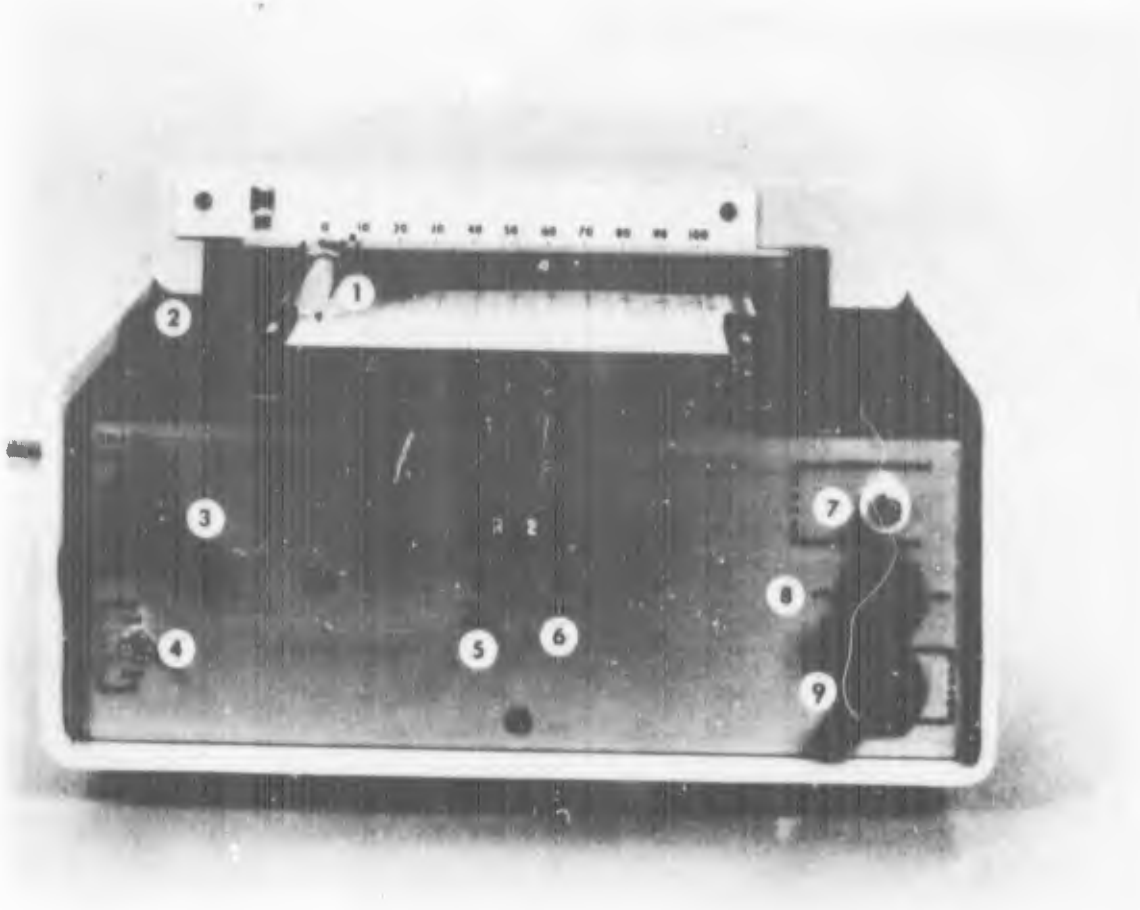



Figure 5A. Front view of potentiometric recorder:

1. Felt-tip pen and holder
2. Manual paper-advance wheel
3. Chart speed-selector switch
4. Power switch
5. Full-Scale adjustment screw
6. Gain adjustment screw
7. Mode selector switch
8. Attenuator adjustment knob
9. Zero adjustment knob

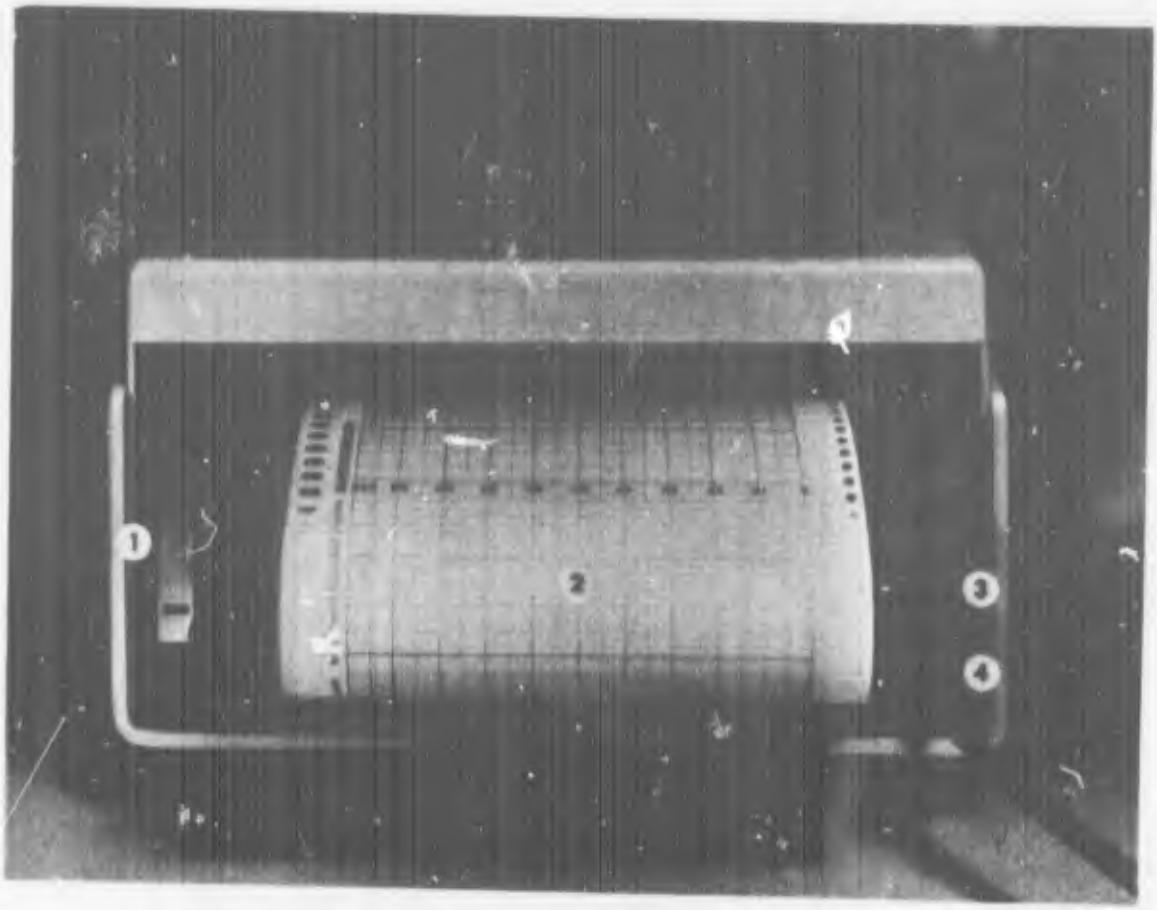



Figure 5B. Rear view of potentiometric recorder:

