An improved portable hyperbaric mountain bubble (10) designed for use at high altitudes to prevent mountain sickness, provides a portable sealed chamber (10) in which a patient (80) may be placed, is equipped with oxygen supply (20) and CO₂ scavenging means, or with a bladder arrangement (50) to eliminate the need for constant pumping. The pressure inside the chamber (10) is raised, providing an interior environment equivalent to a descent from altitude to as low as sea level, to alleviate the symptoms of mountain sickness. In a further embodiment, the mountain bubble is expanded to provide a high altitude habitat suitable for use as a mountain tent.

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IMPROVED HYPERBARIC CHAMBER

Introduction and Background

This invention provides improvements to the invention described in EPO Patent Publication 0277787, published August 10, 1988 by the same inventors. The disclosure of that invention is incorporated herein by reference.

Summary of the Invention

The device of the present invention is designed to provide a portable, compact hyperbaric enclosure for temporary use by a human being or other terrestrial mammal for a beneficial health-related effect. Embodiments of the device are adapted to achieve specific beneficial effects, including, as exemplified herein, relief from altitude sickness, pulmonary edema and rapid decompression. The shapes and sizes of such embodiments vary according to their specific use. For example, an embodiment designed to provide a hyperbaric environment for a climber suffering from altitude sickness need not be much larger than a sleeping bag. These embodiments comprise spherical sides along at least one axis of symmetry, construction of
nonbreathable, preferably flexible material, means for achieving and maintaining air (or other gas mixture) pressure inside the chamber adjustable from 0-10 lbs. per square inch greater than ambient, and preferably 0.2 - 10 lbs per square inch greater than ambient, and means for ingress and egress which can be closed to prevent air loss. Alternative devices have means for achieving and maintaining air or other gas mixture pressure inside the chamber from 0.2 psi to 10 psi greater than ambient and in preferred embodiments the pressure is achieved and maintained in the range from 0.2 psi to 4 psi above ambient.

An embodiment used for alleviating mountain sickness and pulmonary edema will be referred to herein as a hyperbaric mountain bubble.

A hyperbaric mountain bubble is constructed of a flexible, nonbreathable fabric capable of retaining air at a pressure of from about 0.2 psi to about 10 psi gauge, large enough to enclose a human being. The bubble has means for ingress and egress which may be closed to provide an essentially air-tight seal. Means for inflating the bubble and achieving an elevated pressure of from about 0.2 psi to about 10 psi gauge and valve means for controlling air pressure are provided. In one embodiment, means for scavenging excess moisture and carbon dioxide from the interior are provided.
The bubble is preferably constructed in a cylindrical, semispherical or "sausage" shape (cylindrical with hemispherical ends). The bubble may be fully self-supporting or it may have flexible wands or other means for extending the structure to an ambient pressure-inflated condition before being pressurized.

The bubble can be used for any condition of mountain sickness, sleep cycle disruption or pulmonary edema, where a decreased altitude (or increased ambient air pressure) is desired. Each pound per square inch of pressure above ambient corresponds approximately to a decrease of 2,000 feet altitude. The affected individual is placed within the bubble, the entrance sealed and the bubble is then pressurized to the desired pressure, which will vary, depending on the elevation and severity of symptoms. Frequently it is found that a descent of 2,000-4,000 feet provides relief; therefore, 1-2 pounds per square inch gauge of hyperbaric pressure will be adequate in many cases.

The bubble is also useful when a hyperbaric environment is required at low altitudes, such as by divers who require a pressurized environment to control the effects of rapid surfacing.

Essential features of the bubble for its intended use are that it be lightweight, portable, compactly foldable when not in use, and above all, capable of retaining an
internal air pressure of at least greater than 0.2 psi gauge and preferably up to 4-5 psi gauge, although embodiments capable of retaining up to 10 psi gauge are described herein.

Another embodiment of this invention is a closed circuit rebreather which includes the use of an oxygen source and carbon dioxide removal means. This allows the invention to be used without continuous pumping or other attention for a period of hours. This embodiment also allows the chamber to be supplied by means of oxygen containers rather than compressed-air containers which would be less efficient to carry into mountain or other wilderness environments. Compressed air containers would not be useful for this embodiment.

