TO: XXX/Scientific & Technical Information Division
    Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No. : 3,396,719

Government or Corporate Employee :

Supplementary Corporate Source (if applicable) :

NASA Patent Case No. : MSC-12239-W-784

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES ☑ NO ☐

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

Bonnie L. Henderson

Enclosure
Aug. 13, 1968

T. I. TAYLOR ETAL

METABOLIC RATE METER AND METHOD

Filed July 2, 1963

MIXING CHAMBER

METERING

SUBJECT IN SPACE SUIT

AMPLIFIER

TELEMETER

RECEIVER

RECORDER

VENT OR RECIRCULATING SYSTEM

MAS SPECTROMETER

POWER SUPPLY

INVENTORS

T. IVAN TAYLOR & WARREN RUDERMAN

BY

ATTORNEYS

3,396,719
This invention relates to a novel method and apparatus for measuring the dynamic metabolic rate of a human or animal. More particularly, the invention concerns a novel method and apparatus for measurement of respiratorily excreted carbon dioxide in relation to isotope labelled carbon dioxide introduced into the respiratorily excretion of a human or animal, by mass spectrometric methods.

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

In accordance with the present invention, it was found that an isotope dilution method was well suited for the measurement of carbon dioxide output by the human or animal body. Among the isotopes which were considered were oxygen^{18}, carbon^{12} and carbon^{13}. If carbon^{12} is introduced into the expired air stream there is the possibility of exchange of the oxygen^{18} with the water vapor. This would introduce an error. Carbon^{14} labelled carbon dioxide was discarded as a choice because of the deleterious effects of the radioactive carbon^{14} on humans. The stable isotope carbon^{13} has no harmful physiological effects on humans and is an ideal choice.

Although inhaled C^{13}O_{2} would mix relatively rapidly with the alveolar CO_{2} and provide a means of estimating CO_{2} output, the desirability of avoiding the complication of the small amount that enters the body via exchange with bicarbonate led to the discovery of the isotope dilution method of the invention for measurement of the rate of carbon dioxide output and hence the metabolic rate.

The novel isotope dilution method of carbon dioxide metabolic rate measurement, according to the invention, involves introducing carbon^{12} labelled carbon dioxide into a confined expired air stream at a predetermined rate, mixing the C^{12}O_{2} with said exhalations, withdrawing a sample of said mixture and measuring the ratio of carbon^{12} to carbon^{13} in said sample by mass spectrometry. By employing dual collection mass spectrometry an instantaneous ratio of carbon^{12} to carbon^{13} is obtained, thereby providing an instantaneous measurement of the generation of carbon dioxide.

The mass spectrometers employed for the analysis of the mixed gases may be of any suitable type, which is adapted for gas analysis, and which continually analyses, and registers on a recording device, changes in the concentration of C^{12}O_{2} and C^{13}O_{2}, so that readings may be taken and transmitted by telemetry or other means. A suitable type of mass spectrometer can be one in which a part of the gas stream is passed through the spectrometer tube to enter a conventional ionizing head where the gas is subjected to electron bombardment. The ions which are thus formed are accelerated by means of high voltage, collimated and projected into a magnetic field in which the ions of lighter atomic weight are deflected to a greater extent than those of higher atomic weight, and deposited on separate collector plates, the intensity of ion currents being measured by suitable amplifying and recording devices if a dual collector mass spectrometer is used. Then the C^{12}O_{2} and C^{13}O_{2} peaks are recorded simultaneously. In such a case the ratio of C^{12} to C^{13} gives a measure of the instantaneous rate of carbon dioxide generation.

The isotope dilution measuring method of the invention is based upon the following principles. By adding a small stream of isotope labelled C^{13}O_{2} to a gas stream, such as a stream of respiratorily exhalations, at a known flow of C^{12} moles per minute, the C^{13}O_{2} entering the stream from this source is C^{13}Ni, where Ni is the atom fraction of the carbon which is C^{13}. The term “atom fraction” refers to the ratio of the number of atoms (or moles) of the isotope of a particular element in the particular gas stream to the total number of atoms (or moles) of that same element. The entering C^{13}O_{2} is admixed with the carbon dioxide present in the expired
air (which also contains nitrogen, water vapor, and some unconsumed oxygen), and the fraction of $\text{C}^{12}$ in the carbon dioxide of the mixed gas stream is determined by means of a mass spectrometer. From the resulting data, the quantity of carbon dioxide, i.e. the moles of normal $\text{C}^{12}\text{O}_2$ flowing per minute in the expired air, can be computed by means of the following equations:

Since the mass spectrometer must equal the amount of $\text{C}^{12}$ entering, the material balance equation is:

$$\text{C}^{12}\text{N} + \text{CN} = \text{C}^{12} + \text{C}^{12}\text{Ne}$$

wherein:

- $\text{C}$ = moles of carbon dioxide flowing per minute in the expired air;
- $N$ = atom fraction of $\text{C}^{12}$ in the expired carbon dioxide;
- $\text{C}^{12}$ = moles of carbon dioxide enriched in $\text{C}^{12}$ added to the gas stream per minute;
- $\text{N}$ = atom fraction of $\text{C}^{12}$ in the enriched carbon dioxide;
- $\text{N}e$ = atom fraction of $\text{C}^{12}$ in the carbon dioxide after admixing.

Solving Equation 1 for $C$, there is obtained the formula:

$$C = \frac{\text{C}^{12} - \text{Ne}}{\text{N} - \text{Ne}}$$

The atom fraction of $\text{C}^{12}$ in the expired air is known, being essentially $\text{C}^{12}$ in normal carbon dioxide ($N = 0.011$), and both $\text{C}^{12}$ and $\text{Ne}$ are known.

Thus a determination of Ne with a mass spectrometer permits the determination of the molar quantities of Ne, and hence the volume of expired carbon dioxide produced by the subject per minute can be determined. That is, the mass spectrometer measurement resolves the quantity of carbon in the expired air using a dual collector type mass spectrometer. The significant aspect, of course, is a determination of carbon dioxide production per unit time by means of an isotope dilution method and apparatus.

In this way, the novel method of the present invention provides a means of measuring the total quantity of carbon dioxide produced without actually measuring the flow of the expired gases. The value of $C$ thus obtained is expressed in moles of carbon dioxide flowing per minute, and thus is very different from concentration of $\text{CO}_2$ as obtained, for example, with an infrared spectrometer. Thus, the isotope dilution method of the invention provides much more useful information with respect to the metabolic rate of the subject and to his expenditure of energy than any previously known methods, since the isotope dilution method can be used to determine the quantity of carbon dioxide expired per minute.

The above and still further objects, features and advantages of the present invention will become more apparent upon consideration of the following detailed description of one specific embodiment thereof, especially when taken in conjunction with the accompanying drawing, wherein:

The single figure depicts a schematic arrangement of the various components of the apparatus of the invention, and also serves as a flow diagram of the steps of the method.

In the drawing, air containing the normal abundance of carbon dioxide from a supply source 10 is supplied to the subject via tube 11 and a respirator mask or helmet, or the like, shown generally at 12. The exhalations flow from the subject through tube 13 to a mixing chamber 14, to which a supply of $\text{C}^{12}\text{O}_2$ is fed at a controlled rate from a tank 16, via tube 15. The mixed gas stream containing the expired gases, unexpired gases, water vapor and nitrogen, passes via tube 17 to a vent or recirculating system, a portion of the gas stream being supplied, via control valve 18 and tube 20, to a mass spectrometer, shown generally at 21, which may be of any conventional type. If a single collector type mass spectrometer is used, the readings may be taken thereon in.