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ABSTRACT

A detailed description of an instrument for measuring C^{14}, percent CO_2 and C^{14} specific activity in the breath of human subjects is presented. Ionization chamber assay for the C^{14} is used. The design parameters of radioactivity sensitivity and response time are discussed. For simple carbon-14 metabolites some 1 to 10µc are required for an eight-hour respiration analysis with this instrument.

A CARBON-14 RESPIRATION-PATTERN ANALYZER FOR CLINICAL STUDIES[*]

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INTRODUCTION

In a series of reports[1,2] we have described the development of equipment which could continuously monitor the respiratory excretion of carbon-14 in animals following the injection or oral administration of a labeled substrate. A preliminary discussion of the modification of this equipment for clinical studies was given in the Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, 1955.[3] This paper presents a detailed description of the human carbon-14 respiration-pattern analyzer and discusses partially the presentation and analysis of data obtained in a typical measurement.

INSTRUMENT DESIGN AND CALIBRATION

The C^{14} respiration-pattern analyzer essentially consists of three instruments operating together and the attendant flow system. These instruments a (1) an ionization-chamber—vibrating-reed electrometer for C^{14} analysis; (2) an infrared CO_2-gas analyzer; and (3) a combination recorder-ratio analyzer. Fig. 1 shows the relation of these instruments together with a schematic diagram of th flow system. A typical record of the results as they appear on the recorder chart is shown in Fig. 2.

[**]Present address: Department of Chemistry, University of Colorado, Boulder, Colorado.

[1]Tolbert, Hughes, Kirk, and Calvin: Arch. Biochem. and Biophys. 60, 301 (

[2]Tolbert, Kirk, and Baker: Amer. J. Physiol. 185, 269 (1956).

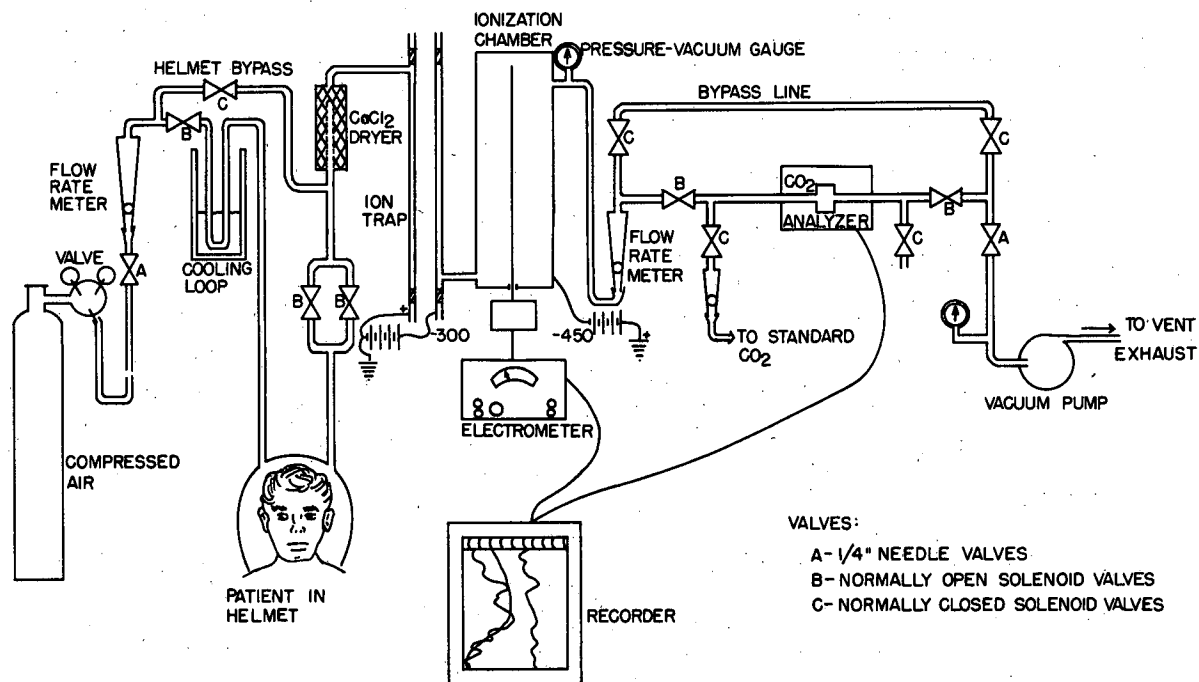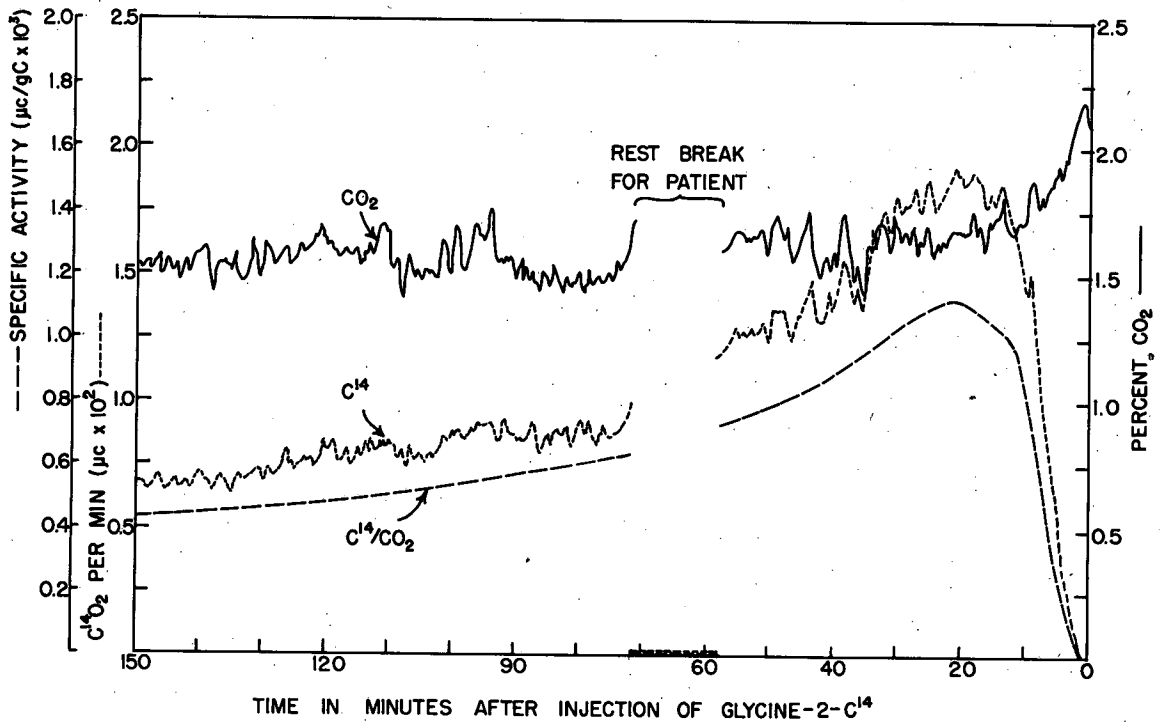[3]Proceedings, Int. Conf. on Peaceful Uses of Atomic Energy, Vol. 12, 281 (1956) UN Publication.

