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Moore et al.

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[54] **DIVER DECOMPRESSION APPARATUS**

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[52] **U.S. Cl.** .... **235/184,** 128/2.1 R, 235/185
[51] **Int. Cl.** **G06g 7/60**
[58] **Field of Search** 235/183, 184, 185; 128/2.1

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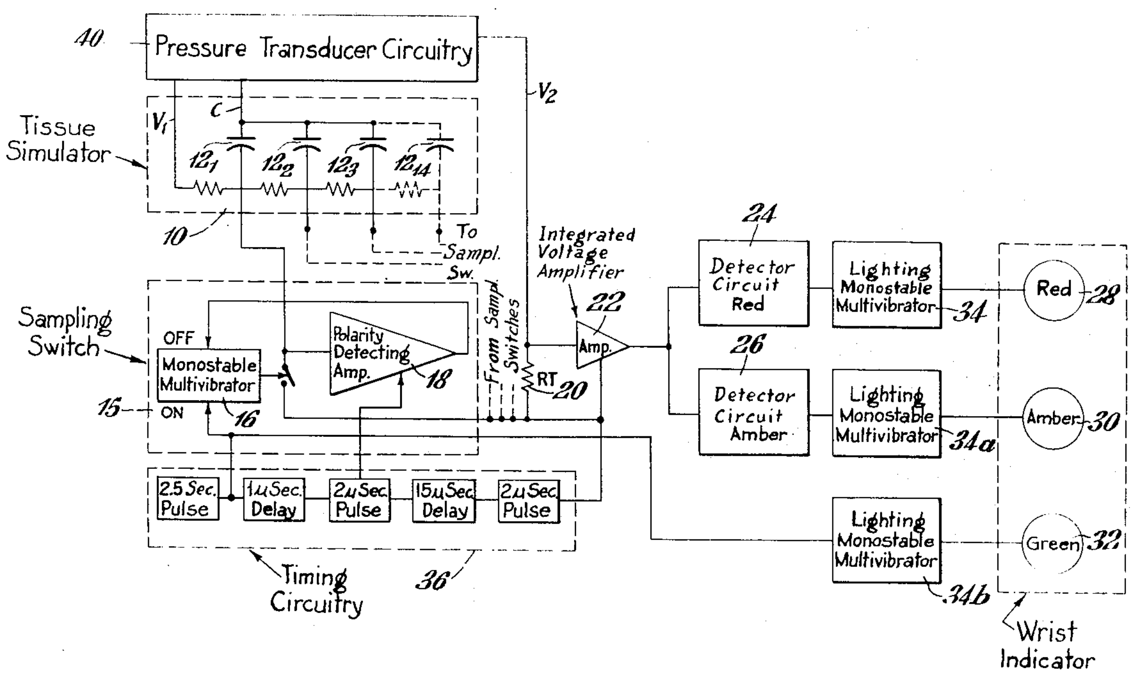
[57] **ABSTRACT**

A diver decompression apparatus for indicating the safe ascent criterion for returning from the ocean depths to the surface, comprising a body tissue simulator, means for sampling exposure to inert gas at various body tissue depths and indication means to determine safe ascent criteria.