This embodiment may be described as a substantially leak-proof rebreather made of nonbreathable material capable of maintaining air pressures in the range from about atmospheric to 0-10 psi greater than ambient, and preferably from about 0.2 to about 10, or more preferably from about 0.2 to about 4.0 psi greater than ambient, comprising carbon dioxide removal means, preferably lithium hydroxide pads inside said chamber, and oxygen input means responsive to drops in pressure below a preselected pressure in said pressure range, preferably about 2.0 psi greater than ambient, resulting from said carbon dioxide removal, to maintain said preselected pressure by oxygen input.
"Substantially leak-proof" as used herein means a leak rate less than about 0.4 l/min, preferably no more than about 0.22 l/min.

"Rebreather" means an embodiment of this invention which is large enough to hold a sufficient volume of air for a human to breathe during a period of time sufficient for an attendant to take care of necessary maintenance tasks other than air maintenance, preferably one-half hour or more. The rebreather must be substantially leak proof, and is large enough to contain a whole human body.

This closed-circuit breathing system supplies air, preferably not oxygen-enriched, at whatever pressure desired, for periods of time (preferably at least about six hours) depending on the amount of oxygen in the oxygen source and the capacity of the carbon dioxide removal means. This embodiment also dispenses with the need for constant monitoring and adjustment of oxygen flow. It is used preferably in mountain environments, but may also be used in any environment where an extended period must be spent in an enclosed space, such as underground or under water. In such environments, the preferred pressure to be maintained within the bubble is atmospheric pressure.

In this embodiment, an oxygen source, preferably a container of compressed oxygen, is connected to the interior
of the chamber through a pressure regulator such that oxygen is bled into the chamber in response to a pressure drop below a preselected pressure. For most mountain applications, the preferred pressure is about 2 psi above ambient. As the air inside the chamber is breathed, oxygen is converted to carbon dioxide and exhaled into the chamber. The carbon dioxide is then removed by the carbon dioxide removal means inside the chamber, preferably scrubber pads such as the lithium hydroxide scrubbers provided by DuPont. Removal of the carbon dioxide results in a pressure drop which activates the pressure regulator to bleed additional oxygen into the chamber. In this way, oxygen is added to the chamber only in amounts required to replace oxygen converted to carbon dioxide by breathing, and the original gas composition of the air is maintained. The original gas composition inside the chamber can be any breathable mixture, including an enriched oxygen mixture, but is preferably normal air composition.

A further embodiment of this invention provides an expedient allowing longer intervals between pumpings to provide fresh air to the bag without the necessity for an outside oxygen source. This embodiment uses an internal bladder disposed within the chamber for the collection of exhaled air, which is designed to exhaust to the atmosphere when fresh air is provided intermittently by pumping or other means. A "bladder" is a flexible bag made of nonbreathable material and capable of inflating and
deflating. It is not necessary that the bladder be made of an elastic material; it may be made of any suitable membrane which is gas-impermeable. A useful bladder may be constructed using a neoprene latex meteorological balloon such as a Douglas bag available from Vacumetrics, Inc., Ventura California.

The bladder is connected via a pressure relief valve through the chamber wall to the outer atmosphere so that when the pumping raises the pressure inside the chamber above the preselected pressure, the exhaled air inside the bladder is exhausted to the outside, and the bladder is emptied. Pumping may be continued until the bladder is completely emptied and if desired, may be further continued to restore pressure lost by leakage or to raise the pressure inside the chamber, provided the pressure relief valve is correspondingly adjusted. Preferably the bladder is connected to a face mask assembly equipped with one-way valves so that the occupant automatically inhales fresh air from the chamber and exhales spent air into the bladder. Any face mask known to the art may be used. A preferred face mask is a Rudolph mask used for exercise stress testing available through Vacumetrics, Inc., Ventura, California.

This embodiment is described as a hyperbaric rebreather or chamber made of nonbreathable material capable of maintaining air pressures in the range from about 0.2 to about 10, and preferably from about 0.2 to about 4 psi
greater than ambient comprising air input means for achieving said air pressures inside the chamber; an internal bladder for collection of exhaled air; pressure-responsive exhaust means connecting said bladder to the environment outside said chamber allowing air in said bladder to exhaust there through at a preselected internal chamber pressure achieved by said air input means; and exhalate capture means for conducting said exhaled air into said bladder and preventing escape of said exhaled air into said chamber. Preferably, this embodiment is a mountain bubble of this invention; although any sealed breathing chamber using ordinary air as an input may be adapted using the bladder as above described.

A further embodiment of this invention is a portable high altitude habitat capable of hyperbaric pressurization.

"High altitude habitat" means an embodiment of this invention suitable for use as a mountain tent in both its pressurized and unpressurized conditions. Preferably it is large enough to allow at least one person, and preferably two, to sit upright, sleep, and perform ordinary functions such as dressing and food preparation.