Fig. 1 Schematic diagram of the carbon-14 respiration pattern
analyzer designed for clinical studies.

Fig. 2. Carbon-14 respiration pattern for Mrs. H. after injection of glycine-2-C[14].

Air from a tank of compressed air is passed through control valves, a flow meter, and a cooling loop and into the helmet for the patient. Air is drawn from this helmet through a dryer to remove condensate, an ion trap to discharge airborn statically-charged particles, through the ionization chamber, the CO_2 analyzer, another flow meter, a flow control valve, and the vacuum pump.
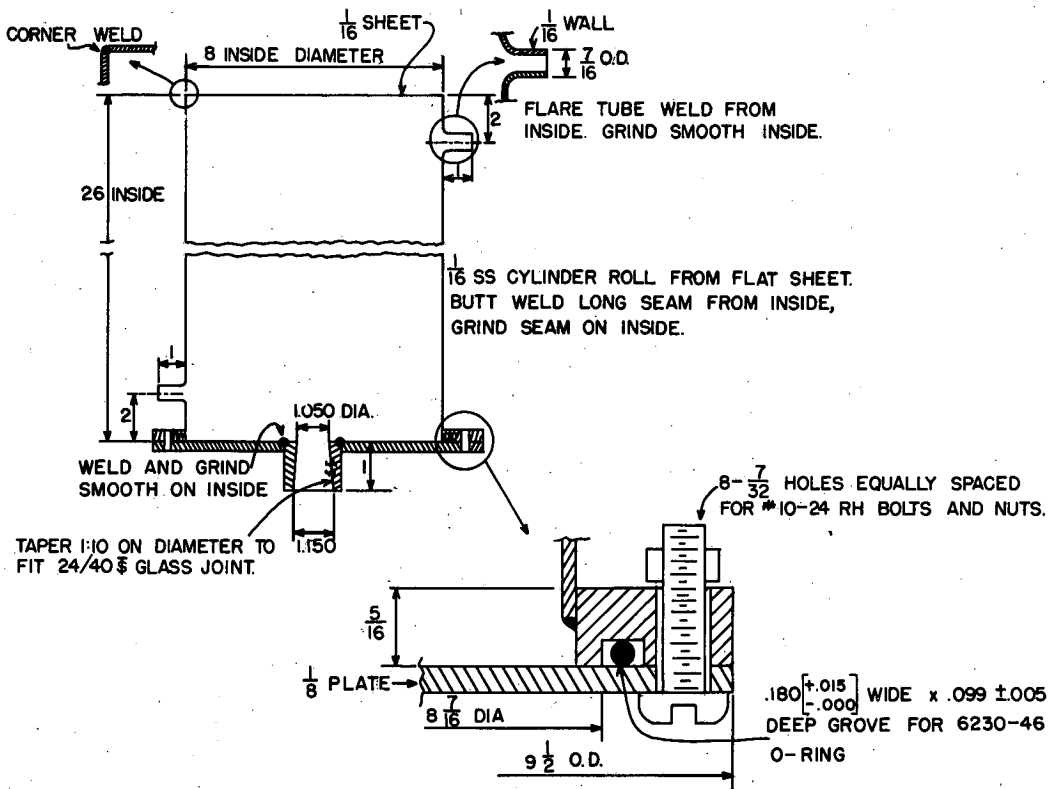
Carbon-14 Analysis

The ionization-chamber—electrometer combination was designed for the best sensitivity that could be combined with a reasonable gas displacement time and electrometer response time (see pages 271-272 of Reference 2). The larger the volume of the ionization chamber, the more signal one can obtain for a given amount of radioactivity per unit volume of air.[4] The 21-liter chamber used is about 95% of theoretical efficiency. On the other hand, very large chambers are unwieldy and require excessively large collection voltages. The 21-liter chamber size was chosen as a compromise. It is sensitive enough to permit human studies with 1 to 10 μc of C^{14}-labeled substrates.