3 Claims, 3 Drawing Figures



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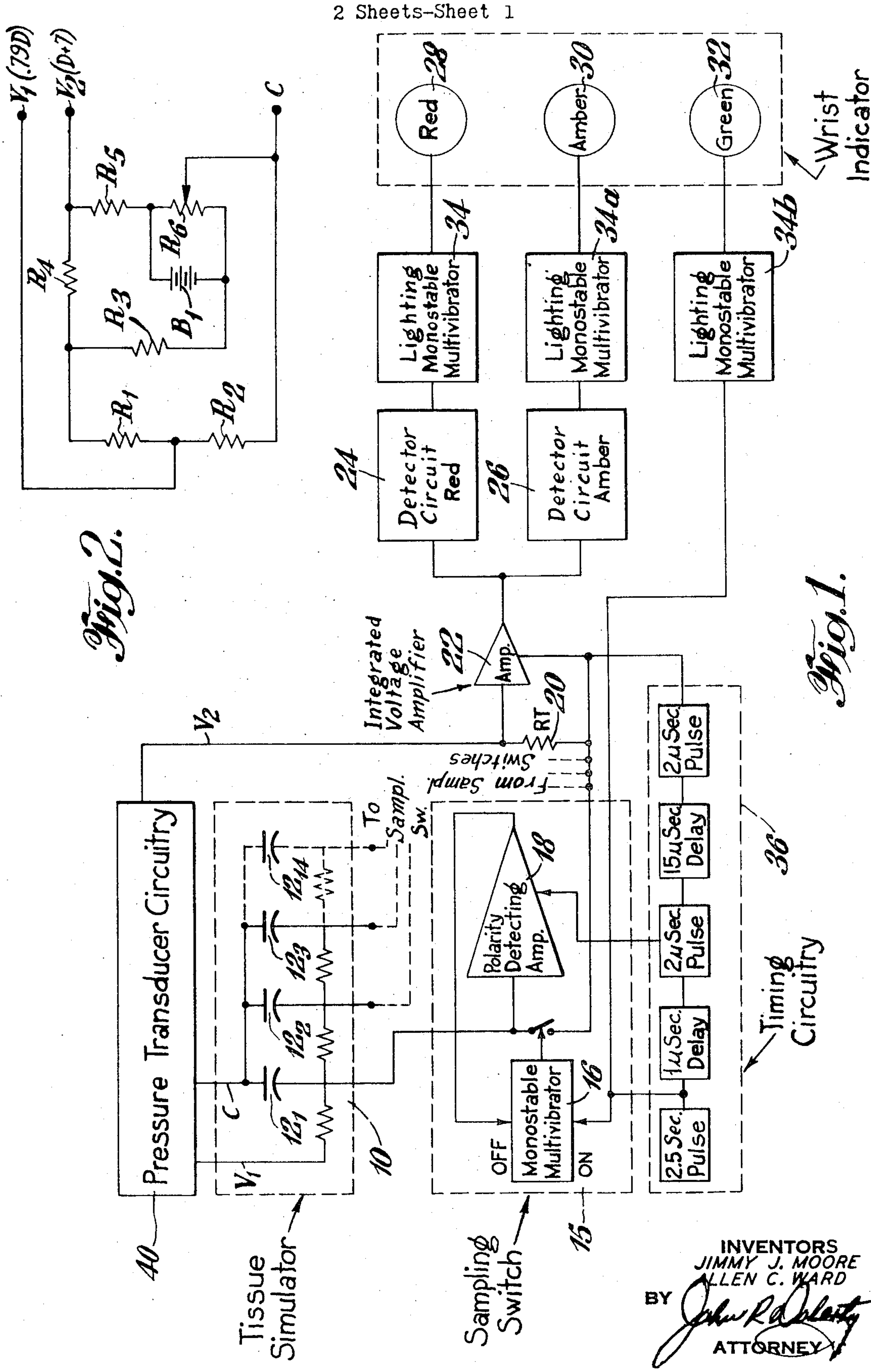