1. Recorder input terminals
2. Recorder spool and chart paper
3. 0.5-amp fuse and fuse holder
4. Power cord

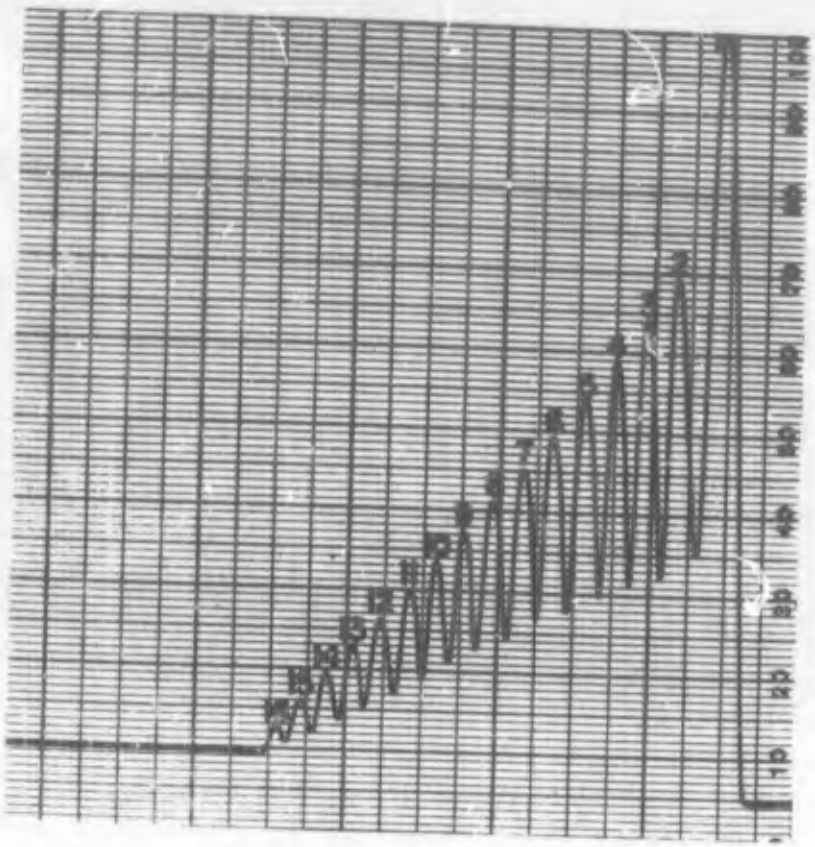


Figure 6. Strip-chart recorder output of change in pathlength measured at 3.5 microns.

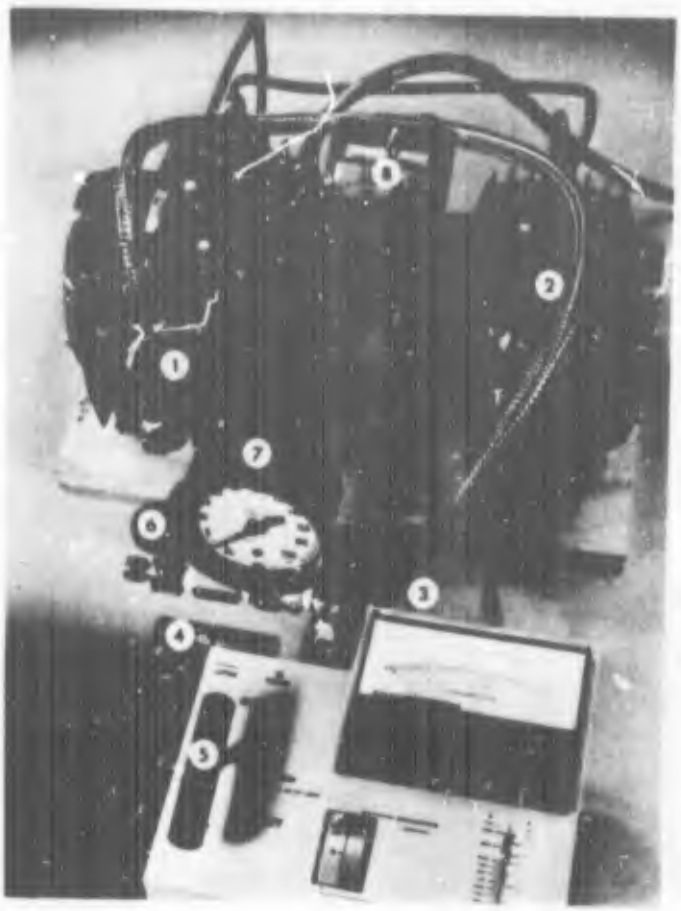



Figure 7A. ABOCD valve positions during gas cell evacuation:

1. Vacuum and inlet quick-connect
2. Pump exhaust and filling valve in EXHAUST position
3. Gas cell inlet quick-connect
4. Gas cell exhaust valve in OPEN position
5. Gas cell inlet and exhaust valve in OPEN position
6. Gas cell exit valve closed, full clockwise
7. Pressure gauge
8. Power switch