The flow displacement half-time of the 21-liter chamber at 10 liters of air per min is (60) (21/10) ($\log_e 2$) (mixing factor) sec or about 87 sec, if we assume the mixing factor is unity. With a 10^{13}-ohm resistor in the electrometer input, the time for 63% response of the electrometer is (10^{13}) x (effective capacity of electrometer input). Because this latter figure is about 10 $\mu\mu f$, the electrometer's 63% response time is 100 sec, which is about equal to the flow displacement time and, therefore, nearly deal for optimum design as well as for proper operation of the ratio analyzer (see later section).

Figure 3 shows a detailed drawing of the ionization chamber. It was made of low radioactivity 18-8 stainless steel; all joints were Heliarc welded, using a stainless steel rod with no flux to prevent the introduction of radioactive impurities. The welds were made on the inside of the chamber and are air-tight, but not high-vacuum-tight. The inside surface of the chamber was cleaned of any roughness and the seams were ground smooth.

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[4] B. M. Tolbert, Ionization Chamber Assay of Radioactive Gases, UCRL-3499, March 1956.

CORNER WELD

$\frac{1}{16}$ SHEET

8 INSIDE DIAMETER

$\frac{1}{16}$ WALL

$\frac{7}{16}$ O.D.

FLARE TUBE WELD FROM
INSIDE. GRIND SMOOTH INSIDE.

26 INSIDE

$\frac{1}{16}$ SS CYLINDER ROLL FROM FLAT SHEET.
BUTT WELD LONG SEAM FROM INSIDE,
GRIND SEAM ON INSIDE.

1.050 DIA.

WELD AND GRIND
SMOOTH ON INSIDE

TAPER 1:10 ON DIAMETER TO   1.150
FIT 24/40 $ GLASS JOINT.

$8-\frac{7}{32}$ HOLES EQUALLY SPACED
FOR #10-24 RH BOLTS AND NUTS.

$\frac{5}{16}$

$\frac{1}{8}$ PLATE

$8\frac{7}{16}$ DIA

$9\frac{1}{2}$ O.D.

$.180\begin{bmatrix}+.015\\-.000\end{bmatrix}$ WIDE x .099 ±.005
DEEP GROVE FOR 6230-46
O-RING

MU-14041

Fig. 3. Sketch of the 21-liter ionization chamber in cut-away
view. The chamber is cylindrical, 8 in. diam. x 26 in.
long. All other dimensions are given in inches.

NOTES:

(1) All material to be 18-8 stainless steel.
(2) All welds to be Heliarc using stainless steel rod and
no flux.
(3) Welds should be air-tight but need not be vacuum-
tight.
(4) Finish gasket surfaces and flange contact surfaces
"f" finish.
(5) Do not sandblast.

The collecting-electrode insulator and probe were from a standard Tolbert-Cary-type ionization chamber with a sapphire insulator. The extension for the short probe that normally comes on this chamber was constructed from a 20-in. length of 1/4-in. O.D. x 3/64-in. wall stainless steel tubing. Preliminary attempts to support this probe with a teflon insulator at the top of the chamber were not successful because of hysteresis currents and flow sensitivity.

In some flow systems static charges in the gas may be generated. These charges are detected by the ionization chamber and show up as spurious signals that appear when gas flow is inaugurated. The system is then said to be flow-sensitive. The problem of eliminating such electrical charges is best solved by proper design of the flow system and choice of materials. When this is not feasible, an ion trap can often correct the difficulties. An ion trap is essentially a pair of parallel plates, close together, connected to a D.C. voltage source. Static electrical charges in the gas flowing between the plates is discharged quickly under these conditions. In a way, an ion trap is a pre-ionization chamber of inefficient design and with no electrometer.

Figure 4 shows the ion trap used in this system. The outside ends of the annular space were sealed gas-tight with a layer of Apiezon M. wax. In the initial assembly of this instrument, tygon tubing was used between the helmet and the flow cabinet (Fig. 1) and there was no ion trap. The C^{14} analysis system was very flow-sensitive. When the tygon tubing was replaced by rubber tubing most of this flow-sensitivity disappeared, but the ion trap was added partially as a precaution. It may not always be necessary to use an ion trap in this system.