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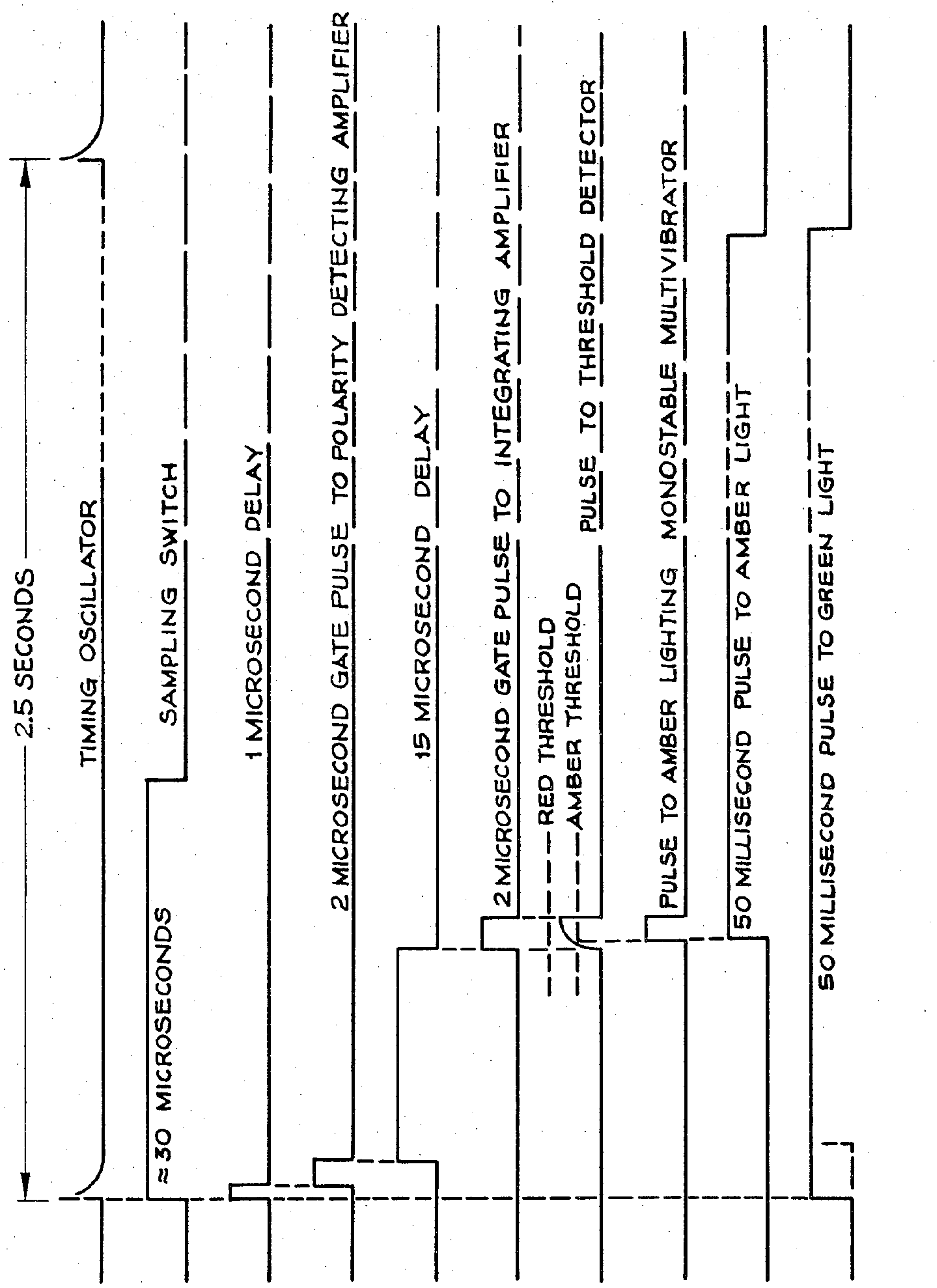

Fig. 3.

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DIVER DECOMPRESSION APPARATUS

The present invention relates to a novel diver decompression apparatus and more particularly to a diver decompression computer for indicating the safe ascent criterion for returning from the ocean depths to the surface.

When making a dive below the ocean surface, divers may be subjected to very high pressures depending upon the depth to which they descend. As a result, the diver's body tissue will pick up inert gas by diffusion which must be released before the diver returns to the surface. This release of the diffused gas must be accomplished over a period of time in order to avoid the effects of decompression sickness. The decompression time period is dependent upon the pressure time to which the diver has been exposed. Therefore, it would be of greater value to a diver to be able to monitor his own ascent to be sure his rate of ascent is not so fast as to expose him to decompression sickness.