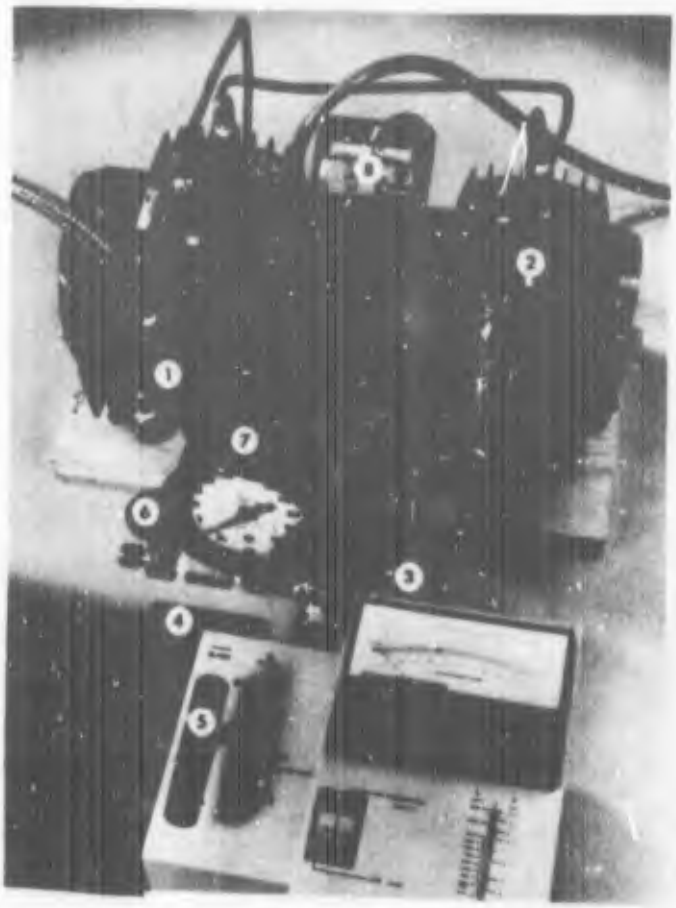


Figure 7B. ABOCD valve positions during gas sampling:

1. Vacuum and inlet quick-connect
2. Pump exhaust and filling valve in FILLING position
3. Gas cell inlet quick-connect
4. Gas cell exhaust valve in OPEN position
5. Gas cell inlet and exhaust valve in OPEN position
6. Gas cell exit valve closed, full clockwise
7. Pressure gauge
8. Power switch

Figure 8. High-pressure gaseous oxygen regulator:

1. Low-pressure adjustment valve
2. Oxygen outlet valve
3. Cylinder valve
4. Low-pressure gauge
5. High-pressure gauge
6. Outlet quick-connect

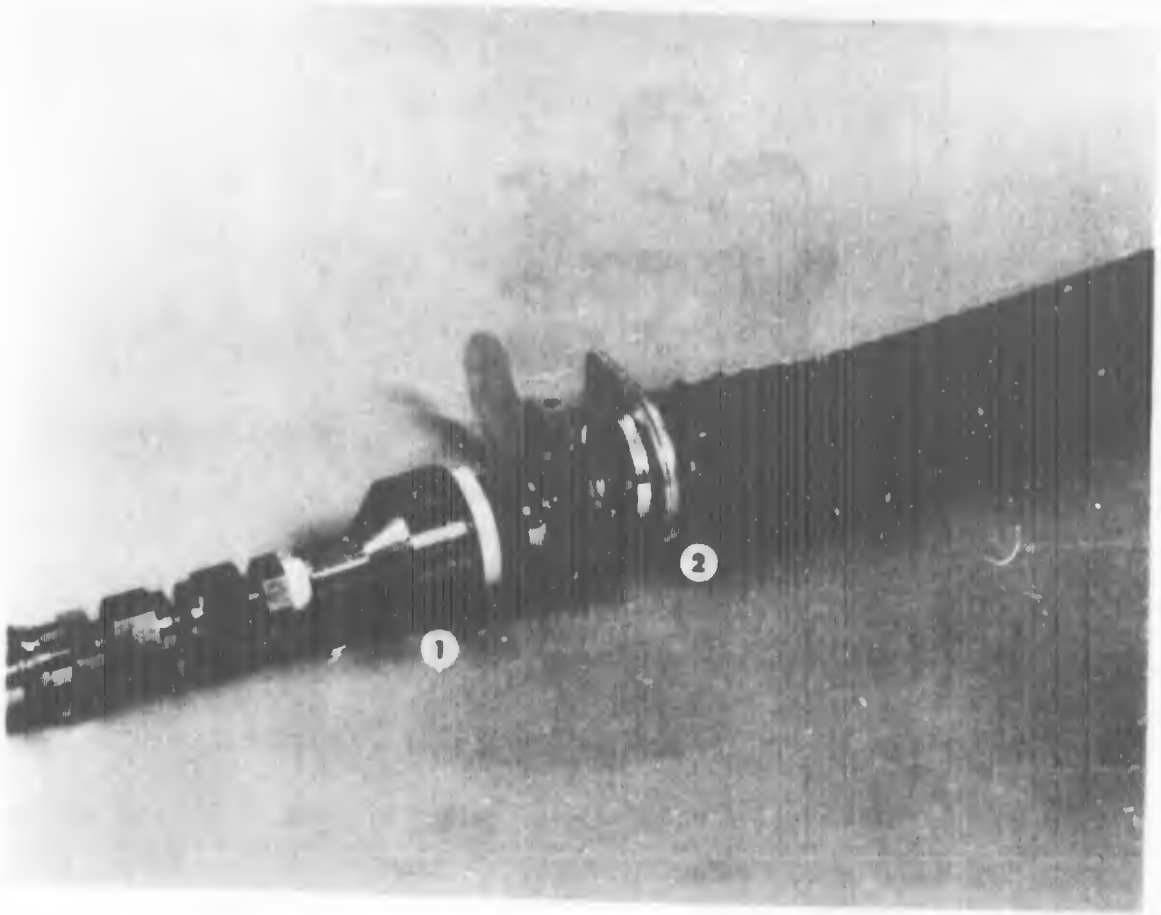



Figure 9. Aircraft-to-analyzer connector:

1. Analyzer-to-oxygen hose adapter
2. Oxygen regulator hose

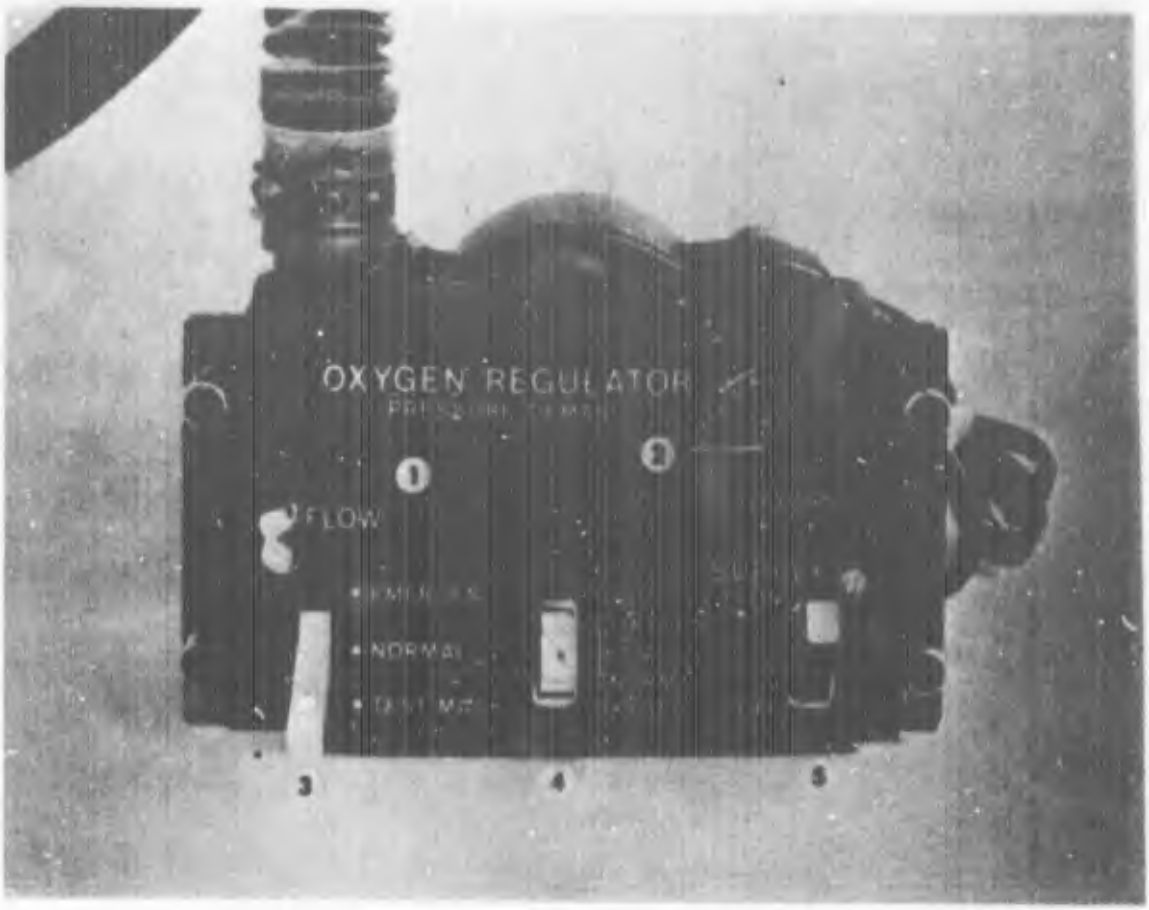



Figure 10. CRU-21/A oxygen regulator:

1. Flow indicator
2. Oxygen pressure gauge
3. Oxygen delivery selector
4. Oxygen mode selector
5. Oxygen Supply switch

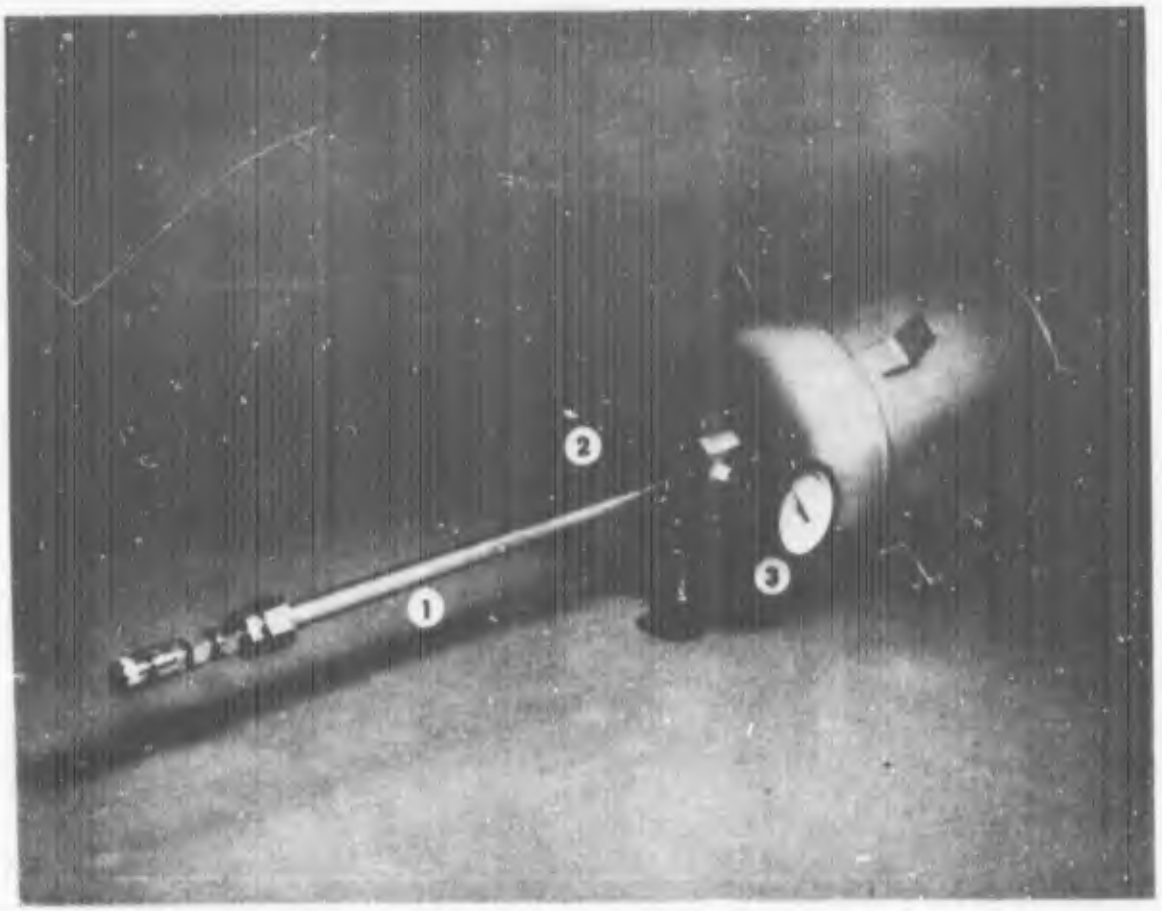



Figure 11. Liquid oxygen sampler with attached sampler-to-analyzer adapter:

1. Sampler-to-analyzer adapter
2. LOX sampler outlet valve
3. LOX sampler pressure gauge

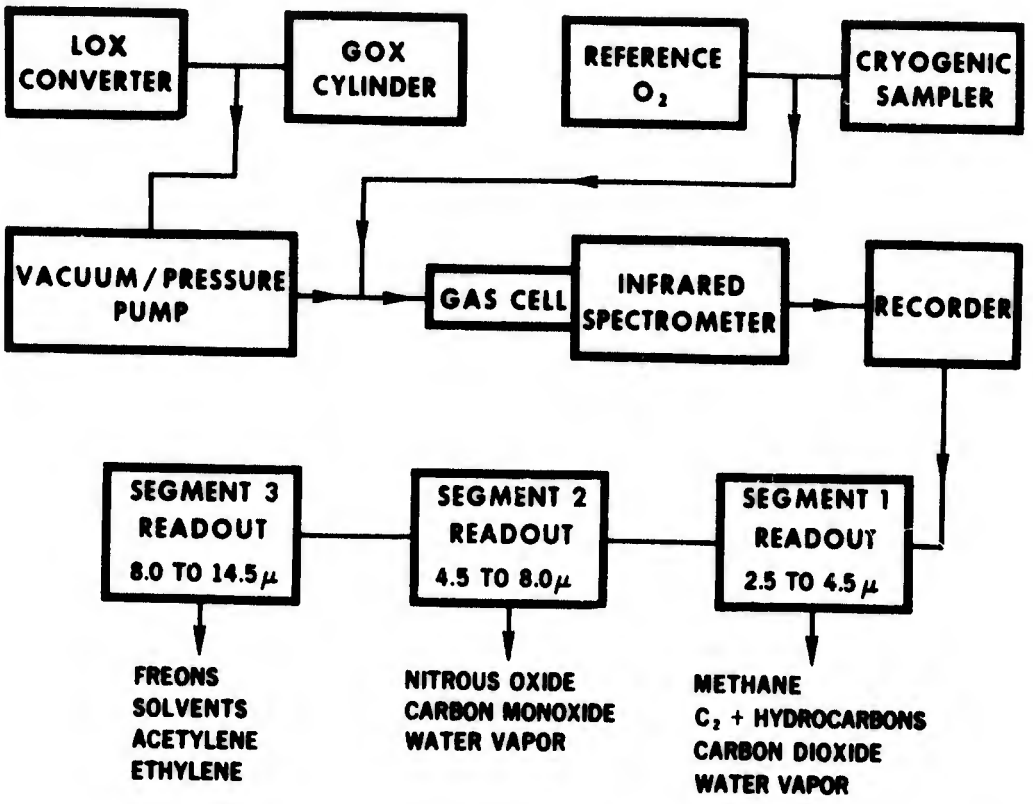



Figure 12. Flow diagram for analysis of contaminated oxygen.

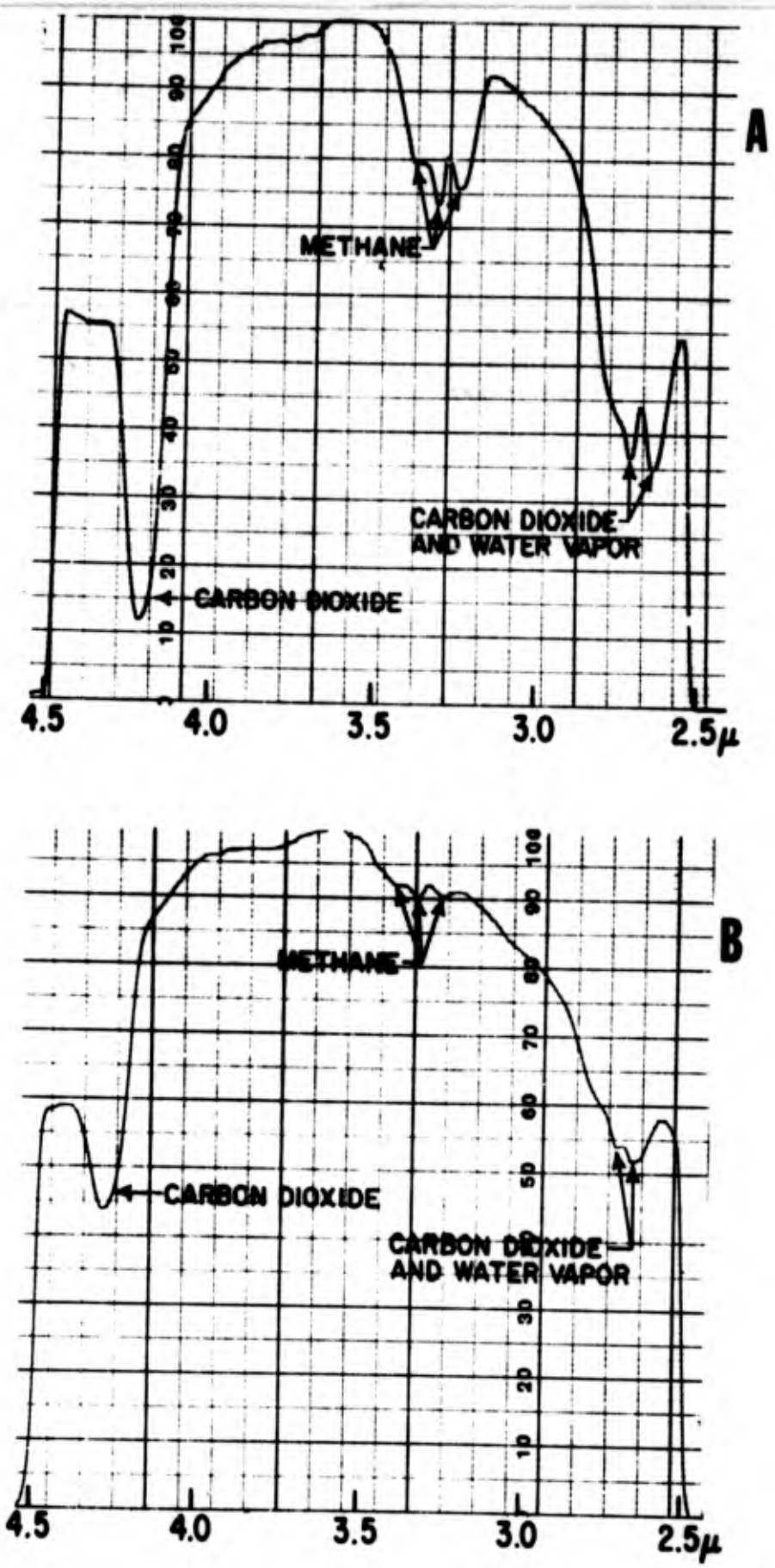
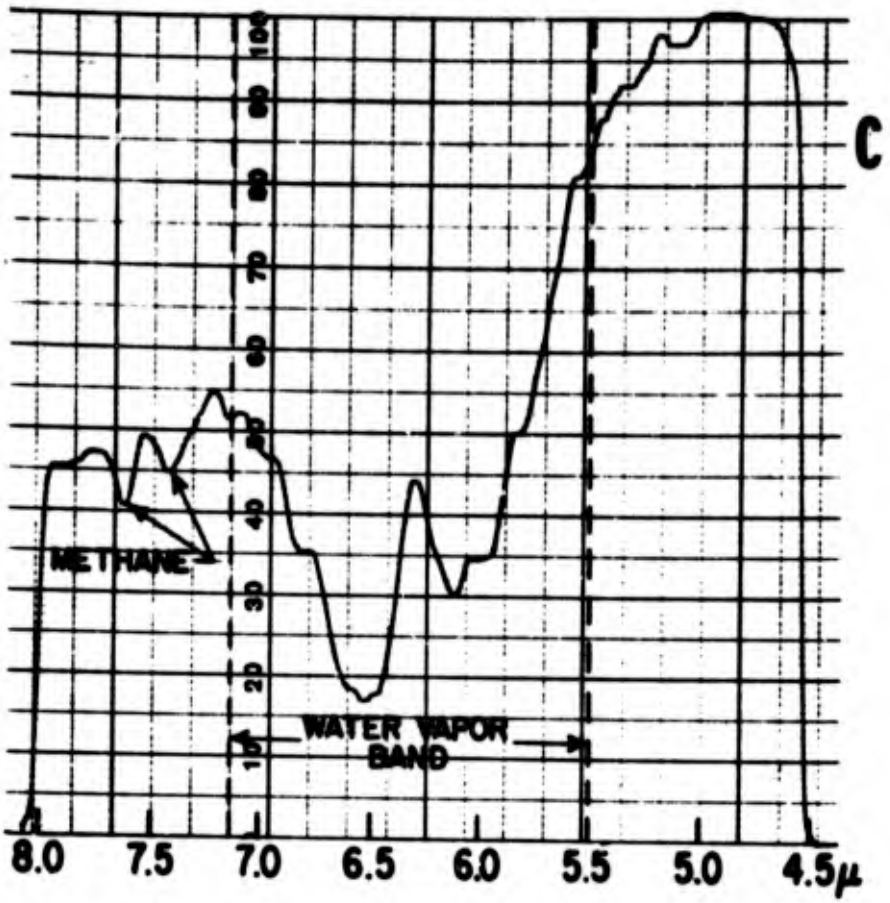



Figure 13. Infrared-absorption spectra of ABO of unknown contaminant concentration; cell pressure 120 psig. Each wavelength segment was analyzed at a 20.25-m pathlength with the exception of segment B which was analyzed at 2.25 meters.



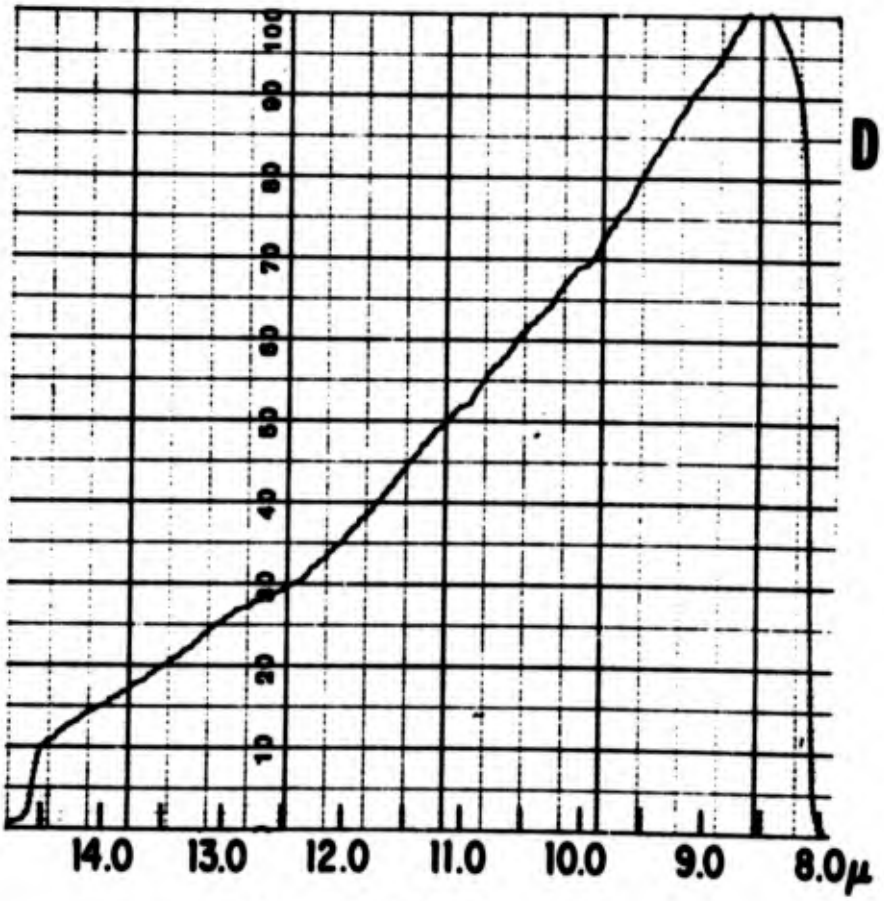




Figure 13 (continued)

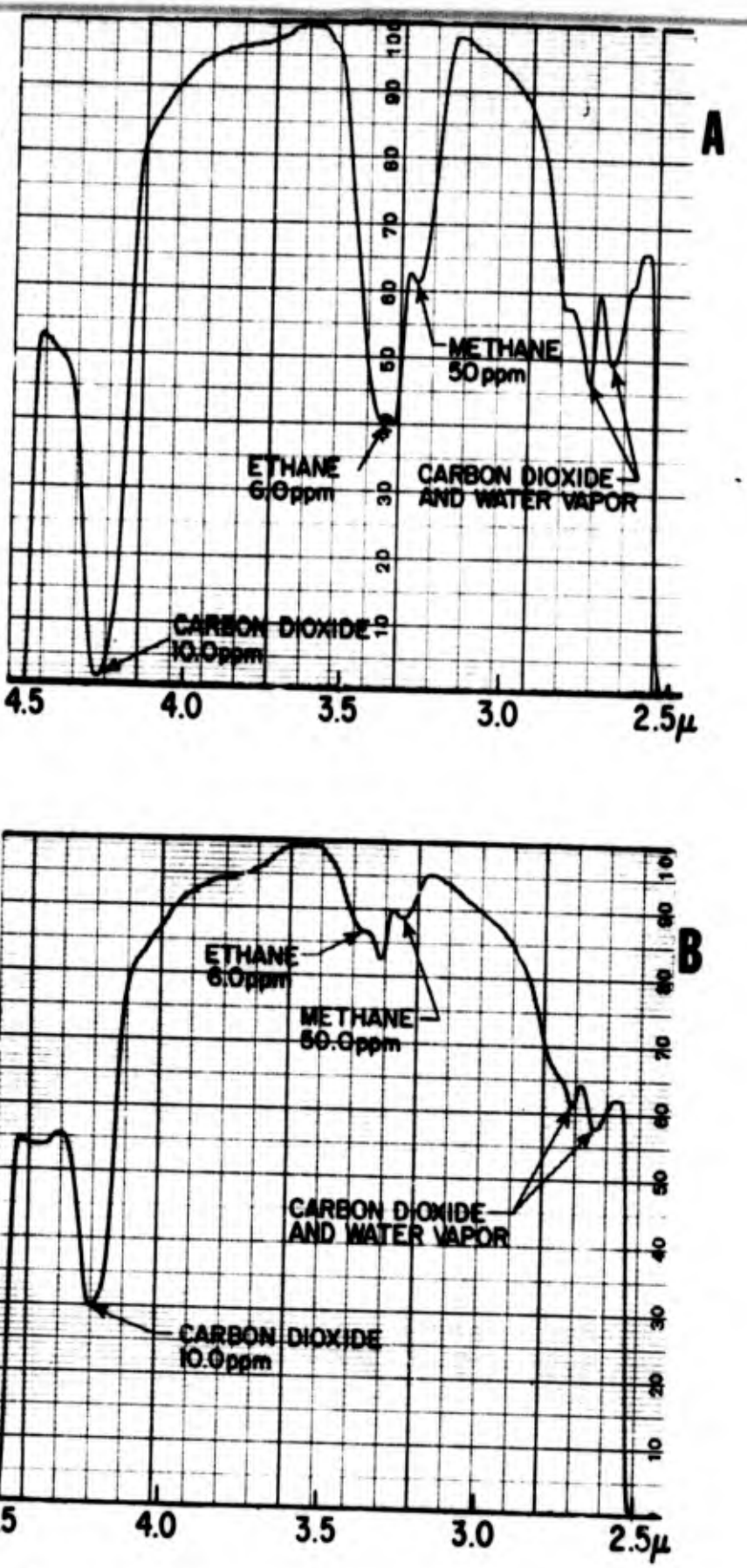
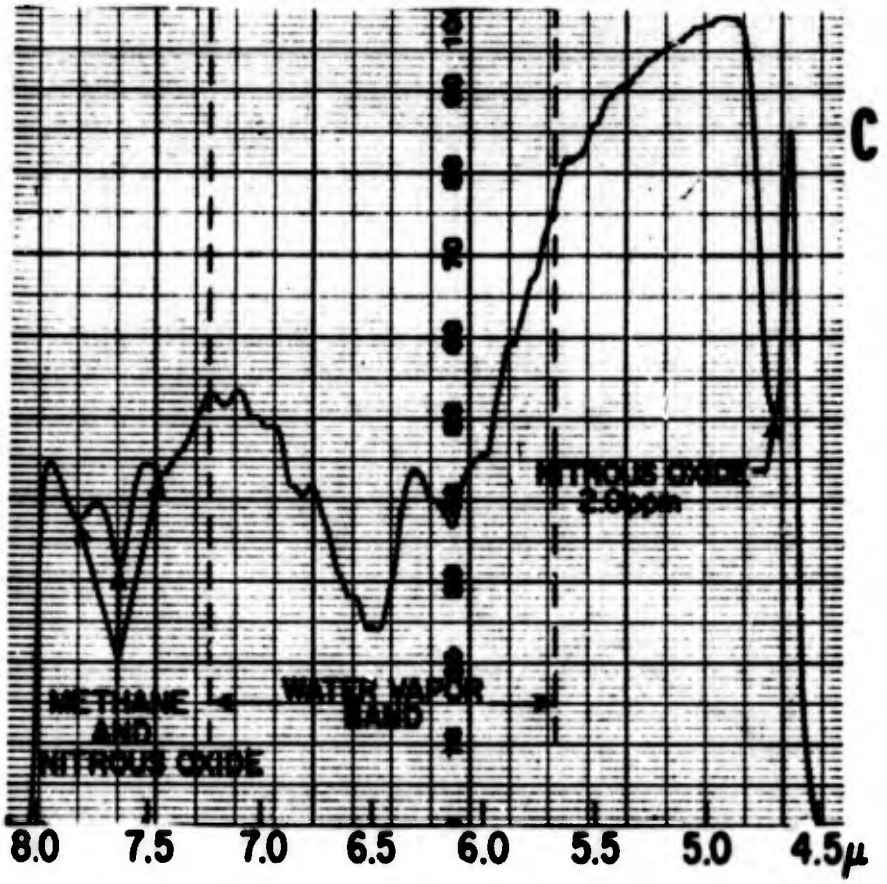



Figure 14. Calibrated infrared-absorption spectra of commonly occurring contaminants in ABO; cell pressure 120 psig. Each wavelength segment was analyzed at a 20.25-m pathlength, with the exception of segment B which was analyzed at 2.25 meters.



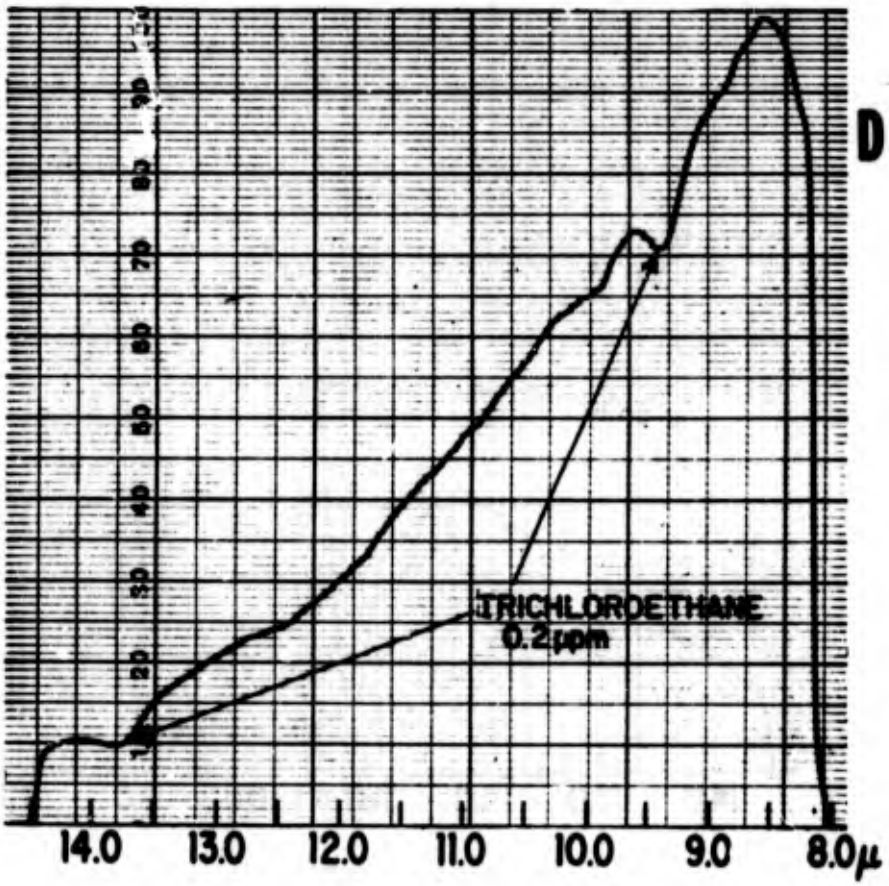
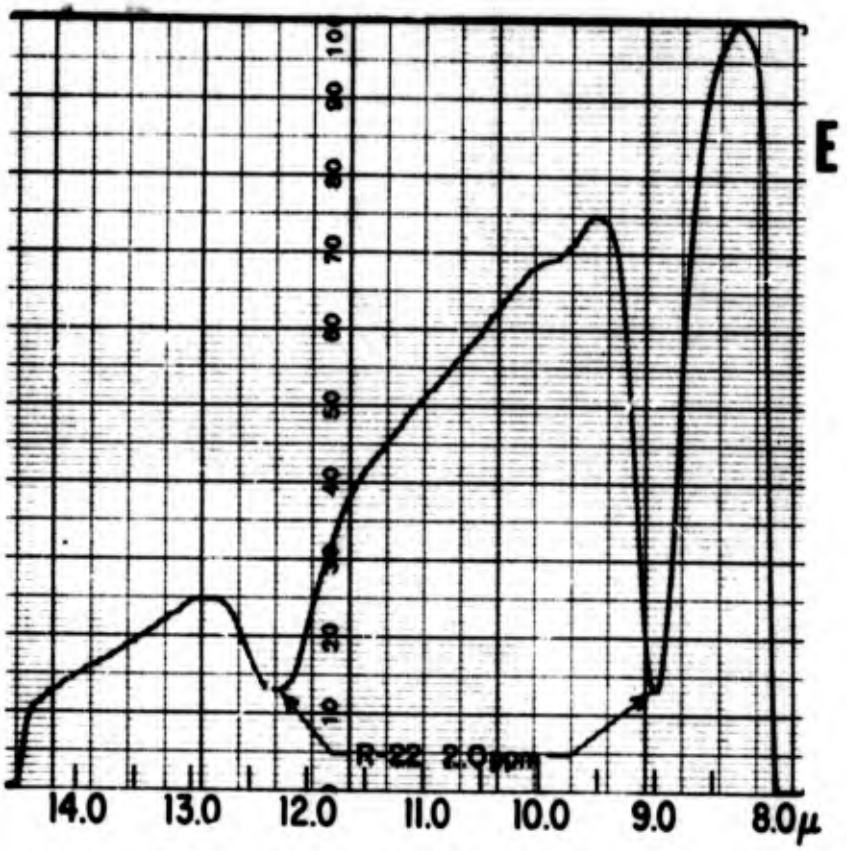




Figure 14 (continued)



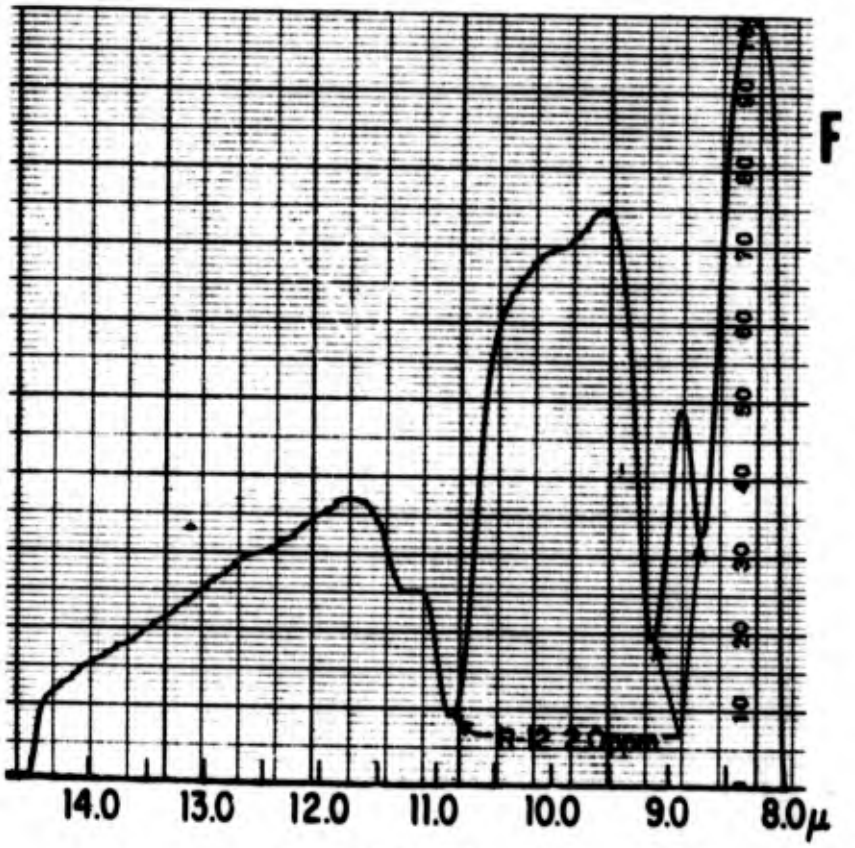




Figure 14 (continued)