Ordinary air, and, in particular, air in certain brick or cement buildings, may contain an appreciable concentration of radon and thoron. These alpha-radioactive gases are decay products from naturally occurring radioisotopes, and their concentration varies with the geological environment, atmospheric pressure, temperature, etc. These alpha-radiations contribute substantially to the ionization chamber background, because they create many ion pairs per event. Furthermore, they are few enough in number that statistical deviations may be significant. Because the half-lives of these gases are short, storage of compressed air in tanks for one month prior to use will eliminate this problem. Actually, most of the activity is scrubbed out in the process of compressing the air, so that it is fairly free of radioactivity. Aged, compressed, water-pumped air is, therefore,
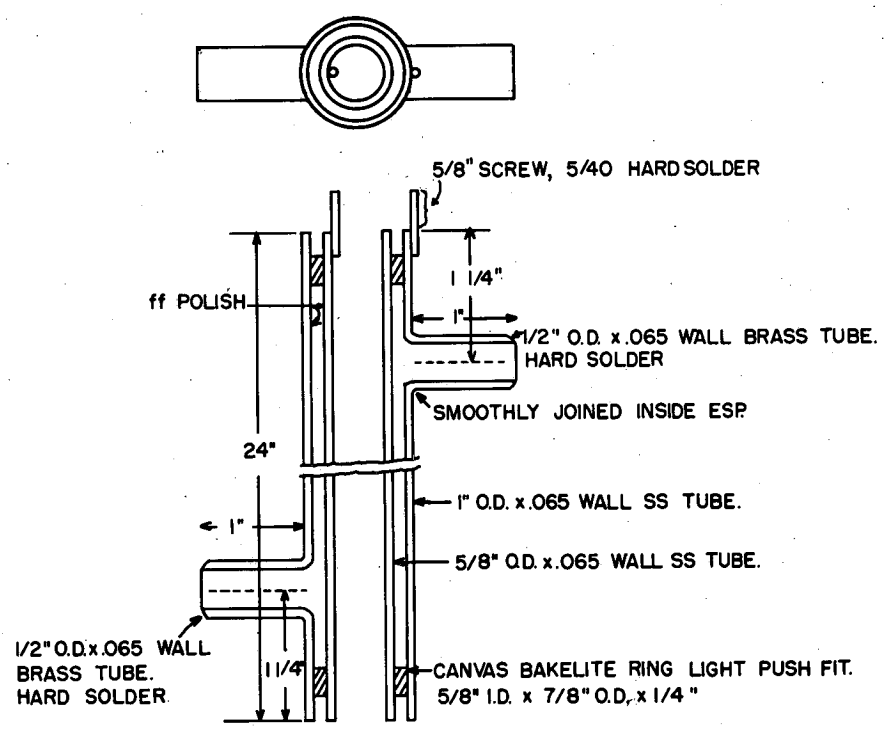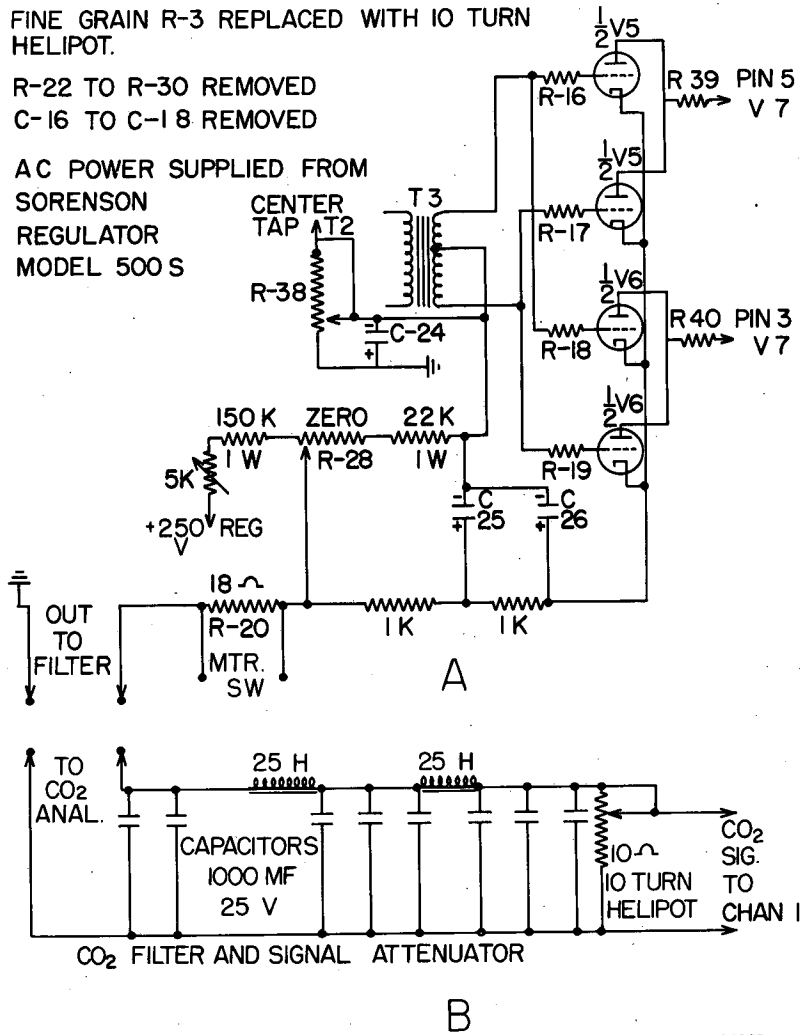
Fig. 4. Ion trap used in this system.

used in the respiration-pattern analyzer to reduce background variation and thus improve the sensitivity of the analysis.

The electrometer, resistor-switching assembly, and resistors must be of the best quality available, because the limiting C^{14} dose to the patient is in part directly determined by the performance of these components. The electrometer is used with the high-resistance-leak method described elsewhere.[4] The resistor assembly should be equipped with 10^{13}- and 10^{12}-ohm resistors. If studies with very large amounts of carbon-14 are anticipated (more than 100 μc injected dose) 10^{11}- and 10^{10}-ohm resistors are necessary. The parts list for the carbon-14 respiration-pattern analyzer in Appendix A indicates our choice of suppliers for the items described above.