It is therefore the principal object of the invention to provide an apparatus which will indicate a safe rate of ascent for a diver from the ocean depths to avoid decompression sickness.

It is a further object of the present invention to provide a diver decompression computer which is lightweight and portable.

The foregoing and other objects of the invention are accomplished by a decompression computer which will implement the safe ascent criteria for a diver, the decompression computer comprising a pressure transducer tissue simulator which can simulate the distribution of exposure in the body tissue of a diver; means for sampling equivalent exposure after any pressure-time product and comparing this exposure to a threshold voltage derived from the pressure transducer; means for integrating any exposure above this threshold and then comparing this integral to a safe constant criterion; and means for indicating to the diver that he has exceeded tbe safe ascent criteria. By the term "safe constant criterion" is meant an emperical value derived from a methematical formula representing tissue absorption of inert gas as a result of increased pressure, which represents the permissible exposure without having to undergo decompression steps during ascent.

In the development of the decompression computer of the present invention, a number of assumptions were made. These assumptions are generally accepted by those familiar with decompression sickness. These assumptions are:

1. An excess of inert gas in the body tissue is the cause of the symptoms of too little decompression time following a dive.
2. Inert gas enters and penetrates the body tissue by a diffusion process at the surface of capillaries.
3. The concentration of inert gas in the body tissue is called the exposure and is due to the diffusion of the gas into the tissue as the diver is exposed to various pressures.
4. Time constants involved with the diffusion process in the tissue are very long compared to the time constants involved with the transport of inert gas between the lungs and capillaries.
5. The layout of capillaries in the body tissue is very complex since there is no uniform pattern.

A fuller understanding of this invention will be facilitated by reference to the accompanying drawing, wherein:

FIG. 1 is a diagrammatic view of a preferred embodiment of the diver decompression circuitry of the present invention;

FIG. 2 is a diagrammatic view of the circuitry of pressure transducer which is an element of the present invention; and

FIG. 3 is a timing diagram which illustrates the operation of the diver decompression computer of the present invention.

With particular reference to FIG. 1, the tissue simulator 10 is composed of a fourteen section resistance-capacitance network, each section having identical time constants. The 95 percent time constant of the entire 14 sections is 900 minutes. The entire network is charged by a voltage derived from a pressure transducer as hereinafter explained, which voltage is a linear function of the water depth. The charge on each capacitor 12_1–12_{14}, which is indicated by the voltage across the capacitor 12_1–12_{14}, represents the exposure at a particular depth in the body tissue at any time. The voltage appearing across the network of the 14 capacitors 12_1–12_{14} represents the exposure into the body tissue at any one time. For a 900 minute time constant this places a stringent requirement on the allowable leakage of the capacitors which must be less than 1×10^{-10} amperes at the largest voltage. Preferably, these requirements may be realized by keeping the maximum voltage for a 200 ft. depth at less than 1 volt and using solid tantalum capacitors.

An electronic sampling switch **15** for sampling the charge voltage on the capacitor of a given RC section must be capable of being turned on separately and when it is turned on it must recognize the polarity of a voltage and turn itself off for one polarity (positive) and remain on for a fixed time for the other polarity (negative) and then turn itself off. During the time that the switch **15** is on it must take very little charge from the capacitor **12** it is sampling and during the time that it is off it must not contribute appreciably to the leakage of the capacitor **12.** This requires a leakage of less than 1×10^{-10} amperes during the off time of the switch **15.** The switch **15** must have a very low voltage drop across it in the on condition, preferably less than 1 millivolt. Preferably, the sampling switch **15** used is a silicon transistor which meets these requirements used in the inverted connection. The switch **15** is controlled by a monostable multivibrator **16** with a fixed on time with the provision that it can be turned off before the fixed time is up. A high gain amplifier **18** is used as a polarity detector which when turned on produces a pulse of sufficient amplitude to turn the monostable multivibrator **16** off if the input is as much as 5 millivolts positive. If the polarity is negative, the multivibrator **16** remains on for the preset time. One electronic sampling switch **15** is required for each capacitor 12_1–12_{14} in the tissue simulator **10.** The total time that the sampling switch **15** may be on is about 30 microseconds out of every 2.5 seconds.