This embodiment is described as a portable high altitude habitat comprising spherical or near spherical sides along at least one axis of symmetry, made of flexible, nonbreathable material capable of maintaining air pressures
in the range from 0 - 10 psi greater than ambient comprising rigid means for supporting said flexible material, means for achieving and adjusting air pressure inside the chamber adjustable from 0 - 10 psi greater than ambient, and comprising an airtight zipper for ingress and egress of an inhabitant disposed in said spherical sides perpendicular to said axis of symmetry.

"Rigid means" for support the high altitude habitat include tent wands, poles, or any material capable of supporting the weight of the habitat to enclose a volume of unpressured air.

It is important that the zipper be placed perpendicular to the axis of symmetry, especially in a chamber as large as a tent which places greater stresses on the zipper along the axis of symmetry than perpendicular to this axis, and depending on the strength of the zipper, these stresses may be sufficient to break the zipper.

The mountain bubble embodiment achieves the following goals: to provide a portable structure of light weight capable of maintaining in its interior an elevated pressure of up to 10 psi above ambient, to provide sufficient interior volume to permit a human being to sleep within a sleeping bag, to provide a design capable of being executed at a cost commensurate with other mountain survival equipment, to provide a living space for mountaineers
suffering from high altitude sickness or who have altitude-related sleeping problems.

The closed-circuit rebreather improvement achieves the following goal: to provide and maintain a breathable air supply in a closed environment, preferably pressurized, for a period of at least several hours without the necessity for pumping, or carrying compressed air canisters, in a pressurized or non-pressurized environment.

The mountain bubble using the bladder achieves the following additional goal: to provide a breathable air supply within a pressurized environment without the necessity for continuous pumping or the necessity to carry oxygen to maintain a breathable oxygen concentration.

The high altitude habitat achieves the following goal: to provide a high altitude tent suitable for normal use by one or two persons without pressurization and able to be pressurized up to 10 psi above ambient pressures when desired to alleviate the effects of mountain sickness.

**Brief Description of the Drawings**

Figure 1 is a diagram of the closed circuit rebreather of this invention using an oxygen supply source and a carbon-dioxide removal source.
Figure 2 shows cut-away views of the bladder-equipped embodiment of this invention. Figure 2A shows the various components of the system and Figure 2B shows the pattern of airflow within the chamber.

General Features of Hyperbaric Chambers of the Invention

The various embodiments herein described, as well as other embodiments constructed according to the teachings herein, have many structural features in common. The devices are portable, which is defined as not intended for permanent installation, but capable of being collapsed, disassembled and moved from one location to another. The mountain bubble described herein is designed to be light and compact enough to be carried in a backpack as normal emergency equipment of a high altitude expedition, e.g., less than about 30 pounds including air supply means, and preferably less than about 20 pounds including air supply means. Alternatively, it can be carried in an ambulance as part of standard equipment for emergency treatment of pulmonary edema at any altitude. The material of the embodiments is flexible, defined as having flexibility characteristics similar to fabric, vinyl or leather. The material is nonbreathable, defined herein as substantially gas impermeable, at least with respect to the major gaseous components of the atmosphere.
The devices of the invention are designed to maintain pressure from 0-10 psi above ambient. For purposes of defining pressures greater than ambient, it will be understood that any such pressure is measured above the normal background of atmospheric pressure fluctuations due to weather. Alternative devices of the invention are designed to maintain pressures from 0.2 psi to 10 psi above ambient, and preferred embodiments maintain pressures from 0.2 psi to 4 psi above ambient.

Many suitable means for introducing air or gas mixtures to achieve a desired pressure are known in the art. The choice thereof will depend on the use to be made of the device, the volume of air to be delivered and the desired rate of circulation. Other considerations, such as temperature, humidity and noise level are also significant. For the mountain bubble, where extreme portability is desired and the total air volume is small, a hand pump such as is used for bicycle tires can be used to inflate the device. Preferably, a foot pump, such as those used for inflation of rubber rafts, is used. Where a constant air flow at preset pressure is desired, a differential pressure gauge with an exhaust valve may be included. Other means, including supplying air or gas from a pressurized tank may be used, as will be understood by those of ordinary skill in the art. It will also be understood that positive displacement pumping means are required because fans,
blowers and the like are not capable of providing the desired range of pressures.

The internal atmospheric composition can be controlled by means known to the art. As examples without any limitation of such means, known expedients for scavenging CO₂ and humidity may be employed, the capacity of such means being provided according to the intended use of the devices.

Temperature can be controlled, where needed, by conventional means external to the devices themselves. For example, a patient in the mountain bubble can be kept warm in a sleeping bag.

The devices are preferably constructed as described in EPO publication 0277787. A window can be provided using a segment of clear vinyl, for example, in order to admit light and reduce feelings of claustrophobia. The shape and placement of windows is a matter of choice available to those skilled in the art. The Talon (Meadville, Pennsylvania) underwater zipper is a preferred means for providing ingress and egress. Other suitable airtight zippers providing the necessary strength and airtightness may be used as known to the art.

The bubble can be free-standing, supported by its own rigidity when pressurized, or it can be supported with flexible wands, attached to the inner walls of a
conventional tent or provided with inflatable ribs, all according to expedients known in the art of tent design.

The problem to be overcome is that the pumping means must be compact and lightweight and therefore likely to be of limited capacity. It is therefore desirable to provide a separate way of initially filling the bubble essentially full to ambient pressure. One expedient is to provide a bubble that is dimensioned to fit within a conventional mountain tent, with ties, Velcro fasteners (Trademark Velcro Industries, NV, Willamstad, Curacao, Netherlands Antilles) or the like to attach the bubble walls to the tent walls, thereby opening the bubble and filling it with air at ambient pressure. Another embodiment includes flexible wands of, e.g., aluminum or fiberglass which can be inserted in tubes or channels to hold the bubble erect, as in conventional mountain tent design. Such a bubble could be used either free-standing, or inside a conventional tent. Another expedient is to provide an inflatable shell around the bubble itself. The outer shell could be pressurized, for example, by hot air provided by a cooking stove. In the latter embodiment, an added advantage of interior warmth and insulation is provided by the outer layer.

The improved high-altitude habitat of this invention is suitable for all purposes of a high-altitude mountain tent, allowing sufficient interior space for sleeping, dressing, eating and the like for one or two persons. The
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habitat is equipped with windows, an inlet valve for pressurization via a pump, an outlet valve, which may be a pressure relief valve designed to release pressure at a pre-selected value such as 2 psi greater than ambient, and a zipper for ingress and egress placed transversely, or at right angles to the long axis of the chamber for greater strength.

In operation, the habitat is set up, using wands, poles or other rigid supports, to enclose a volume of unpressurized air. If pressurization is desired, the occupant enters the habitat, and it is pressurized through an input valve using a pump or other source of air. The habitat is preferably equipped with oxygen and lithium hydroxide carbon dioxide removal pads sufficient to provide a period of several hours for sleeping without the necessity for pumping. The habitat may alternatively be equipped with a bladder arrangement as described herein to allow a period during which no attention to maintaining a fresh air supply need be given.

In basic design the mountain bubble is cylindrical or sausage-shaped, long enough to allow a human subject to lie full length within it, as well as a sleeping bag or blankets for warmth. The diameter is sufficient to provide some air space above the patient. A suitable breathing atmosphere may be provided by a portable closed circuit oxygen scuba respiration system such as that manufactured by Rexnord
Breathing Systems, Malverne, Pennsylvania, which can be carried inside the bubble.

A preferred closed-circuit rebreather of this invention uses the mountain bubble construction described herein. Without the closed-circuit breathing modification the patient is completely enclosed in the bag which is inflated and pressurized to simulate descent in altitude. CO₂ produced by the patient is vented from the airtight bag by means of a pressure relief valve, while fresh air is brought in from the outside via a high volume foot pump. In order to eliminate the vigorous pumping that is necessary to maintain a suitable atmosphere in the bag, the closed-circuit rebreathing provides a completely portable, self-contained life support system that supplies oxygen as it is consumed and removes the waste CO₂ as it is produced using lithium hydroxide pads for absorption. The entire closed-circuit rebreather, which maintains a homeostatic atmosphere in the chamber for six to eight hours, weighs less than six pounds. The chamber with the self-contained life support system weighs less than 18 pounds. It finds its greatest use in medical mountain clinics, isolated ski areas and as standard equipment for mountain search and rescue units.

A person suffering from altitude sickness can be put into the chamber and benefit from the effects of increased barometric pressure while causing virtually no added hardship on his or her companions. Physical descent down a
mountain is no longer necessary with the chamber, and no gas concentration maintenance such as regular pumping is necessary with the closed-circuit breathing system. The entire set-up fits easily into a mountaineering tent, so that both the patient and the individual monitoring the patient can be sheltered from the severe weather.

The duration of treatment with no maintenance has been tested to six hours. This time period could be lengthened through use of an increased number of LiOH pads and larger or additional O₂ bottles as will be apparent to those skilled in the art.

As described above, the basic preferred mountain bubble or chamber is a cylindrical eight pound nylon bag that is sealed with an air-tight zipper. The bag is equipped with windows and a variety of intake and exhaust valves that allow inflation via a high performance raft foot pump to two psi gauge (103 mmHg). The chamber with foot pump weighs ten to twelve pounds, depending on the choice of pump. Laboratory tests have shown that continuous ventilation of the bag 42 liter/min, serves both to bring in fresh oxygen and vent out CO₂, such that the O₂ concentration in the chamber never drops to below 20% and CO₂ never reaches a 1% level (2).

Field tests done by Hackett et al. (1989) "A Portable, Fabric Hyperbaric Chamber for Treatment of High Altitude
Illness," Sixth International Hypoxia Symposium, Chateau Lake Louise, Alberta, Canada, in the summer of 1988 on Mt. Denali and by Taber and Gamow (1989) "Treatment of AMS at the HRA Clinic at Pheriche Using the "Gamow Bag" During the 1988 Fall Climbing Season," Sixth International Hypoxia Symposium, Chateau Lake Louise, Alberta, Canada, at Pheriche, Nepal, have demonstrated that when patients suffering either from severe pulmonary edema, and/or cerebral edema are subjected to a two-hour treatment in the chamber, dramatic improvement from AMS occurs. Although there is no doubt that the chamber in its basic design saves lives, it suffers from two drawbacks. In order to vent the chamber properly the foot pump must be operated on the average 15 times a minute, a procedure that can exhaust even a vigorous mountaineering companion. In addition, since the foot pump is most conveniently operated from a standing position, the chamber cannot be used inside a small mountain tent with both the chamber and a person operating the foot pump inside the tent.

A solution to the problem is to equip the chamber with a small closed-circuit breathing system. A closed-circuit rebreather is a device which must both remove the CO₂ from the exhalant and replace the O₂ consumed by the patient. Such devices have been routinely used by divers, firemen and miners. Difficulties in the past have been that all these devices have been unacceptably heavy, bulky in size, and expensive. They also have had very short duration times and
have all required the user to wear a face mask. The embodiment here described is a true closed-circuit rebreather that can be added to the bag and weighs less than six pounds. It is relatively inexpensive, requires no mask, and can maintain a resting person with the proper atmospheric environment (21% \( \text{O}_2 \) and 0.8% \( \text{CO}_2 \)) for six hours.

To test the effectiveness of the closed-circuit rebreather of this invention, the following experiments were performed. The portable hyperbaric chamber used was manufactured by Hyperbaric Mountain Technologies, Inc., Boulder, Colorado. When fully inflated, it is 2.08 m long with a diameter of 0.54 m. The internal volume is 476 liters. The chamber is constructed from polyurethane coated oxford nylon fabric. Four windows 10 cm square of 2 mm thick clear vinyl are located at the head of the chamber, to allow observation of the patient at all times.

In order to maintain a constant internal pressure, the chamber has two 2 psi pressure relief valves. The chamber was initially pressurized with a bellows type raft pump. When it is used in the non-closed circuit mode, the chamber is ventilated by pumping 10 to 15 times per minute. The \( \text{CO}_2 \) scrubber was made by and supplied by DuPont Company. The scrubber consisted of a series of one foot square pads that had been impregnated with LiOH. One pad has been determined to last on the order of 20 minutes. The pads function not only to remove the \( \text{CO}_2 \) but also the accumulated moisture. A
Matheson, model 8-2, pressure regulator, full scale range 0 to 3 psi, was used to both maintain chamber pressure and to also replace the spent oxygen.

Although the Matheson is an ideal pressure regulator for the laboratory experiment, in real field use a light 0.39 kg pressure regulator produced by Circle Seal Controls (Anaheim, California), is preferably used. The oxygen bottle contains 136 liters when pressurized to 1750 psi. This amount will supply enough O₂ for a person at rest for six hours. For field use, the O₂ bottles can be filled to 3000 psi, thus significantly extending the duration of the oxygen supply. The concentration of CO₂ and O₂ were determined using a Hewlett Packard Patient Gas Monitor, model 78386A.

In testing the closed-circuit breathing system to be used with the mountain bubble, a series of preliminary tests were done to demonstrate the effectiveness of each component of the system.

The first test consisted of measuring the leak rate of the hyperbaric bag. It is necessary to use a chamber with a negligible leak rate to ensure a constant balance of gases; that is, the system has to be truly closed. The leak rate was determined by fully inflating the chamber (to 2 psi gauge), then taking periodic readings from the external pressure gauge.
Leak rates were calculated as follows:

Using the ideal gas law approximation, one finds that the amount of air pumped into or leaked out of the chamber versus the gauge pressure on the bag is given by

$$\frac{dV}{dP} = \frac{V}{P_{AM}}$$

(1)

where:

\[dV\] = volume of air (at ambient pressure) pumped in or leaked out;

\[P\] = pressure on gauge;

\[V\] = volume of bag (476 l);

\[P_{AM}\] = ambient pressure;

\[= 640 \text{ mmHg in Boulder, CO}\]

\[= 760 \text{ mmHg at sea level}\]

This equation gives a result of \(0.744 \text{ l/mmHg in Boulder, Colorado}\) where the experiment was performed, and \(0.626 \text{ l/mmHg at sea level}\). Leakage was measured directly in mmHg per unit time. Combining these measured values with equation (1) gives the leak rate in l/min.

$$\frac{dV}{dP_g} \frac{dP_g}{dt} = \frac{dV}{dt}$$

(2)
The value obtained for the chamber under study was:

\[
(0.744) \frac{(9\text{mmHg})}{30\text{ min}} = 0.22\text{ l/min}
\]

It was hoped that this leak rate would prove to be negligible. A non-negligible leak rate would be evident as an oxygen buildup in the fully integrated system.

The second phase of testing involved measuring the kinetics of the \(\text{CO}_2\) absorption portion of the system. \(\text{CO}_2\) from gas cylinder was bled into the chamber via a flow regulator. The flow regulator was set to deliver either 0.3 l/min or 0.5 l/min. Ten LiOH pads were suspended in the chamber. The \(\text{CO}_2\) concentration remained below about 1% until the pads' absorptive capacities were exhausted. After about 120 minutes at 0.5 l/m and about 180 minutes at 0.3 l/m, the percent \(\text{CO}_2\) began to rise rapidly from less than 1%, reaching 6% within about 210 minutes at a bleed rate into the chamber of 0.5 l/m and within about 360 minutes at a bleed rate of 0.3 l/m. These data demonstrate the kinetics of \(\text{CO}_2\) absorption by the LiOH pads.

A human subject was then placed in the chamber and the \(\text{CO}_2\) concentration was measured either with no \(\text{CO}_2\) scrubber or with 14 pads of the \(\text{CO}_2\) scrubber. Following this, a second human subject was placed in the chamber with either no \(\text{CO}_2\) scrubbing pads or with 6 pads. In the experiment using 14
pads, the percent CO₂ remained essentially constant for 180 minutes at 0.5%, as compared to a rapid steady rise to about 4.0% in 60 minutes using no pads. In the experiment using 6 pads, the percent CO₂ rose slowly from about 0.5% to about 1.0% in about 15 minutes, reached about 2.0% after about 120 minutes, and about 3.0% after about 180 minutes, beginning to rise more steeply at about 150 minutes. The LiOH pads thus were shown to successfully prevent CO₂ buildup in the chamber. On the average, and to a rough approximation, the usable lifetime per pad is approximately 20 minutes.

The third stage in the testing process involved measuring the oxygen consumption of a human subject as a function of time. These measurements were taken both with and without LiOH pads, but with no other regulation of gases. Oxygen was replaced by a pressure regulator attached to an oxygen gas cylinder. The pressure in the bag fell from 98 mmHg to 40 mmHg, both because of chamber leakage and because chamber air was bled out in order to measure the oxygen concentration. There was a dramatic and steady decrease of oxygen inside the chamber when no supplementation was available. The rate of decrease indicates that with or without the LiOH pads, the O₂ concentration reaches dangerous levels (about 12%) within approximately two hours. (The experiment using no LiOH pads was terminated after 45 minutes.)
The final phase of testing involved combining a human subject, the pressurized chamber, the LiOH pads, and an O₂ supplementation system.

The chamber was inflated by means of a foot pump to 2 psi gauge. The O₂ regulator was then set to maintain the chamber at that pressure. With a completely leak-proof chamber the only loss of pressure in the system is due to O₂ consumption by the subject, thus the O₂ regulator allows replacement of exactly that which has been used. Six hours was estimated to be the lifetime of the 136 liter O₂ bottle. The CO₂ and O₂ gas concentrations were measured as functions of time, and both curves are essentially flat, rising less than about 1%, over the entire six-hour duration of this experiment.

It has thus been shown that a leak-rate of 0.22 liter/min. can be considered essentially air-tight. The LiOH pads successfully control the CO₂ concentration, and the O₂ bottle/regulator component successfully replaces the O₂ used by the subject while, at the same time, maintaining chamber pressure. The duration of treatment with no maintenance has been tested to six hours. This time period could be lengthened through use of an increased number of LiOH pads and larger or additional O₂ bottles as will be apparent to those skilled in the art.
It will be apparent that variations in materials, construction techniques, and pressure maintenance and control means are possible within the scope of ordinary skill in the relevant arts. Added refinements, including temperature and humidity control, lighting and electrical hook-ups may be included. Such refinements and modifications alone or in combination are deemed to fall within the scope of the claimed invention, being refinements or equivalents available to those of ordinary skill in the relevant arts.

Detailed Description of the Drawings

Figure 1 shows a preferred closed-circuit rebreather of this invention. The basic mountain bubble (10) is equipped with a canister of compressed oxygen (20) attached through a pressure regulator (30) to an inlet (35) into the chamber via an air hose (40). Lithium hydroxide pads (50) for absorbing carbon dioxide are shown in a cutaway view of the inside of the chamber. A pressure relief valve (60) which may be designed to automatically release pressure at a pre-selected pressure value is also provided. An optional foot pump (70) connected through an air hose (75) to an inlet (76) is also shown. If desired, a gas analyzer (80) may be attached to the bag to monitor oxygen and carbon dioxide content, as was done for the experiments described above to determine effectiveness of various parameters of the system. The chamber is equipped with clear vinyl
windows (90) and reinforced with straps (100) equipped with handles (110). The longitudinal stripe (120) represents a heat-seal seam made during construction of the basic mountain bubble.

In operation, the chamber is pressurized as desired to a pre-selected value. This embodiment may be operated at atmospheric or ambient pressures as well as at hyperbaric pressures. A patient inside the chamber inhales air having a normal oxygen concentration of about 21%, and breathes out air in which some of the oxygen has been converted to carbon dioxide. The carbon dioxide is absorbed onto the lithium hydroxide pads (50), causing lowering of the pressure within the chamber. When the pressure is reduced below the pre-selected value to which the pressure regulator (30) has been set, oxygen is bled from the oxygen canister (20) into the chamber to replace the absorbed carbon dioxide. In this way, only the oxygen which has been converted to carbon dioxide in the patient's lungs is replaced. The oxygen bottle and lithium hydroxide pads may be replaced as necessary.

Figure 2A shows the bladder-equipped hyperbaric chamber (10) of this invention. A foot pump (20) is attached to the chamber via air hose (30) through a one-way inlet valve (40). Disposed within the bag is a bladder (50) made of a flexible material. The bladder is connected via a pressure relief valve (60) designed to release pressure at a pre-
selected pressure (preferably 2.0 psi above ambient pressure) through the chamber wall (70) to the outer atmosphere which is at a lower pressure than the pressure inside the chamber. A patient (80) inside the chamber is fitted with a face mask (90) attached to his head by straps (95). The face mask (90) is equipped with a one-way intake valve 100 through which air is inhaled from the interior of the chamber. Exhalation occurs through a one-way valve (110) connected to the bladder (50) via an air hose (120).

Figure 2B shows by means of arrows, the airflow pattern of the bag in operation. The chamber is pressurized by means of the pump (20) and air flows into the chamber through the valve (40). The patient (80) equipped with mask (90) inhales through valve 100 drawing fresh air into the mask from the chamber. Air is drawn into the patient's lungs (85) as shown by the dotted arrows, and exhaled through valve (110) through air hose (120) into bladder (50). When the bladder (50) is full, or partially full, at the operator's convenience, the pump (20) is again operated, raising the pressure inside the chamber above the pre-selected pressure to which the pressure relief valve (60) responds. As the pressure inside the chamber rises above the pre-selected pressure, pressure relief valve (60) releases air from bladder (50) through the chamber wall (70) into the outer atmosphere, thus emptying the bladder. Pumping is continued until the bladder is emptied. In this
way a fresh air supply for breathing is maintained inside the chamber without the necessity for continuous pumping.

The foregoing description is provided by way of illustration and not by way of limitation. It should be apparent that a number of modifications may be made by those skilled in the art to the embodiments depicted and described, all within the scope and spirit of the disclosure hereof, and such modifications are within the scope of this invention.
WE CLAIM:

1. A substantially leak-proof rebreather comprising a chamber large enough to contain a whole human body made of flexible, non-breathable material capable of maintaining air pressures inside said chamber in the range from about atmospheric to 0 - 10 psi greater than ambient comprising: carbon dioxide removal means inside said rebreather, and oxygen input means responsive to drops in pressure below a preselected pressure inside said rebreather chamber resulting from said carbon dioxide removal to maintain said preselected pressure by oxygen input.

2. The rebreather of claim 1 wherein said oxygen input means comprises a compressed oxygen container connected to said chamber through a pressure regulator.

3. The rebreather of claim 1 wherein said carbon dioxide removal means comprises lithium hydroxide pads.

4. The rebreather of claim 1 further comprising gas analyzing means for monitoring carbon dioxide and oxygen concentration inside the rebreather.

5. The rebreather of claim 1 wherein said pressure is maintained from about 0.2 to about 4.0 psi greater than ambient.
6. The rebreather of claim 1 wherein said pressure is maintained at atmospheric pressure.

7. A hyperbaric chamber comprising a chamber large enough to contain a whole human body made of nonbreathable material capable of maintaining air pressures inside said chamber in the range from about 0.2 to about 10 psi greater than ambient comprising air input means for achieving said air pressures inside said chamber; an internal bladder for collection of exhaled air; pressure-responsive exhaust means connecting said bladder to the environment outside said rebreather allowing air in said bladder to exhaust therethrough at a preselected internal chamber pressure achieved by said air input means; and exhale capture means for conducting said exhaled air into said bladder and preventing escape of said exhaled air into said chamber.

8. The chamber of claim 7 wherein said exhale capture means comprises a face mask comprising a one-way intake valve and a one-way exhaust valve connected to said bladder whereby inhalation occurs through said intake valve from the interior of said rebreather and exhalation occurs through said exhaust valve into said bladder.
9. The rebreather of claim 7 wherein said means for achieving air pressures inside said rebreather comprise pumping means connected to said rebreather through one-way intake valve.

10. A high altitude habitat comprising the rebreather of claim 1 or the internal bladder of claim 7.
**INTERNATIONAL SEARCH REPORT**

**International Application No:** PCT/US 90/02164

**I. CLASSIFICATION OF SUBJECT MATTER**

(according to international Patent Classification (IPC) or to both National Classification and IPC)

**IPC:** A 61 G 10/02, A 62 B 31/00

**II. FIELDS SEARCHED**

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<td>Classification Symbols</td>
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Documentation Searched other than Minimum Documentation to the extent that such Documents are Included in the Fields Searched

**III. DOCUMENTS CONSIDERED TO BE RELEVANT**

<table>
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<tr>
<th>Category</th>
<th>Citation of Document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to Claim No.</th>
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<tbody>
<tr>
<td>X</td>
<td>FR, A, 1582749 (DRÄGER) 3 October 1969 see the whole document</td>
<td>1,7,8</td>
</tr>
<tr>
<td>X</td>
<td>BE, A, 567038 (MERTENS) 14 May 1958 see page 2, line 14 - page 3, line 26; figures 1,2</td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>EP, A, 0277787 (GAMOW) 10 August 1988 see column 6, lines 43-50; column 10, lines 26-63; column 11, lines 11-42; claim 10; figures 1,6A,6C (cited in the application)</td>
<td>1,2,5,10</td>
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**IV. CERTIFICATION**

**Date of the Actual Completion of the International Search:** 3rd August 1990

**Date of Mailing of this International Search Report:** 07. 09. 90

**European Patent Office**

**Signature of Authorized Officer:** F.W. HECK

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</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>US, A, 2401230 (R.S. COLLEY) 28 May 1946 see the whole document</td>
<td>1, 9, 10</td>
</tr>
<tr>
<td>A</td>
<td>DE, A, 3004156 (HAUSER) 6 August 1981 see page 4, lines 6-14; page 6, lines 15-36; page 7, lines 1-22; figures</td>
<td>1, 9, 10</td>
</tr>
<tr>
<td>A</td>
<td>US, A, 3729002 (MILLER) 24 April 1973 see column 2, lines 9-53; figures 1-3</td>
<td>1, 2</td>
</tr>
<tr>
<td>A</td>
<td>FR, A, 1406060 (AMANJEAN) 1965 see the whole document</td>
<td>1, 2</td>
</tr>
<tr>
<td>A</td>
<td>EP, A, 0171551 (DORNIER SYSTEM) 19 February 1986 see claim 3</td>
<td>3</td>
</tr>
</tbody>
</table>
This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 04/09/90. The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

<table>
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<tr>
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<tr>
<td></td>
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<td>19-02-86</td>
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