The collection voltage for the ionization chamber is supplied by five 90-v B batteries connected in series to deliver 450 v. This voltage is not quite up to the chamber-plateau voltage, but it provides better than 95% collection. The 21-1 chamber shows an unshielded background in our concrete building of 1.35×10^{-14} amps (i.e., 135 mv on the 10^{13}-ohm resistor). The calibration constant for the ionization chamber is 1.40 μc C^{14} per 10^{-11} amp. Thus, a respiration per minute of C^{14} containing 4000 dis./min. activity would be equal to the background. This much activity would be measured with a $\pm$ 10% accuracy because we believe the background to be reliable to about 10%. The detection limit of the instrument is, therefore, about 20 dis./min of C^{14}/1 of air. Natural levels of C^{14} cannot be detected with this instrument.

The CO_2 Analyzer . There are no commerically available infrared CO_2 analyzers that are completely satisfactory. The model chosen (as indicated in Appendix A) combines best the characteristics of compactness and reasonable cost. These instruments have a nonlinear response and a pulsing output signal, both of which must be appropriately corrected. The response may be linearized by building into the instruments a circuit to increase the amplifier gain as the CO_2 concentration increases. Because in this application, CO_2 concentrations of only 0 to 3% will be encountered, linearization was accomplished simply by changing the bias on the signal rectifiers. It is desirable to have one side of the output signal at ground potential. The circuit changes made are shown in Fig. 5a. Additional filtering was added, between the analyzer and recorder, to reduce the noise and 60-cy component in the output signal. This is shown in Fig. 5b.

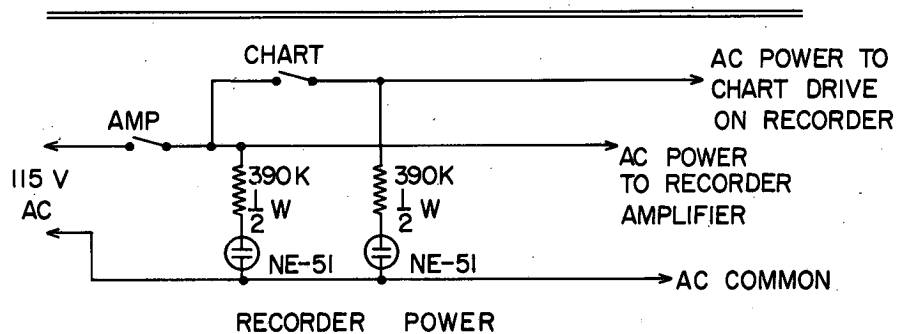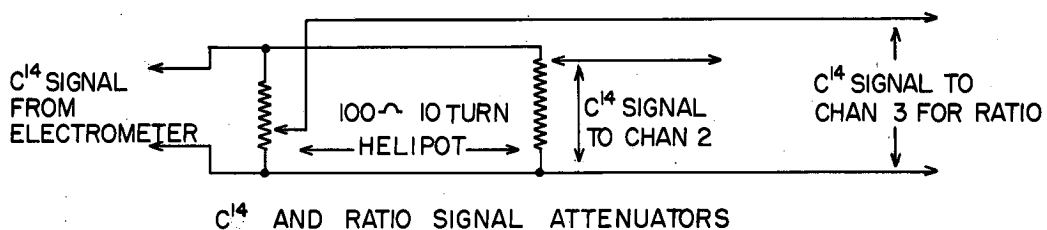FINE GRAIN R-3 REPLACED WITH 10 TURN
HELIPOT.

R-22 TO R-30 REMOVED

C-16 TO C-18 REMOVED

AC POWER SUPPLIED FROM
SORENSON
REGULATOR
MODEL 500 S

Fig. 5. A. Modification of Model 16 infrared gas analyzer.
         B. CO_2 filter and signal attenuator.

The CO_2 analyzer must be standardized regularly and the linearity of response checked. For this procedure, two tanks of compressed gas are required, containing 1% and 3% CO_2-in-air, in addition to the pure air tank. These reference tanks of gas can be purchased from most suppliers of this type of material, but it is necessary to standardize them oneself. This is most easily accomplished by passing the gas through a short train of apparatus as follows: Flow meter, H_2SO_4 bubbler, Ascarite CO_2 absorber, water saturator (a water bubble column) and a wet-test meter. After equilibration of the system, the CO_2 absorber is tared and reinstalled in the train. After about 250 cc of CO_2 have been absorbed, the CO_2 absorber is reweighed and the percent CO_2 calculated. Allowance should be made for the partial pressure of water vapor in this calculation.

The Ratio Analyzer and Recorder. The electrical signals from the electrometer and CO_2 analyzer are controlled with attenuation potentiometers and sent to a ratio analyzer-recorder. The attenuation is provided by three 10-turn helical pots which set the level of (a) the C^{14} signal to the carbon-14 recording channel, (b) the C^{14} signal to the ratio recording channel and (c) the CO_2 signal for both the percent CO_2 and the ratio recording channels. In this unit there is a problem in providing an adequate percent-CO_2 signal for the ratio analyzer. It is necessary to maintain a percent-CO_2 signal strength of about 1 ma minimum in order to generate sufficient error signal to keep the dead zone of the recorder small. This is accomplished by (a) modification of the CO_2-analyzer output section (see previous section), and (b)   maintaining about 1 to 2% CO_2 in the air to be analyzed (by proper choice of flow rate). Figure 6 shows details of the circuitry of the control panel, and Fig. 7 shows the modification required for the potentiometer recorder.

The theory of operation of the ratio recorder is quite simple and has been previously described.[2] Filtered output of the CO_2 analyzer is applied to Channels 1 and 4 of a 6-channel Leeds and Northrup recorder. Channels 2 and 5 receive a signal from the vibrating-reed electrometer which is measuring C^{14}. In Channel 3 and 6 positions of the recorder a C^{14} signal is applied to the recorder input. At the same time the internal reference voltage of the recorder is removed and replaced by the CO_2 signal. In this manner a ratio of the two signals is plotted. This switching is done with a 4-pole 12-position switch, fabricated from Leeds

C¹⁴ SIGNAL
FROM
ELECTROMETER

100 ∼ 10 TURN
←— HELIPOT —→

C¹⁴ SIGNAL
TO CHAN 2

C¹⁴ SIGNAL TO
CHAN 3 FOR RATIO

C¹⁴ AND RATIO SIGNAL ATTENUATORS

CHART

AMP

115 V
AC

390 K
$\frac{1}{2}$ W

390 K
$\frac{1}{2}$ W

NE-51   NE-51

AC POWER TO
CHART DRIVE
ON RECORDER

AC POWER
TO RECORDER
AMPLIFIER

AC COMMON

RECORDER   POWER

MU-14040

Fig. 6.   Control panel circuitry.

Fig. 7. Circuitry modifications of the Leeds and Northrup
6-channel "Speedomax" potentiometer recorder.

and Northrup switch decks, which augments the regular channel-selecting switch normally supplied with the recorder. Positions 7 through 12 duplicate Positions 1 through 6 on both switches. This operation determines the ratio of the C^{14} to the percent-CO_2 signal, and when this ratio value is combined with the proper calibration constants gives the specific activity of the $C^{14}O_2$.

The Flow System. As outlined earlier the flow system is designed to handle 10 liters/min of air. Most of the parts are standard (see Appendix A). Tygon tubing of 1/4-in. I. D. is used throughout for connection except that rubber tubing is used between the helmet and the flow cabinet. Copper T's (1/4-in. streamlined) are used for junctions, together with standard 1/8-in. I. P. S. pipe to 1/4-in. hose couplings.

A series of solenoid valves is used to provide flow control for special purposes, such as calibration. Normally open or normally closed valves are chosen so that in routine operation no valve will be energized, thereby eliminating problems of vibration or induction of currents. Thus one normally closed and three normally open valves constitute a bypass for the gas flow in the helmet. Four normally closed and two normally open solenoid valves provide a bypass for the CO_2 analyzer and a simultaneous opening to the standardized CO_2-in-air tanks. An apparently superfluous valve in the bypass section of this system is introduced to maintain approximately constant pressure drop regardless of swtich control setting; an orifice could replace it.

It is necessary to keep pressure drops to a minimum throughout the system, because these introduce errors in the C^{14} and CO_2 gas-analysis and flow meters. (See Appendix A). The major source of flow resistance occurs in the solenoid valves and in the $CaCl_2$ dryer. The 3/32-in. orifice valves are none too large for this system, and larger valves should be considered for future systems. The most critical point of flow restriction occurs just after the helmet, and here two valves in parallel have been used to reduce pressure drop.

In the flow system as described (see Fig. 1) there is a pressure drop between the helmet and the ionization chamber of 10 mm Hg. Between the helmet and the CO_2 analyzer the drop is about 20 mm Hg. This means that if both instruments are calibrated at 760 mm pressure, then the sensitivity of the ion chamber will appear to be decreased by about 1.3% under normal operating conditions and that of the CO_2 analyzer by 2.6%. These differences are not great, but should be taken

into consideration when calculating the standardization constants for the system. A sensitive pressure gauge on the ion chamber is added to preclude the possibility of unknowingly drawing any appreciable vacuum thereon. Such vacuums can induce spurious ion-chamber currents.

The helmet is a spherical transparent plastic shell[*] (see Fig. 1). Openings at the front and rear are closed with clear 1/4-mil mylar sheet held on with Scotch adhesive tape. This provides a vision plate that is transparent to sound. The patient is much more at ease if he can easily hear and talk to the people around him. A positive seal between the helmet and the patient is not provided. A polyethylene sheet is attached to the helmet and drapes over the shoulders and front and back of chest. A broad strap is loosely tied around the chest close up under the arm pits. This provides sufficient seal when air is positively delivered and withdrawn from the helmet at 10 liters/min.

Such a system is comfortable, and even restless patients can tolerate several 2-hr sessions interrupted only by short break periods. We have tried face masks, but find they are not well accepted for long periods of time. Anything that restricts the patient's breath flow, even slightly, is undesirable. During the course of the run the patient is comfortably seated in a lounge chair (see Appendix A) which may readily be adjusted to any position between sitting and almost prone, according to the preference of the patient. The air inlet is through two tube in front of and at either side of the nose and mouth. Air is withdrawn from the side of the helmet. Because air is supplied at 10 liters/min and the average person breathes some 7 liters/min an excess of fresh air is provided. Some mixing occurs, however, and this results in some rebreathing of air by the patient.

Because the head is a major site of body-heat evolution in a dressed individual it is advisable to cool the inlet air. For this purpose we have placed an 8-in.loop of the tubing to the helmet in a 1-quart dewar filled with liquid nitrogen The flow rates and heat transmission of the rubber tubing are such that a desired amount of cooling is obtained. Many other systems could also be used, such as a copper spiral in a dry ice-acetone bath.

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[*]Bought at the local toy shop as a spacehelmet.

Calibration and Standardization. - The calibration of the CO_2 analyzer is accomplished using three tanks of air containing 0%, 1%, and 3% CO_2. The instrument should be linear (within ± 1%) between 1% and 3% CO_2 and should show a zero signal with 0% CO_2 in the analyzer. Otherwise the ratio-analyzer data cannot be reliable. Because the average patient will produce enough CO_2 to give 1 to 2% CO_2 in the 10 liters/min air it is usually convenient to adjust the CO_2-analyzer gain control so that 1% CO_2 equals 40% of recorder scale, and 2% of CO_2 equals 80% of recorder scale for a given setting of the attenuation potentiometer (usually 50 on a scale of 100).

The calibration of the C^{14} analyzer requires two steps. The first is repeated at two-week to one-month intervals. The second represents a permanent calibration of the ion chamber. In the first step, a precision potentiometer voltage source[*] is connected to the vibrating-reed electrometer head. Negative voltage is applied to the center electrode and the positive lead is connected to the feedback line. With the turret switch in the open position, the electrometer on the 100-mv scale and the attenuation potentiometer set (usually 20 on a scale of 100), the system is aligned by means of the electrometer-calibration potentiometer. The linearity of the recorder-electrometer response should also be checked.

In order to calibrate the ion chamber a known amount of C^{14} in 2% CO_2-in-air must be introduced. This could be done with a vacuum line. If several calibrations may be required it is easier to prepare a standard tank of $C^{14}O_2$ in 2% CO_2-in-air. A commercial compressed-air tank is evacuated on a vacuum line. Enough $BaC^{14}O_3$ to give a desired specific activity is converted into CO_2[5] and drawn into the tank. The tank is then filled to one atmosphere with CO_2 from another cylinder and the pressure is raised to 700 lbs/sq.in. with a tank of compressed air. Gas in this reference tank is allowed to mix and then analyzed for C^{14} activity by filling previously calibrated ion chambers of known volume with the gas and recording the signal produced. This given signal may then be converted to µc/cc for the gas mixture. The specific activity of the gas we used was 1.86×10^{-4} µc/cc gas. Percent CO_2 may be determined by the method previously described for the standard CO_2-in-air tanks.

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[*]Such as Leeds and Northrup galvanometer No. 8667.

[5]Calvin, Heidelberger, Reid, Tolbert, and Yankwich, Isotopic Carbon, (Wiley, New York 1949), p. 153.

This standard gas was allowed to flow through the ion chamber until a constant signal from the electrometer was observed. This signal value was then used to calibrate the ion chamber for the given set of resistors. The specific activity was too high to permit calibration of the 10^{13}-ohm resistor. This resistor may be compared to the 10^{12}-ohm resistor after flushing out part of the radioactivity from the chamber.

The flow meters should be calibrated against a wet-test meter. The pressure in the ionization chamber and in the CO_2 analyzer should be measured under standard operating conditions and a small correction made for the reduced pressure. The flow meter in part of the system coming from the helmet also should be corrected for the error induced by operation at reduced pressure. This is most easily accomplished by putting a T-tube in place of the helmet. The T-tube is then connected to a mercury manometer. Air is fed to the system at 10 liters/min and the exhaust flow is adjusted so that neither positive nor negative pressure appears in the manometer. The reading of the flow meter is then the desired setting for this flow rate.

Experimental Procedure. - Much of the experimental procedure may be varied to suit the given research or clinical test problem. In general, the patient is put into the unit about one-half hour before the administration of the radioactive compound. These thirty minutes are used to determine the C^{14}-analyzer background signal (so it may be subtracted out before the run actually begins), to allow the patient to get used to the helmet and to relax, and to sweep out some of the a-active gas in the patient's system. About five minutes before radioactivity administration, the background is subtracted out by adjustment of the electrometer zero control.

During the actual run, electrometer scales and ratio-recorder attentuation are adjusted to keep the potentiometer in the middle or upper half of the recorder chart. It is customary to leave the recorder going, but with the attenuation helipots set at zero when the patient leaves for a rest break, thus simplifying the recording of data and integration of the curves. An operator should be in attendance at all times. However, unless failure of both the exhaust and air-feed systems should occur simultaneously, the patient is not in danger of any great discomfort, since the loose helmet-to-body seal would permit air ingress or exhaust.

Analysis of the Data. -   The recorder chart contains three curves--percent CO_2, total C^{14} per unit of time, and specific activity, i.e. the C^{14}/percent CO_2. We have analyzed these data as follows: The percent CO_2 curve is integrated with a polar planimeter (Appendix A) and calculated out to give average percent CO_2 which is corrected to a gravimetric rate figure:

(ave. percent CO_2) (flow rate in liters/min) (density CO_2 in mg/liter)=mg CO_2/min The carbon-14 curve is integrated for 20-to 60-min intervals, and the cumulative excretion of $C^{14}O_2$ curve is constructed. This is calculated into units of percent of the injected dose.

The specific activity curve is calculated into units of $m\mu c$ of C^{14}/gram of carbon/given injected dose of C^{14}. This curve is then transferred to semi log or other graph paper as needed for the analysis.

For studies where there is considerable variation in patient size, we may normalize the data to a 70 kg-man using the formula of Kleiber.[6] In this process the percent-CO_2 figure is multiplied by the ratio $(70/W)^{0.75}$ where W is the patient's weight in kg. The specific activity of the $C^{14}O_2$ for a given size injected dose is divided by this factor. The cumulative C^{14} curve does not need to be normalized.

Table I lists the limiting sensitivity and precision of carbon-14 respiration-pattern analysis for adults and infants when various labeled compounds are injected.

[6]M. Kleiber, Physiol. Rev. 27, 511 (1947).

Table I

Limiting sensitivity and precision of carbon-14 respiration patterns for adults and infants[a]

Patient	Substrate	Total activity i.v. injection μc	Flow rate (liters per min.)	CO_2 (%)	Chamber size (liters)	Maximum signal (% of background)	Specific-activity precision (%)	Reliability of integrated curve (%)
70-kg. adult	Acetate-1-C^{14}	0.01 c,d	10	2	20	20	± 20	± 10
70-kg. adult	Acetate-1-C^{14}	0.005	10	2	20	10	±100	± 25
70-kg. adult	Glucose-C$_6^{14}$	1	10	2	20	150 to 200	± 2	± 2
70-kg. adult	Glucose-C$_6^{14}$	10	10	2	20	1500 to 2000	± 2	± 1
70-kg. adult	Glycine-2-C^{14}	1	10	2	20	100	± 3	± 3
70-kg. adult	Glycine-2-C^{14}	10	10	2	20	>1000	± 2	± 1
70-kg. adult	Uric-2-C^{14} acid	10	10	2	20	100	± 3	± 3
5-kg. infant	Acetate-2-C^{14}	0.01	2	1 to 1 1/2	20	70	± 5	± 3
5-kg. infant	Glucose-C$_6^{14}$	0.06	4	1/2 to 5/8	20	50	±10	± 4
5-kg. infant	Glucose-C$_6$	0.1	4	1/2 to 5/8	20	80	± 5	± 3

[a] Estimated values from rabbit studies.

[b] Background fluctuates by ± 10%, so a given observed value has a lower precision than if measured over a period of time and averaged.

[c] 1 μc = 2.2×10^6 dis/min; 0.01 = 22,000 dis/min; and 0.001 = 2,200 dis/min.

[d] A 70-kg man contains about 17 kg carbon, which has a natural radioactivity level of 12 dis/min/gm. This gives a total natural C^{14} burden of about 0.1 μC.

APPENDIX

Parts list for human carbon-14 respiration pattern analyzer

Item No.	Description	Estimated Cost
1	Vibrating-reed electrometer, Model 31, (Applied Physics Corp., Pasadena, Calif.)	$ 1,550
2	Turret switch for vibrating-reed electrometer with 10^{13}, 10^{12}, 10^{11} and 10^{10} ohm resistors (Applied Physics Corp., Pasadena, Calif.)	250
3	Infrared gas analyzer, Liston-Becker Model 16, (Beckman Instrument Co., Liston-Becker Division, Stanford, Connecticut)	1,050
4	Six-channel Speedomax potentiometer recorder, Type G. 10-mv full scale sensitivity, 6 in./hr chart speed. 2 to 3-sec full-scale response time, with chart paper 425, (Leeds and Northrup, Philadelphia, Pennsylvania)	1,200
5	Sorensen voltage regulator, Model 250S, (Sorensen and Co., Inc., Stanford, Connecticut)	200
6	Two Bud cabinets, 5-1/2 ft, on caster-wheel frame base, No. CR-1772. Without base, $54/each. (Any electronics supplier.)	108
7	Ion-chamber probe and insulator assembly to fit a Tolbert-Cary type ionization chamber	125
8	Twenty-liter ionization chamber, stainless steel	200
9	Solenoid valves: (Skinner Electric Valve Co., New Britain, Connecticut)	
	5 Normally open, Catalog No. V5D1460SR, 3/32 in. orifice, 1/8 in. NPT outlets $11/each	55
	5 Normally closed, Catalog No. V5D200, 3/32 in. orifice, 1/8 in. NPT outlets $9/each	45

Item No.	Description	Estimated Cost
10	Two Fischer-Porter flowmeters. Precision bore Flowrator, Catalog No. 2F-1/4-16-5 with ground glass joints; with float No. SS-14, Fischer and Porter Co., Hatboro, Pennsylvania)	$ 50
11	Fischer-Porter flowmeter. Precision bore Flowrator Catalog No. 08F-1/16-16-4, with joints; with float No. SA-16 (Fischer and Porter Co., Hatboro, Pennsylvania)	24
12	Two 1/4-in. needle valves	10
13	Wet-test meter, Catalog No. A118-3, with litre dial, copper drum, removable back, (American Meter Co., 950 Tennessee St., San Francisco, California)	170
14	Ion trap. Estimated cost....	50
15	Ten B batteries, 90-volt, RCA Type No. V5090	10
16	Recorder control panel and signal filter, containing three 100-ohm, 10-turn helipots	200
17	Nitrogen regulator valve, modified to fit compressed-air tanks, Hoke needle valve attached	25
18	Vacuum pump, Model 0321, (Gast Mfg. Corp., Benton Harbor, Michigan)	150
19	Plastic Helmet (Any large toy department)	15
20	One-quart Dewar for liquid nitrogen	10
21	Pressure vacuum gauge	5
22	Rotary selector switch, 4-pole, 12-position, Catalog No. 31-3-0-4 (Leeds and Northrup Co., Philadelphia, Pennsylvania)	35
23	Amphenol blue-ribbon connector, Catalog No. 26-159-10	10
24	Gears: One pair mitre gears, LM STD 3270-B-3	5

Item No.	Description	Estimated Cost
25	Lounge chair, BarcaLonian, (Barcalo Mfg. Co., 1927 Elmwood Ave., Buffalo, New York)	$ 125
26	Polar planimeter, Catalog No. 123A, with linear adapter Catalog No. 136 (59 in.) (Los Angeles Scientific Instrument Co., 2451 Riverside Drive, Los Angeles, California)	200
	Total estimated cost	$ 5,507.00