The electronic integration is accomplished by converting each of the sampled capacitor 12_1–12_{14} voltages which is above the threshold V_1, FIG. 2 to a current and summing these currents in a single resistor **20.** The voltage developed across this resistor **20** is then amplified by amplifier **22** and used to trigger a detector circuit

24,26 which is composed of a tunnel diode and transistor. The tunnel diode is used because its trigger point is stable over the expected operating temperature range. The voltage amplifier **22** is turned on after the polarity detecting amplifiers **18** in the sampling switches **15** with sufficient delay to allow switching transients to subside. Two detectors **24,26** which are set at different trigger levels are used; one **24** for a red light and one **26** for an amber light.

The desired information must be presented to the diver on a visual display. Three flashing lights **28,30,32** are used. One is a green light **32** to indicate that the electronics is functioning. One is an amber light **30** to give a warning when the diver is within approximately 10 ft. of requiring a decompression stop. The third is a red light **28** which indicates that a decompression stop is necessary. The separation of the amber light **30** trigger point from the red light **28** trigger point is nonlinear with depth becoming less than 10 ft. at the shallow depths. In order for a flashing light to be visible the duration of the flash must last at least 40 milliseconds. A **50** millisecond duration is used in the decompression gauge. A monostable multivibrator **34,34*a*,34*b*** is used to trigger each light **28,30,32.** Each time a sampling period is initiated the green light **32** is flashed. Each time an integration is performed, which is each sampling period, the amber **30** and red **28** lights will flash only if the appropriate detector **24,26** is energized. The detectors **24, 26** are manually settable. The trigger levels are set to be the maximum equivalent exposure without decompression for the red light **28.** The same level plus the *D*+7 reference is used for the amber light **30.** Warning of an impeding decompression stop is given some ten feet prior to ascent depth at which the diver must stop.

The timing is selected with several considerations in mind. Preferably, and with particular reference to FIG. **3,** the capacitors 12_1–12_{14} should not be sampled any oftener than required by the information rate in order to preserve their information on the exposure distribution.

Additionally, the lights **28,30,32** must not be flashed any oftener than necessary in order to preserve battery life and reduce battery size. With these factors in mind, a sampling rate was chosen at approximately once every 2.5 seconds. This is also the rate of flashing the lights **28,30,32** which simplifies the electronic circuitry.

A single unijunction transistor oscillator circuit **36** is used to generate a pulse every 2.5 seconds. This pulse triggers all **14** sampling switches **15** simultaneously turning them on. After a **1** microsecond delay to allow switching transients to subside the polarity detecting amplifiers **18** in the sampling switches **15** are turned on for approximately 2 microseconds. Those amplifiers **18** that have a positive input turn their switches off. Again after a 15 microsecond delay to allow switching transients to subside the integrator voltage amplifier **22** is turned on for 2 microseconds and the output pulse applied to the amber red detectors **26, 24.** The lights **28,30,32** that were turned on in the process remain on for approximately 50 milliseconds. Approximately 30 microseconds after the initiation of the sampling cycle all remaining sampling switches **15** are turned off by their own monostable multivibrator circuits **16.** After approximately 2.5 seconds the process is repeated.

The pressure transducer **40** is required to produce two voltages which are a function of water depth. One voltage is proportional to 0.79D and the other voltage required is proportional to D + 7 feet, where D is the water depth in feet. The voltage proportional to 0.79D is used to charge the tissue simulator **10** and the voltage proportional to D + 7 is used as the reference in the sampling circuits. Preferably, the pressure transducer **40** used is a sea water potentiometer whose resistance will vary linearly with depth. This transducer **40** is used in the circuit shown in FIG. **2** to derive the two voltages. Since the pressure transducer **40** measures absolute pressure a voltage representing 33 feet of water is produced at the surface. In order to obtain $D + 7$, 26 feet of this must be balanced out and to obtain D all 33 feet must be balanced out.

In order to produce voltages proportional to D and D + 7, the elements of the pressure transducer circuit, as shown in FIG. **2,** should have the following values: $R_1 = 10.5K$; $R_2 = 39.2K$; $R_3 = 2430\Omega$; $R_4 = 56.2\Omega$; $R_5 = 210\Omega$; $R_6 = 987\Omega$; and $B_1 = 1.35$ V. This will give 0.79D at V_1 and $D + 7$ at V_2.

There are four different battery supplies used in the decompression gauge. A 1.35 volt supply is used to supply voltage to the pressure transducer **40.** A 2.7 volt supply is used to bias off the transistor sampling switches **15.** One 4.05 volt supply is used to supply all of the sampling switch amplifiers **18,** the integrated voltage amplifier **22,** and the timing circuitry **36.** Another 4.05 volt supply is used to furnish power for the detectors **24, 26** and three lights **28,30,32.** Three batteries in parallel are used for each of the 4.05 volt supplies. Two batteries are used in parallel for the 1.35 volt supply and one battery is used for the 2.7 volt supply. The drain on the batteries is such that the gauge will operate continuously for one week on one set of batteries over the expected operating temperature range.

EXAMPLE I

A gauge was packaged in the form of a brass cylindrical housing approximately 5.5 inches long by 2.4 inches in diameter. There were two separate water tight housings. The top portion which occupies about 2.5 inches of length houses all of the electronics except the lighting circuits. The bottom portion houses the pressure transducer, the lighting circuits and the batteries. The three lights which were potted in epoxy were supplied as a separate package to be mounted on tbe wrist of the diver and connected to the decompression gauge by a waterproof cable and waterproof stuffing gland. Another waterproof stuffing gland was used to house a socket which was used for zeroing the gauge. An external shorting plug was used with this socket to set the gauge to zero before starting a dive.

What is claimed is:

1. An apparatus for determining a safe ascent rate for a diver to prevent decompression sickness, comprising:

a. a pressure transducer capable of producing an output voltage which is a linear function of water depth;

b. a body tissue simulator capable of simulating the amount of inert gas distributed in the body tissue at various water depths, said simulator comprising a resistance-capacitance network connected in series with said pressure transducer whereby the capacitor included in each section of said network is charged by said output voltage from said pressure transducer;

c. means for sampling the voltage across each section of said resistance-capacitance network of said simulator;

d. means for summing the sample voltages across each section of said resistance-capacitance network, including a resistor and an amplifier; and

e. at least one detector circuit connected in series with said summing means which is capable of producing an output signal proportional to the voltage across said resistor, indicating the safe ascent rate to the diver.

2. The apparatus defined by claim 1 wherein said sampling means comprises a monostable multivibrator and a polarity detecting amplifier.

3. The apparatus as defined by claim 1 wherein said body tissue simulator comprises a 14 section resistance-capacitance network wherein each section has the identical time constant.

* * * * *

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,746,850 Dated July 17, 1973

Inventor(s) Jimmy J. Moore et al.

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Title page, 2nd column in line naming Attorneys, "James C. Arymtes" should read -- James C. Arvantes -- .

Column 1, line 18, "greater" should read -- great -- .

Column 3, line 61, "amber red detectors" should read -- amber and red detectors -- .

Column 4, line 50, "tbe" should read -- the -- .

Signed and Sealed this

sixteenth Day of *December 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks