DC 55

1.- General.

…till now, you were using the Cousteau-Gagnan regulator which is an open circuit, meaning that all exhaled gas is thrown away.

- You will now use DC55 (initials of the inventor: Duffaut Casenave and year 55) which is an autonomous diving apparatus using nitrogen-oxygen mix (O_2 N_2) in a semi closed circuit.
- Effective stability of breathed mix is obtained independently from diver, depth and work by the leakage of a certain volume of gas, proportional to breathing amplitude.
- This is a “demand type” apparatus.

- Other types: By-pass and constant flow.

2.- Diminishing of moving gas quantity.

Due to:
- O_2 metabolism
- CO_2 fixing in scrubber,
- Controlled leakage.
-Automatically compensated by the top flange of breathing bag pushing on LP demand valve.

3.- Advantages of DC 55.
- High duration:
- Totally non magnetic.
- Discretion (silence, bubble diffusion).
- Depth from surface to 55m (following gas mix)
-All joints are o ring type not needing excessive torque but need to be maintained very clean.

2/-gas mixes classification - conventional colors.

4 mixes are used with DC 55:

1/- 60 mix(60 % 02 - 40 % N2).
- from surface to 25 m.
- unlimited duration at 25m , no deco stops.
- 60 mix tanks have a black neck and 3 white stripes

2/- 50 mix (50%o2 - 50%N2)
-from surface to 30m
-1h 30 duration at 30m without deco stops.
- till now, only used at II GPDT in Brest

3/- 40 mix (40%O2 - 60% N2)
- with this gas mix rebreather Must be fitted with additional injector
- from surface to 45m
- 40 mix tanks have a black neck and 2 white strips

4/- 30 mix (32.5% O2 - 67.5% N2)
- with this gas mix rebreather Must be fitted with additional injector
- from surface to 55m
- for diving with 30 mix DC55 is fitted with :
    - one 30 mix tank on the right
    - one pure oxygen tank on the left

Oxygen tank is used to make deco stops and during coming back to surface.
-Pure oxygen tanks have a black neck

NOTE: only BS mining divers and mining officer diver are allowed to dive 30 mix.

3.- Description of apparatus:

1/- Frame:
polyester fiberglass, very fragile , diffusing hood.

2/- Tanks
- 2 tanks, non magnetic metal.
- 3 liters
- service pressure: 150 bar
- on each side of scrubber cartridge

3/- scrubber

- divergent shape ensures maximum efficiency of sodalime and allows room for tanks.
- a perforated brass plate is welded at the bottom of the scrubber about 10mm from base to avoid sodalime in the inhale and exhale tubing
- a middle separator welded to the base up to 10mm form the top and makes 2 communicating halves. This separator forces gases to cross the whole scrubber.
- input and output tubing is welded to the base and connected to breathing hoses by rubber tubing.

External wall is made from brass and thermally insulated.

- holds about 2Kg of sodalime

- Filling is achieved via a round door, wearing o ring on the upper side

4/- HP bridge.

On the bottom, maintaining tanks in place, permitting pressure equilibrium between tanks and feeding the regulator.

5/- HP – MP regulator

a/ description:
- made of chromed brass, only one moving part : the differential piston
- this piston which opposite sides are unequal in surface is traversed by a conduit communicating between HP and MP chambers which are isolated from ambient by O rings.
- the small end of piston supports a nylon poppet which is closing HP when MP reaches a certain value.

- A spring that piston must force to close HP ensures a minimal 10-12 bar MP (max 14bar)

On release, it maintains piston in the high position , HP nozzle open.
- 2 equilibrating holes are drilled in the regulator body, allowing ambient pressure communicating with the largest lower face of piston .
-. During the dive, hydrostatic pressure will add to the spring force, obtaining a MP dependent from ambient.
- A sintered metal filter is fitted at the inner port .

the regulator is perfectly silent,
every movement is on O ring

b/- function:
-

when the tank is opened, gas is fed to the regulator via HP tubing
gas enters regulator trough sintered metal filter via an inlet conduit which is bigger in diameter than outlet. There is achieved a first detent by laminating.

Since piston is maintained in high position by the spring and gas pressure on the small side, gas comes through piston via axial conduit , filling MP chamber , closed by LP poppet which is closed in release position.
Since LP poppet is closed, pressure will build up in MP chamber.
When pressure will have reached a minimum of 10-12 bar, the force on the lager side of piston will be greater than the smaller one added of the spring force. Piston will come down and close the HP input

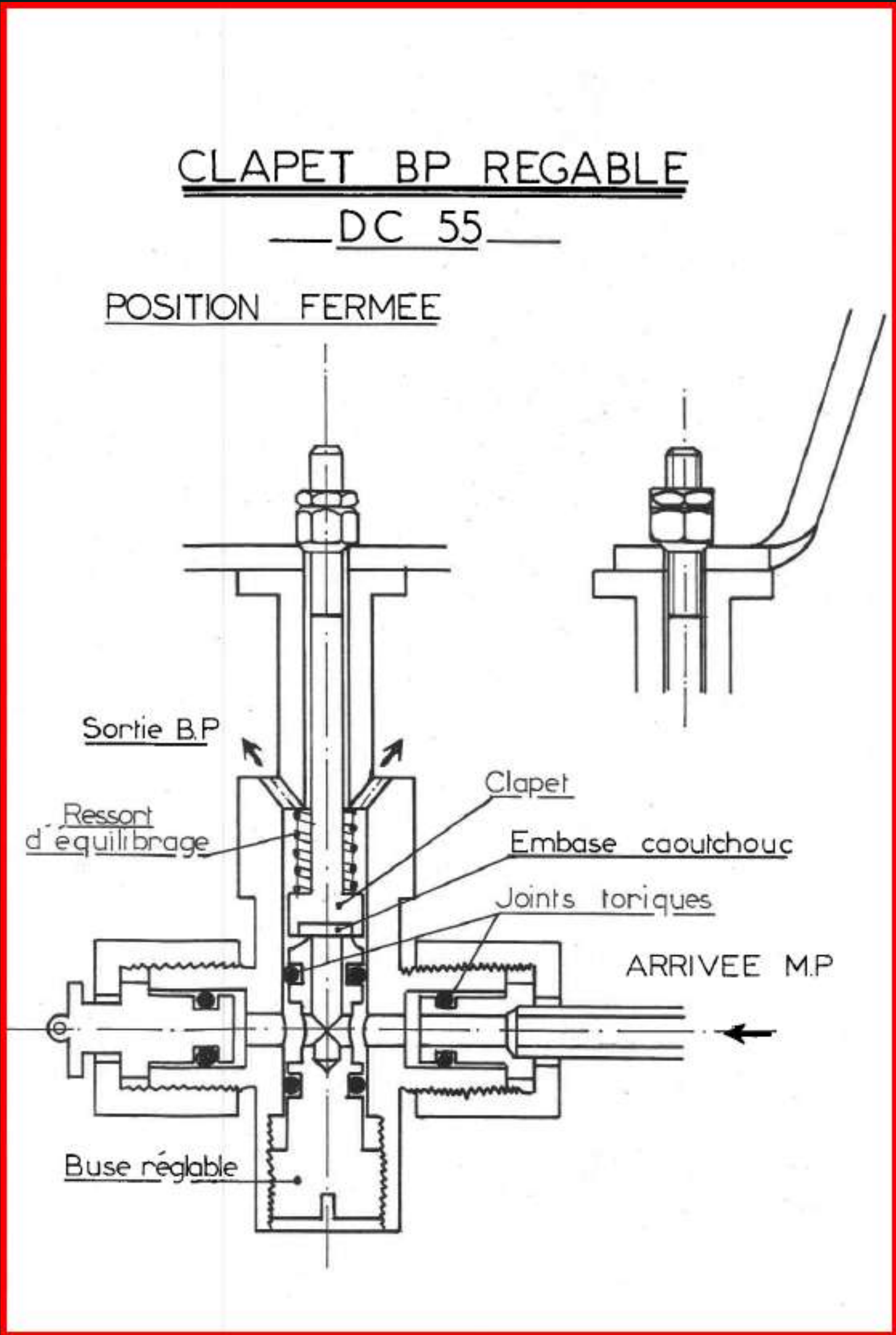
6/- MP tubing.

Used to carry medium pressure gas mix from HP - MP regulator to the LP poppet valve.

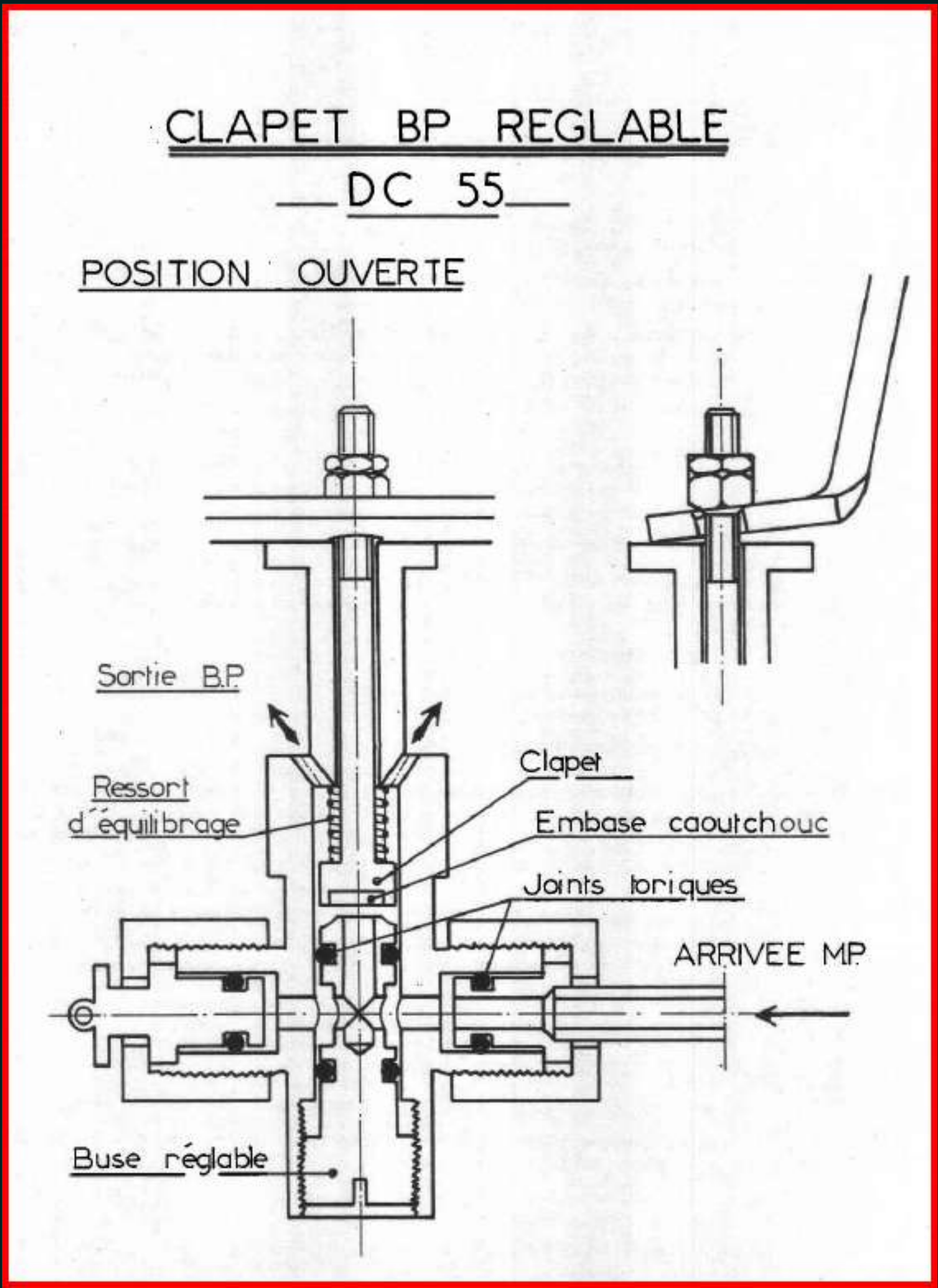
7/- Adjustable LP valve.

- Affixed on the lower fixed flange.
- This is the « on demand valve » of the breathing bag .

Each time the upper flange will go down, following a volume diminishing of gas mix in the breathing bag, enough to push on the fork commanding LP valve opening.



CLAPET BP REGABLE
DC 55
POSITION FERMEE
Sortie B.P
Clapet
Ressort d'equilibrage
Embase caoutchouc
Joints toriques
ARRIVEE M.P
Buse réglable


CLAPET BP REGLABLE
DC 55
POSITION OUVERTE
Sortie B.P
Ressort d'équilibrage
Clapet
Embase caoutchouc
Joints toriques
ARRIVEE M.P
Buse réglable

b/- function:

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When pressure will have reached a minimum of 10-12 bar, the force on the lager side of piston will be greater than the smaller one added of the spring force. Piston will come down and close the HP input
Description :
A body on which is affixed MP tubing and spare injector tubing
An externally adjustable MP nozzle
A stainless steel poppet with a rubber base
A closing spring for the poppet

Function : the diver is breathing normally in his apparatus will inhale the mix contained in the big breathing bag
After a few inspirations, the volume of mix will diminish (see §2) it will diminish till the bag is almost empty, the mobile upper flange will push the fork commanding LP poppet which will open, allowing gas mix from MP regulator to fill the breathing bag which will inflate pulling up the upper flange
The LP for is then released and the poppet valve closed again.
A new cycle is about to begin.
Poppet adjusting is done at the shop.

8/- big breathing bag :
-Made of molded neoprene rubber, foldable, bellow type.
-Plastic rings at the inside make a certain rigidity leading to good shape conformity
-On the lower side, it is hold on the flange by a metal collar.
On the top side is the upper mobile flange also hold by metal collar.
Makes a “flywheel” role.
Communicate to the contained gas mix the ambient hydrostatic pressure.

9/- small bag
molded neoprene rubber
folds up as the big bellow type bag, no internal stiffener
internal volume is 12.7 times smaller than the big one, commonly said that the ratio is 1/13
on the lower side it is fixed on the transfer and non return valve box which is affixed on the lower flange
held in place by nylon wire

note: you must then understand that small bag will always follow the big one movements up and down.

<u>10/- lower fixed flange</u>
-chromed brass
rigidly hold on the base by 4 nuts
holds inhale and exhale tubing
on the center a 30mm hole allows attachment of transfer and non return valve support
a blind O ring fitted nut holds support in place.
Supports the breathing bag bellow.
Supports the LP poppet valve body.

<u>11/- upper mobile flange</u>
-chromed brass
-supports upper side of breathing bag bellow, follows its movements
- on the center a 30mm hole supports the controlled leakage and overfill valve.
This valve is at the outside of the flange, protected by a grid with an opening on the center , allowing leak testing of small bag and non return valve.

<u>12/- inhale filter</u>
-brass base, covered by fine metallic mesh.
-comes inside the inspiration tube , facing the hole from scrubber which leads cleaned gas into the big breathing bag.
- at the base a cone pushes on a brazed flange inside the inspiration tube, making all the gas mix passing through the filter.

<u>13/- controlled leakage and relief valve.</u>
- molded in a heavy rigid rubber assuring a 30 grams opening force.
– affixed on the top side of the small breathing bag.

Carries 2 roles :

-Communicating from small bag to the outside (creating controlled leakage)
-Overfilling valve on the ascent to surface

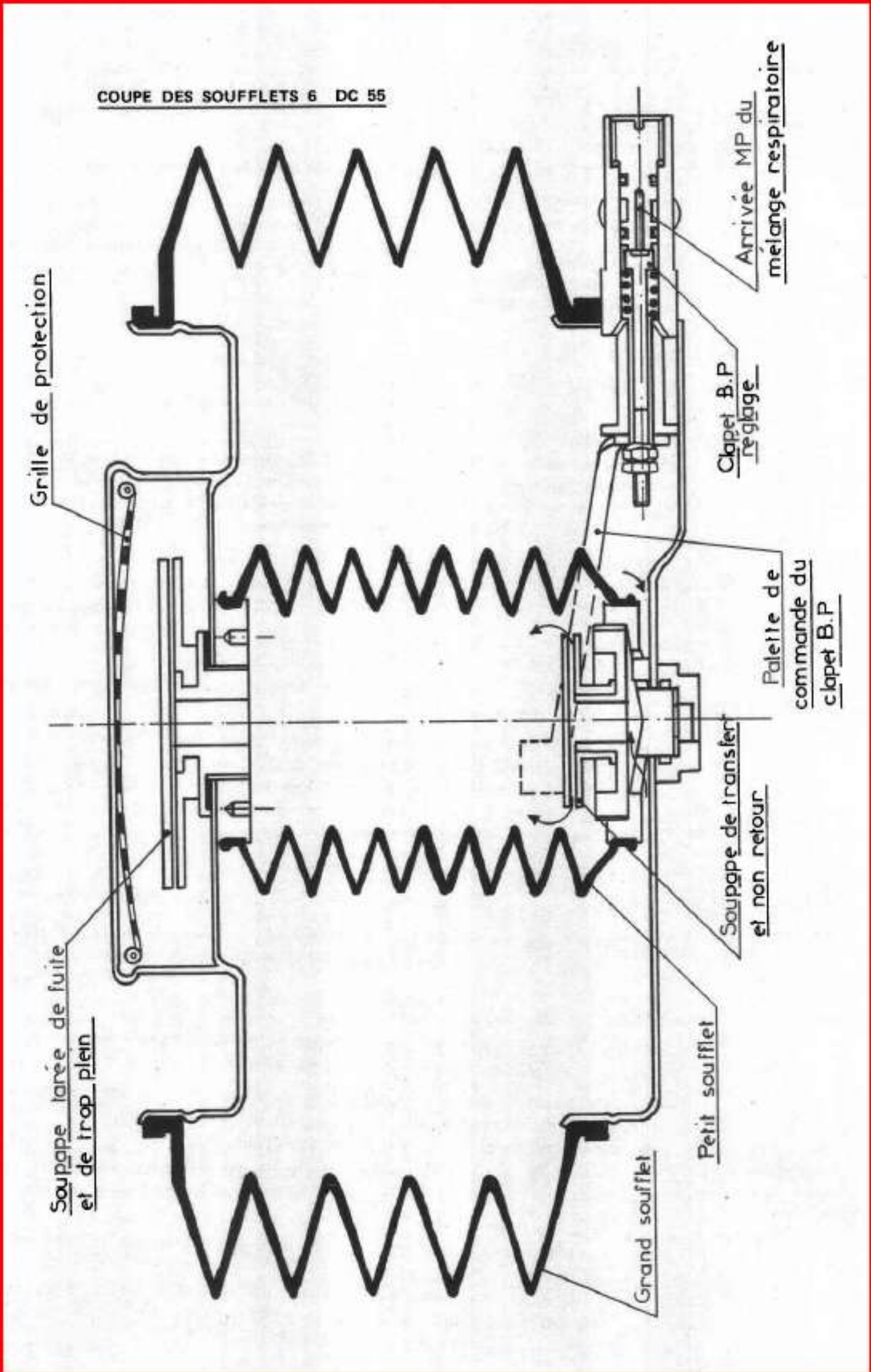
Ambient pressure will diminish on ascent inflating breathing bags
At a certain moment upper flange will operate relief valve allowing excess gas to come out.

It will work the same way if the LP poppet valve is leaking a continuous flow in the breathing bag

14/- Transfer and non return valve

-molded rubber
- On the lower side of small bag
- 2 important roles:
-Allowing a part of the gas arriving in the big bag to enter the small one
-Not allowing gas in the small bag to return to the big one on the down movement
-Gas has only one way out: the controlled leakage and relief valve which 30 grams resistance will force non return closed.

This document is a translation of the DC55 training. It has been translated for informative purposes only and cannot be used as a trainings manual! Please read the disclaimer on this website. Translation by J.F. Mussen



4 functioning:

1/- let's start with bags on the lower position (emptied)

-when tank is opened, gas mix will run through HP bridge, through the HP MP regulator and MP tubing to the LP poppet valve (closed)
-when pressure has build up to 10-12bar (max 14) the differential piston will close HP seat.

2/- inspiration

-you inspire in the mouthpiece:
-exhale valve closes on its seat
-inhale valve opens
-a depression is building up in the big breathing bag pulling upper flange down.
-upper flange pushes un the LP poppet valve fork, making it open. Gas mix enters then in the breathing bag.
- bag inflates and LP valve relieved.
- from the gas mix entering breathing bag, you will breathe a certain part, when 1/12.7 will enter the small bag through the non return transfer valve.

3/-expiration
-you expire in the mouthpiece:
- inspiration valve closes on its seat
-expiration valve opens
- these 2 valves will make all exhaled gas pass through scrubber where it will leave CO2 the cleaned gas will enter the big bag via the transfer valve.

4/- second inspiration phase
-at the next inspiration phase, the big bag will come down, pulling the small one. In this one a 30grams overpressure will build up.
-the non return transfer valve will close, acting as a non return valve
-the bags are continuing their way down, following diver inspiration, the pressure in the small bag will be over 30 grams and relief valve opens, escaping a part of the small bag contents (1/12.7 of total volume)
- a leakage occurs till the beginning of the next expiration.
NOTE
This apparatus escapes gas at the inspiration phase
-bubbles are practically invisible at surface since diffusion through drilled cover .

5/- why a controlled leakage ?

- you know that in a gas mix contained in your tanks, only oxygen maintains your life.
- Nitrogen is a non metabolic gas which is totally sent back to breathing bag on exhale
- Added to this nitrogen is the one already present in the apparatus before diving
- If the controlled leakage doesn't exist, after a few inspiration the bag would only contain nitrogen and holding it inflated and making impossible the opening of the LP poppet valve
- A sudden loss of conscience by hypoxia will happen.

IMPORTANT:

-Your safety RELIES on this leakage !
-A leaking transfer and non return valve or a broken small breathing bag will make your apparatus to work in closed circuit mode ! the same hazard for the same causes!
-That's why **the pre-dive checks have to be thoroughly and seriously done**.
- the smallest neglect at this time WILL have serious consequences!

5.- Setting up the device

1/- before use of DC55 following operation must be done:

2/- filling the scrubber

- open filling door and affix dedicated funnel
- sleeve sodalime to get rid of dust which could be absorbed when using apparatus.
- Incline device, HP bridge to the top and fill .
- Tap each side of scrubber with hand
- Incorrect filling of scrubber will allow gas to tunnel through sodalime leading to an incomplete CO_2 capture
- When the scrubber is filled to the top, be sure that the O ring of the door is perfectly clean, slightly greased, close it

3/- tanks

- take 2 tanks at the mix room
- be sure that the mix you are taking correspond to the target depth
- check tank pressure and mount them on the rebreather

6.- checks

1/- leak test of transfer/non return valve and small bag

- open mouth piece valve

- fill the bag
- put a finger on the center of controlled leakage valve to close orifice and push slightly
- bellow will come down about 2/3 of height and then resist.
- If it comes completely down, there is a leaking small bag or transfer an non return valve

2/- big breathing bag leaks

-close mouthpiece and fill breathing bag.
-put a finger at the center of leakage valve and push slightly
-the breathing bag must NOT come down, otherwise there is a leak.

3/- controlled leakage valve check

-fill bags with mouth
-close mouth piece
- bags will come down and stabilize half way

4/-LP poppet valve leak test

-open right tank
-slightly fill breathing bag (avoid upper flange pushing LP valve opening fork)
-close mouthpiece
- bags must not inflate (no leak noise must be perceptible)

5/-LP poppet valve sensitivity

-leave a tank open
-open mouthpiece valve
-bags will come down, upper flange weight will push on LP valve lever occurring a small leak into bags
-close mouthpiece, leak ceases.

6/- inspiration flapper valve check

-hand squeeze exhale tube and blow slightly in mouthpiece breathing bag must not inflate
-on inspiration, gas comes normally

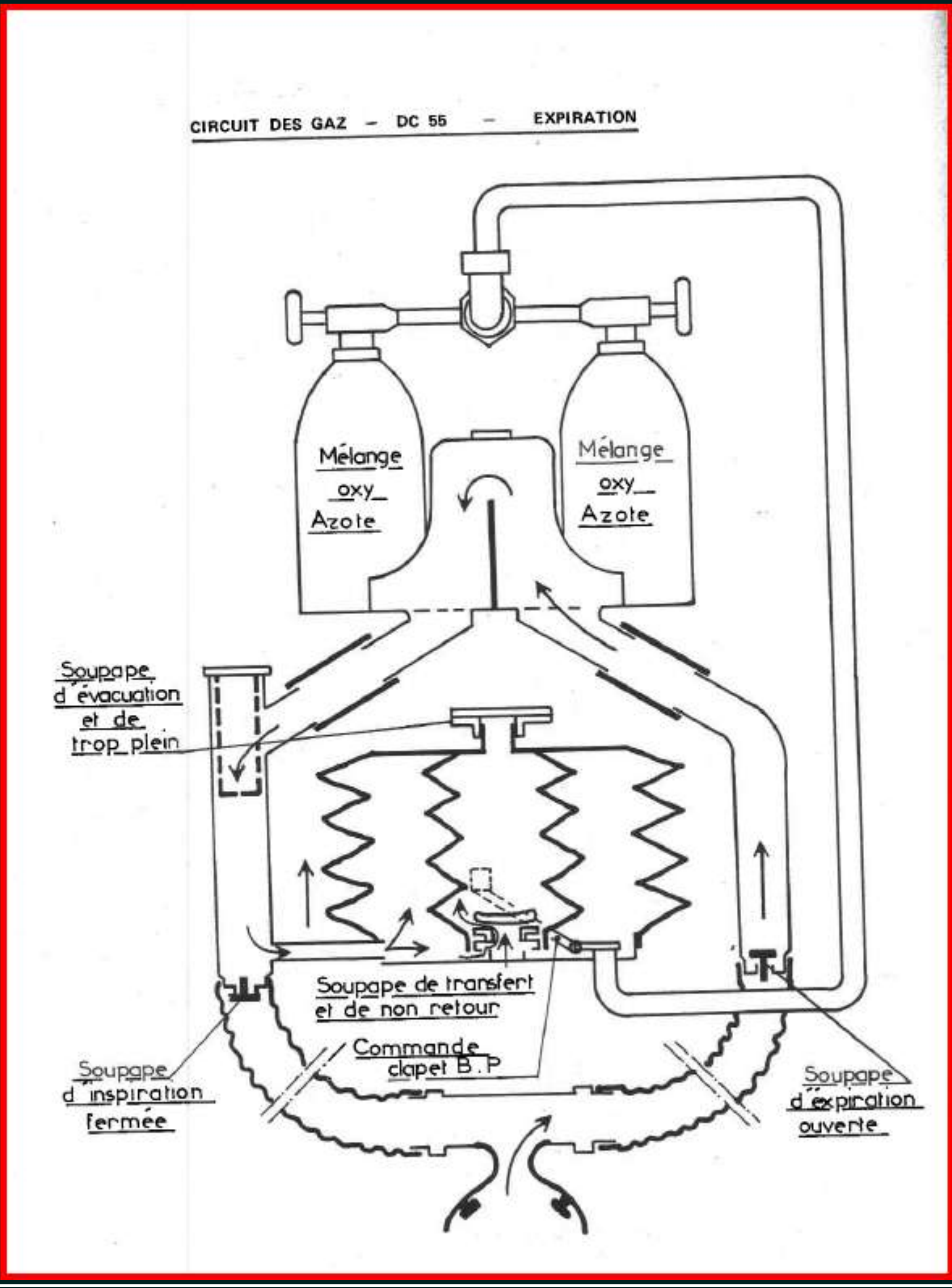
7/- exhale flapper valve check

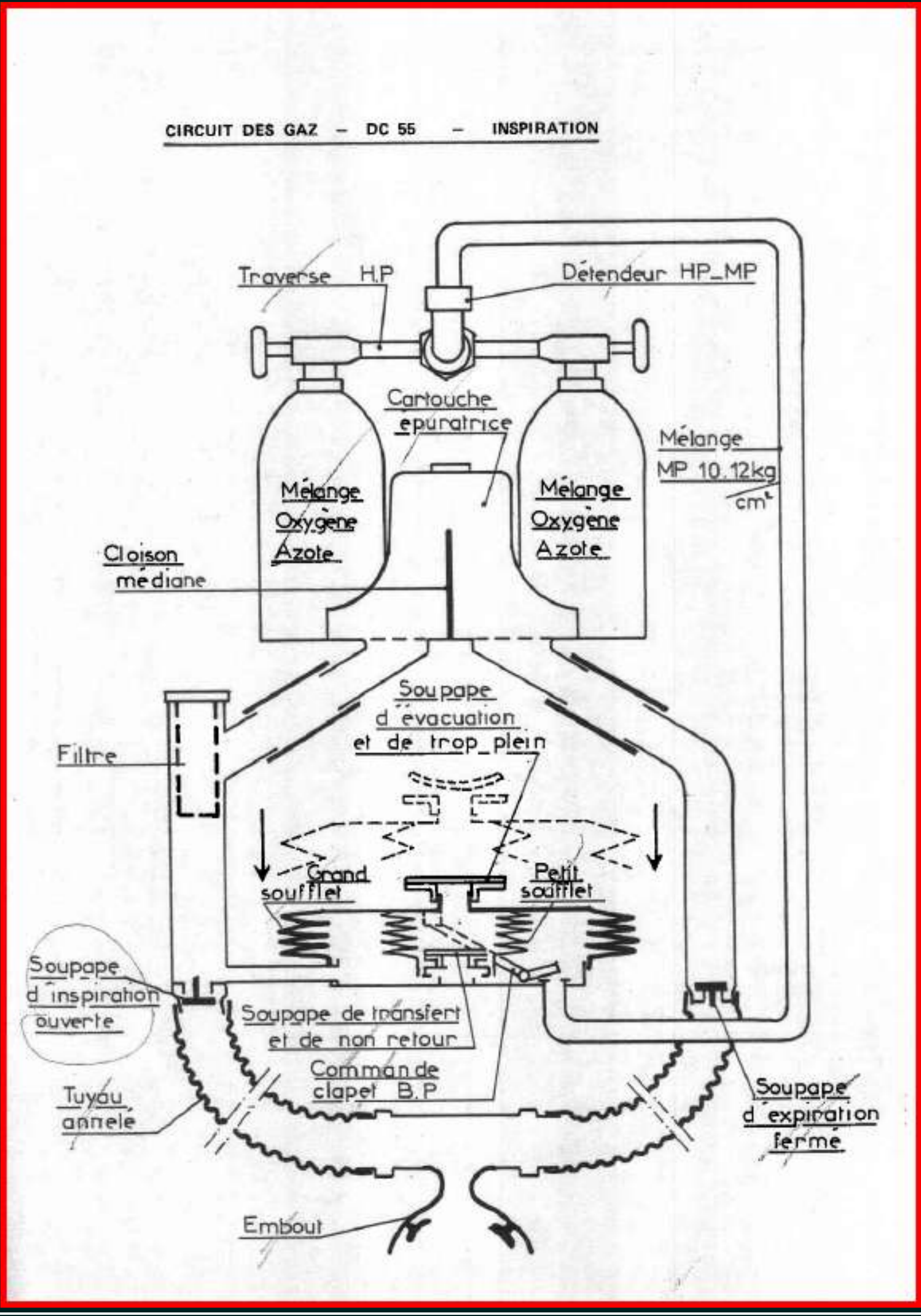
-hand squeeze inhale tube, inhale, no gas should arrive
-on blowing, the bag must inflate.

8/-Complete rig leak test

-open tank
-fill bags
-close mouthpiece and put rig in water including mouthpiece, leaving a finger on controlled leakage / overfill valve orifice
-thoroughly check for bubbles

NOTE: in waiting position the rig has to be flat, breathing bags on the lower side, half filled , tanks closed and mouthpiece in the “TUBA(snorkel)” position




CIRCUIT DES GAZ – DC 55 – INSPIRATION
Traverse H.P
Détendeur HP_MP
Cartouche épuratrice
Mélange MP 10.12kg/cm²
Mélange Oxygène Azote
Mélange Oxygène Azote
Cloison médiane
Soupape d'évacuation et de trop_plein
Filtre
Grand soufflet
Petit soufflet
Soupape d'inspiration ouverte
Soupape de transfert et de non retour
Commande clapet B.P
Tuyau annelé
Soupape d'expiration fermé
Embout

7.- Safety recommendations for DC55 60%

1/- People only allowed to dive DC 55 with 60% mix are:
-combat divers
-demining divers
-habilitated people from GERS and of L'ECOLE DE PLONGEE within duties of these organizations.

2/-a numbered plate is in the transport box of each apparatus holding record of usage duration between each scrubber refill.
3/- sodalime must conform to GERS specification must be changed after 4 h of continuous diving, duration reduced by safety to 3h in case of successive dives. Short duration dives allow higher efforts and following higher CO2 production

4/- planned duration for a dive must not exceed remaining sodalime usage time.
A wet sodalime must be changed.

5/- important safety instructions:
-each dive is conducted by a responsible diving director and checked by a dive controller
-at peace time, surface supervision is made by a small boat
-a specialized nurse must be present and ready .

-a fast transport must be available to bring victim to a specialized doctor with reanimating equipment, as near as possible from diving site.

-except if impossible (towed diver)
divers are sent by a 2 buddy's team attached together by a safety rope of a length appropriated to working conditions
PA buoy (bcd) is mandatory
Diving apparatus is tightly strapped to avoid breathing resistance leading to breathlessness.

-Rigging:

-a surface:
-wear the PA buoy (bcd)
-wear depth meter compass and knife
-wear rebreather
-take place on the scale
-attach yourself
-put mask on
-connect yourself

-open right tank (left is the reserve)
-breath normally

-b underwater
- using depth of DC55 60% is surface to 25m. any duration no deco stops .

check correct function of the leakage valve of your buddy since you are in water
check your own rig (little noise at the end of inspiration)

do not blow by the nose
-this way, you will vary the gas mix effectively breathed
-frequent nose expirations will admit more fresh mix in the bag leading you to breath a mix close to the one in the tank, leading to possible hyperoxia.
In case of breathlessness:
Cease all activity
Lay on side, the bag will be at the same hydrostatic pressure that your lungs, you will then breathe easily.

Equilibrating tanks
During diving, when breathing becomes difficult, open left tank to equilibrate pressures. You will hear gas running. Leave it open for 1 minute and close again, left tank will serve for future equilibrating.

NOTE if there is no leakage (stuck leakage valve, stuck non return valve, leaking small bag…) blow by the nose and come up , you will then breathe in open circuit the mix in the tank , avoiding anoxia. Make surface and breathe air.

Back to surface:
Close mouthpiece
Close tank
In the case of unwanted surfacing, never forget to close mouthpiece before "unplugging"
Do the same when a sick diver has to surface. If he is unable to do the maneuver, his buddy will do it for him.
In any case , avoid water coming in the apparatus via mouthpiece.

8.- current maintenance

- rinse apparatus tanks in place, closed mouthpiece
- remove tanks and check pressure
- remove scrubber door to check sodalime
- if wet, remove it.
- If necessary, rinse scrubber, on upright position
- Let it dry and refill

- Change sodalime if the duration limit is reached
- Remove breathing hoses and rinse mouthpiece/ hoses.
- Do not rinse inside of hoses with water jet, you might jam flapper valves.
- Let it dry away from the sun which will degrade rubber.
- Re assemble after having cleaned and silicon greased O rings

2/- periodically

-remove big bag upper flange
-wipe inside and let dry
-check inhale and exhale rubber tubing and collars
-remove inspiration filter and rinse

Important: no grease nor oil should be used with this apparatus, use only silicon grease

9.- periodical controls

-a logbook holds trace of functioning incidents, checks and repairs of each apparatus.

-authorized dismantling are only breathing hoses, flapper valves, filter, tanks and eventually HP regulator, other works are for the specialized workshop of each unit.

-non return valve has to be changed each 6 month.

-monthly, each unit in service is checked by commandment of unit.

-repairs are asked to AF following an order to repair work is done by the builder or the military workshop of the fleet.

M type additional injector

1.- description

additional injector is inserted between a MP connection and the inhale tubing
no tools needed since it uses O ring fittings.
Composed of an hydrostatic valve admitting automatically supplemental gas mix and a flow regulator giving desired flow.

2.- hydrostatic valve

a poppet is closing input nozzle
the poppet rod is connected by piston and spring to the hydrostatic membrane.
The calibrated spring determine opening and closing depth of the hydrostatic valve .
Adjustment is made by turning up left or right input nozzle.

3.- Flow regulator

MP gas mix cross hydrostatic valve, a spiral small diameter tube, regulating flow by lamination and comes to inspiration circuit.
Flow adjustment is made at assembling.

4.- hydrostatic valve adjustment

- slowly increase regulator output pressure till obtaining flow stop on the flow meter.
- closing pressure read on regulator indicator must be between 1.5 and 1.8 bar (relative pressure)
- from 2.5bar, decrease hydrostatic pressure to obtain a constant flow on flow indicator.
- opening pressure read on regulator indicator must be between 1.8 and 1.5 bar (relative)

5.- flow regulator adjustment

- close completely regulator to operate at atmospheric pressure
check MP pressure on the 50bar indicator, must be 12bar (between 10 and 14 bar)

6.- changing injector adjustments:

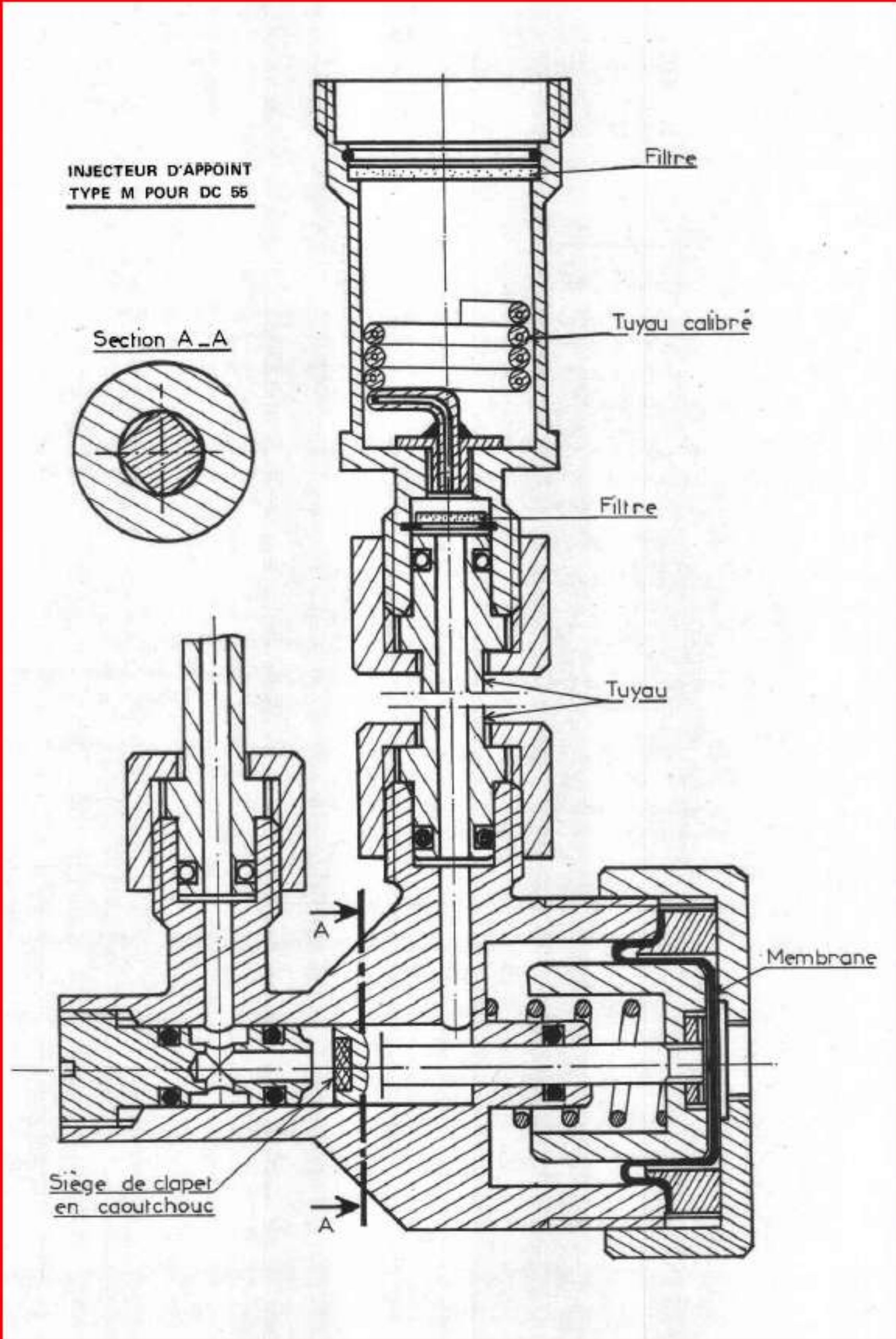
test bench is as indicated in § 2.

7.- hydrostatic valve

the calibrated spring determine closing and opening depth, adjustment ins made by rotating input nozzle

8.- flow

adjustment made at assembly.



INJECTEUR D'APPOINT
TYPE M POUR DC 55
Section A_A
Filtre
Tuyau calibré
Filtre
Tuyau
A
Membrane
Siège de clapet
en caoutchouc
A

injector adjustment - test bench

1.- test bench

parts:

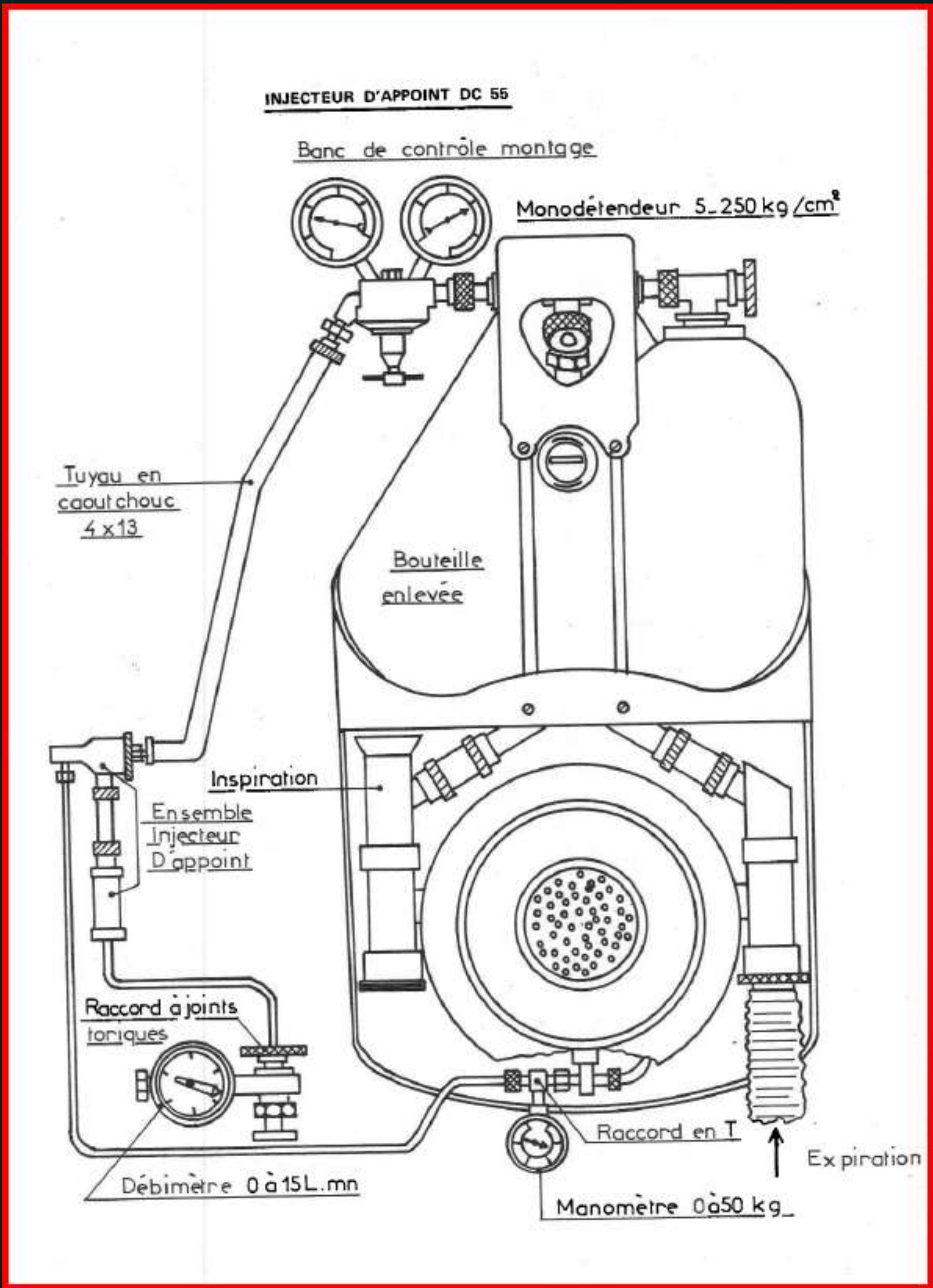
- 5 - 250 bar regulator with HP and LP indicators connected to DC 55 HP bridge (regulator replacing one of the tanks)
- a brass cap closing one injector end.
- A LP rubber tube from regulator to hydrostatic pressure input of the hydrostatic valve.
- A 0/16 liter / min flow indicator on the other end of injector.
- A 50 bar indicator on a T fitting inserted on gas tubing from LP poppet valve of DC 55 to injector

2.- test bench assembly

- test bench is mounted on a DC55 on which a tank is removed
- regulator is rigidly fixed on HP bridge.
- injector is rigidly fixed on DC55 by input pipe , as usually , on LP poppet valve but inspiration tube is disconnected.
- flow meter is connected to injector at the place of inspiration tube, the other side is closed by a cap
- the special rubber tube from regulator to pressure input of hydrostatic valve.

3.- injector set point checking

- test bench as point 2.-, open tank which must hold more than 100 bar , preferably 40 mix.


INJECTEUR D'APPOINT DC 55
Banc de contrôle montage
Monodétendeur 5_250 kg/cm²
Tuyau en caoutchouc 4 x 13
Bouteille enlevée
Inspiration
Ensemble Injecteur D'appoint
Raccord à joints toriques
Débimètre 0 à 15L.mn
Raccord en T
Expiration
Manomètre 0à50 kg_

safety recommendation for DC 55 fitted with additional injector

1.- at surface

- use snorkel . breathing on rebreather before diving will shorten considerably duration. (injector continuous flow)
-

2.- on descent

- be sure that injector is flowing : put inspiration hose on your ear, flow must be heard.

If not, breath in open circuit, blowing through the nose and make surface.
Use immediately snorkel (anoxia)

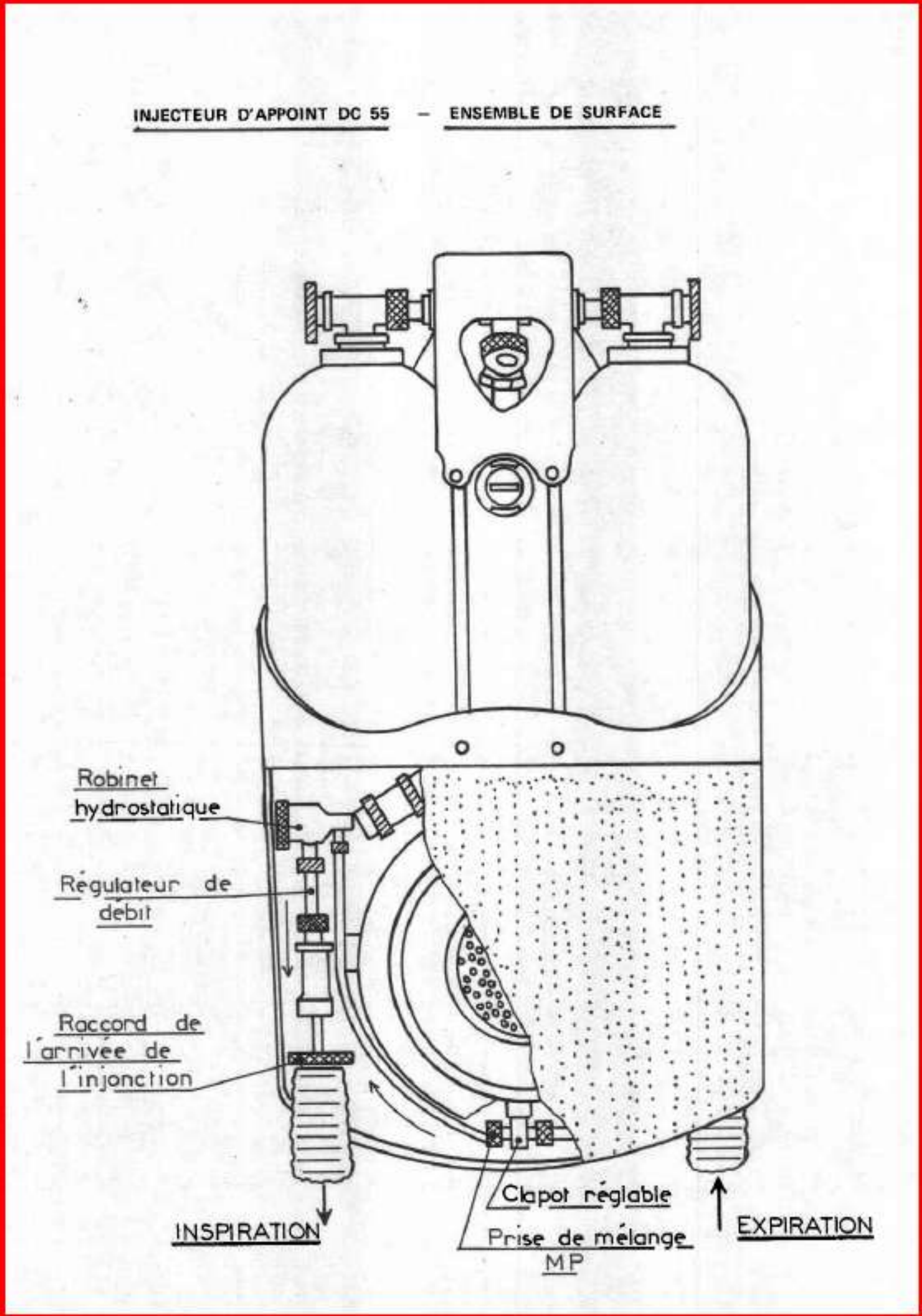
- ensure injector has stopped below 18m
if still flowing, make surface (hyperoxia)

3.- on ascent

ensure injector is flowing over 15m. if not , make open circuit by expiring by the nose.
If necessary make deco stops at surface use snorkel immediately.

4.- DC 55 fitted with injector transportation

never transport DC 55 fitted with injector with 2 tanks in place! If an accidental tank opening happens, it will flow through injector without noticing , making risk of diving with an empty reserve tank.


INJECTEUR D'APPOINT DC 55 – ENSEMBLE DE SURFACE
Robinet hydrostatique
Régulateur de debit
Raccord de l'arrivée de l'injonction
INSPIRATION
Clapot réglable
Prise de mélange MP
EXPIRATION

DC 55 nitrogen equilibrium rate

It is about knowing how nitrogen rate is changing while diver is breathing on apparatus

1.- simplest conditions, let's suppose:
-constant ambient pressure
-constant work and regular breathing
meaning oxygen used on each breath , breathing amplitude and duration of breathing cycle constant.

At the beginning lungs and countelungs might be full or empty.
We make no supposition on this.

- let's call breathing loop the lungs, big bag, and dead space of apparatus (small bag not included)
- let's consider the moment when at the end of an inspiration bags are completely empty and call b0 the nitrogen rate in the breathing loop at the end of the next expiration E0
- one can admit that at that moment the upper flange will operate LP poppet valve which will open to give a certain amount of mix from the tanks through HP-MP regulator
- let's call :

b1 nitrogen rate in the breathing loop at the end of E1 expiration following E0
b2 " " " E2 " " E1
b3 " " " E3 " " E2

bn " " " En " "
En-1

where

a : nitrogen rate in tank
V : inspirited mix volume
V': expired mix volume
S : annular volume between big bag and small bag at the end of each inspiration
F : the volume entering the small bag at the end of each expiration
A: the volume coming from tank at each inspiration
M : the dead volume of the breathing loop
(apparatus dead space + lung dead space)
D : metabolized Oxygen on each respiration
C : consumption coefficient at P pressure , defining metabolized volume of oxygen for a volume of inspired mix.
P : absolute pressure

NOTE:
- following beginning hypothesis all these quantities are constant.
- all volumes measured here are at P pressure.

- volumes V, V', S, F, A, and D are linked by the following relationships:

V = S +A
V' = S + F
D = V – V'
S/F = K (volumetric ratio big bag / small bag)
C = D/V

- at the end of inspiration I1:
- the nitrogen volume in the breathing loop will be : (S+M) b0 + Aa
- the mix volume will be V + M
- the nitrogen rate will be :

$$\frac{(S + M)\, b_0 + A_a}{V + M}$$

We will neglect nitrogen dissolved in organism.

- at the end of E1 inspiration :
- - nitrogen volume in the small bag and breathing loop will be: (S + M)b0 + Aa

- mix volume will be : V' + M

- nitrogen rate will then be :

$$b_1 = \frac{(S + M)\, b_0 + A_a}{V' + M}$$

$$b_1 = \frac{S + M}{V' + M}\, b_0 + \frac{A_a}{V' + M} = \lambda b_0 + \mu \quad \text{où } \lambda \text{ et } \mu \text{ sont des constantes}$$

- as well, we will have:

$$b_2 = \lambda b_1 + \mu = \lambda(\lambda b_0 + \mu) + \mu = \lambda^2 b_0 + \mu(\lambda + 1)$$

$$b_3 = \lambda b_2 + \mu = \qquad = \lambda^3 b_0 + \mu(\lambda^2 + \lambda + 1)$$

$$b_n = \lambda b_{n-1} + \mu = \qquad = \lambda^n b_0 + \mu(\lambda^{n-1} + \lambda^{n-2} + \ldots + \lambda + 1)$$

$$\Delta = \lambda^{n-1} + \lambda^{n-2} + \ldots + \lambda + 1$$

$$\Delta\lambda = \lambda^n + \lambda^{n-1} + \lambda^{n-2} + \ldots + \lambda^2 + \lambda$$

$$\Delta\lambda - \Delta = \lambda^n - 1$$

et : $S = \frac{KV'}{K+1}$ d'où $F = \frac{V'}{K+1}$

Or : $V' = V - D = V - \frac{C_0}{P} V = \frac{V(P - C_0)}{P}$

D'où : $F = \frac{V}{K+1} \frac{P - C_0}{P}$

et : $A = \frac{C_0}{P} V + \frac{V}{K+1} \frac{P - C_0}{P} = \frac{C_0 V (K+1) + V(P - C_0)}{P(K+1)}$

$$\lambda = \frac{C_0 V K + C_0 V + PV - C_0 V}{P(K+1)} = \frac{PV + C_0 V K}{P(K+1)}$$

$$A = V \frac{P + KC_0}{P(K+1)}$$

D'où : $b = a \frac{A}{F} = a \frac{V \frac{P + KC_0}{P(K+1)}}{\frac{V}{K+1}\left(\frac{P - C_0}{P}\right)} = a \frac{P + KC_0}{P - C_0}$

$$\boxed{b = a \frac{P + KC_0}{P - C_0}}$$

2.- b variations as a function of pressure
a and K are constants . let's continue to suppose diver work constant and perfectly regular breathing (constant C0)
we see that b is an homographic decreasing function of P.

the shape of the curve depends obviously of a and C0 parameters

-b variation following quick descents and ascents:
We saw that equilibrium rates we defined as the limit of bn will only be reached after a certain number of breathings.
Let's suppose equilibrium rate b is reached at any P1 pressure , the diver descents instantly and is at a new P2 pressure = qP1 (practically a good diver is able to descent at 1m /s bearing large pressure variations in a short time)
Let's call W the total volume of breathing loop.
Initial mass of gas mix which was filling W volume at P1 pressure will fill a volume W' at P2 pressure , as:

$$W P_1 = W' P_2 \quad ; \quad W' = \frac{P_1}{P_2} W = \frac{W}{q}$$

W, the total volume of breathing loop will stay unchanged , the volume at P2 pressure that tank will supply is :

$$W - W' = W - \frac{W}{q} = W\left(1 - \frac{1}{q}\right) = W \frac{q-1}{q}$$

and nitrogen rate will be:

$$b' = \frac{W' b + (W - W') a}{W}$$

$$b' = \frac{\frac{W}{q} b + W \frac{q-1}{q} a}{W} = \frac{b}{q} + \frac{q-1}{q} a$$

$$b' = \frac{b}{q} - \frac{a}{q} + a = \frac{b-a}{q} + a$$

if the diver comes back immediately at P1 pressure, the breathing loop volume will expand and gas in excess will flow through overfill valve keeping W total volume unchanged, b' nitrogen rate itself unchanged

a second descent at P2 pressure will raise nitrogen rate to the value:

$$b'' = \frac{W'b' + (W - W')a}{W}$$

$$b'' = \frac{\frac{W}{q}\left(\frac{b-a}{q} + a\right) + W\frac{q-1}{q}a}{W} = \frac{b-a}{q^2} + \frac{a}{q} - \frac{a}{q} + a$$

$$b'' = \frac{b-a}{q^2} + a$$

and so on till n descent where nitrogen rate will be :

$$b^{(n)} = \frac{b-a}{q^n} + a$$

Lorsque $n \to \infty$, $q^n \to \infty$, $\frac{b-a}{q^n} \to 0$, donc $b^{(n)} \to a$

obviously this is theoretical but practically the diver is breathing continually during descents and ascents, nitrogen rate always tends to equilibrium rate.

3.- b variations as a function of work.

We know that oxygen usage increases with work.
Following individual differences, extreme generally admitted values are:

- at rest : D = 400 cm³ / min] at atmospheric
- intense work : D = 4000 cm³/min] pressure

since breathing increase also with work, consumption coefficient , since not rigorously constant, is not varying too much.

It was determined for a certain number of subjects, at rest and giving an amount of work comparable to a diver

Following individual variations, it vary from 0.035 to 0.055

In the equilibrium rate formula, we see ,for a determined P pressure, b varying with C0 and always in the same direction as this.

<u>4.- b variations following irregular breathing</u>

till now, we were assuming V breathing amplitude rigorously constant.
for a given work, breathing amplitude is around a mean value and irregularities low.
Anyway observing a deep breath following regular breath is not rare.

Let's call V + delta V the volume of this inspiration (delta V is maximum variation regarding mean value)

If mean nitrogen rate was :

$$b = \frac{P + KC_0}{P - C_0} a$$

since volume delta V is coming from tanks nitrogen rate has become :

$$b' = \frac{(V + M) b + \Delta V a}{V + M + \Delta V}$$

after this sudden variation if P pressure the rate will also tend to the initial value. Short term variations are without any physiological consequences.

<u>5.- b variations following nitrogen dissolution in organism during diving or elimination of nitrogen during ascent.</u>

In the case of semi closed rebreather, these variations are neglectable since:

- nitrogen partial pressure is only slightly increasing as a function of depth.
- nitrogen rate in the bag tends to take rapidly the equilibrium rate.

<u>6.- conditions to keep b within acceptable limits</u>

we saw that b had to be always within :

$$100 - \frac{17}{P} \text{ (ANOXIE)} \Rightarrow b \leqslant 100 - \frac{17}{P}$$

$$100 - \frac{200}{P} \text{ (HYPEROXIE)} \Rightarrow b \geqslant 100 - \frac{200}{P}$$

but for a given P pressure , b will vary in the same way as C0.
Then it is sufficient to use for C0 its maximum value in the fires inequality ant its minimum value in the second one to be in the safe area.

$$a \frac{P + 0{,}055\ K}{P - 0{,}055} \leqslant 100 - \frac{17}{P}$$

$$a \frac{P + 0{,}035\ K}{P - 0{,}035} \geqslant 100 - \frac{200}{P}$$

7.- K influence

K is the characteristic of the apparatus.

- discretion: since F leakage is in reverse proportion of K, discretion will be as better as K is bigger.
-
- Duration: duration will be as longer as the leakage is smaller. (as K is bigger)
-
- Vertical range: neglecting b, C0 value at denominator vertical range is equal to P2-P1 with:

$$a \frac{P_2 + 0{,}035\ K}{P_2} = 100 - \frac{200}{P_2}$$

$$a \frac{P_1 + 0{,}055\ K}{P_1} = 100 - \frac{17}{P_1}$$

Soit : $a P_2 + 0{,}035\ Ka = 100\ P_2 - 200 \quad \text{et} \quad P_2 = \frac{200 + 0{,}035\ Ka}{100 - a}$

$a P_1 + 0{,}055\ Ka = 100\ P_1 - 17 \quad \text{et} \quad P_1 = \frac{17 + 0{,}055\ Ka}{100 - a}$

D'où : $P_2 - P_1 = \frac{183 - 0{,}015\ Ka}{100 - a}$

And we see that vertical range will be bigger as well as K will be smaller.

- equilibrium rate settling time

we established the relationship

$$b - b_n = \lambda^{12} (b - b_0)$$

for a same value of b0, the equilibrium rate will be reached as faster as

$$\lambda = \frac{S + M}{V' + M}$$

will be smaller and lambda will be as smaller as S/V will be smaller:

but :

$$K = \frac{S}{F} = \frac{S}{V' - S} \; ; \; KV' - KS = S \; ;$$

$$S(K + 1) = KV' \quad \text{et} \quad \frac{S}{V'} = \frac{K}{K + 1}$$

so, S/V' will be as smaller as K will be smaller.
And equilibrium rate will be as smaller as K is smaller.

K has to be once as big as possible and one as small as possible. An intermediate value of 12.7 has been chosen.

8.- influence of a:

- vertical range :

we established

$$P_2 - P_1 = \frac{183 - 0{,}015\,Ka}{100 - a}$$

the vertical range will be as greater as a is big.

- accidental variations of b

we established b' nitrogen rate at the end of an accidentally too deep was:

$$b' = \frac{(V + M)\,b + \Delta Va}{V + M + \Delta V}$$

$$\text{D'où :} \quad b' - b = \frac{(V + M)\,b + \Delta Va - (V + M)\,b - \Delta Vb}{V + M + \Delta V} = \frac{\Delta Va - \Delta Vb}{V + M + \Delta V}$$

$$b' - b = \frac{\Delta V}{V + M + \Delta V}(a - b) = \frac{\Delta V}{V + M + \Delta V}\,a\left(1 - \frac{P + KC_0}{P - C_0}\right)$$

and accidental variations of nitrogen rate following irregular breathing will be as bigger as a is bigger.

9.- dead space influence.

Influence of M dead space has important effects on apparatus function.

- Duration and discretion: on quick ascents the volume of gas mix evacuated by the overfill valve will be as greater as the total apparatus volume is bigger.
It is then advisable for duration and discretion that M will be as small as possible.

- equilibrium rate settling time :

we saw that equilibrium rate is reached as faster as $\frac{S + M}{V' + M}$ is smaller
So, M has to be as small as possible.

- Accidental variations of b:

We established :

$$b' - b = \frac{\Delta V}{V + \Delta V + M}(a - b)$$

b' – b will be as low as M is high; Vn large dead space has a stabilizing influence.
10.- ALL CONCLUSIONS OF THIS THEORETICAL STUDY HAVE BEEN EXPERIMENTALLY CONFIRMED

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40 and 30% gas mixes usage with DC55

For 40 and 30% gas mix usage the DC must be fitted with an accessory named "additional injector"

To fully understand this injector necessity we must study gas mix behavior from the moment they entered breathing bag of the apparatus.

At the moment of immersion, nitrogen of atmospheric air contained in apparatus and in lungs will add to the one in the tanks.

Effectively breathed mix will not have the same O2-N2 percentage as the one in the tanks.

1.- EQUILIBRIUM RATE

1/- to get a stable oxygen rate at each usage depth, it is necessary to make a leakage proportional to effectively breathed volume (work of the small bag)

2/- theoretical study showed that if we call :

a: nitrogen rate in tank

b: equilibrium rate of nitrogen in the mix given by the apparatus and effectively breathed.

P : absolute pressure at usage depth

C0: oxygen consumption coefficient at atmospheric pressure
(rate between volume of metabolized oxygen over breathed mix volume)

K : rate between breathed volume and leakage volume.

We have the relationship :

$$b = a \frac{P + KC_0}{P - C_0}$$

in which K and a are constants

K = volumetric rate big bag over small bag = 12.7

C0 varying slightly from 0.035 to 0.055

3/- equilibrium rate as a function of pressure is represented by a curve which allure depends of a and C0 values.

4/- oxygen partial pressure MUST always be comprised between 0.17 bar and 2 bar, oxygen concentration in the gas mix must always be comprised between:

$$\% O^2 = 0{,}17 / P \quad \text{et} \quad \% O^2 = 0{,}2 / P$$

$$(Pp = P\ abs \times \%)$$

and diluent which is the complement between:

$$\% N^2 = 1 - 0{,}17 / P \quad \text{et} \quad \% N^2 = 1 - 2 / P$$

$$\text{soit :} \quad b = \% N^2 \times 100 = 100 - 17 / P$$

$$\text{et :} \quad b = \% N^2 \times 100 = 100 - 200 / P$$

5/- b value will have to be comprised between the two curves (anoxia and hyperoxia) corresponding to following functions.

<u>2.- injector necessity.</u>

1/- now , we know that effectively breathed mix is not the one in the tanks, lets use the case of a diver breathing a 40% mix at 40 meters.

<u>-Effectively breathed mix will be :</u>

$$b = a \frac{P + K C_0}{P - C_0} \quad ; \text{ prenons } C_0 = 0{,}050$$

$$\text{soit} \quad b = 60 \frac{5 + (12{,}7 \times 0{,}050)}{5 - 0{,}050}$$

$$b = 68 \% N^2 \quad \text{soit} \quad 32 \% O^2$$

O2 partial pressure will be :

$$Pp = P\ abs \times \%$$

$$\text{soit} \quad Pp = 5 \times 0{,}32 = 1{,}6\ kg/cm^2$$

this pressure is correct.

2/- let's take now the case of the same diver breathing the same mix at 3 meters.

- effectively breathed mix will be:

$$b = a \frac{P + K C_0}{P - C_0}$$

$$b = 60 \frac{1{,}3 + (12{,}7 \times 0{,}050)}{1{,}3 - 0{,}050}$$

$$b = 92\ \%\ N^2 \quad \text{soit} \quad 8\ \%\ O^2$$

- oxygen pressure will be :
-

$$Pp = P\ abs \times \%$$

$$Pp = 1{,}3 \times 0{,}08 = 0{,}104\ kg/cm^2$$

We remark that Pp O2 is badly below lower limit which is 0.17 bar (HYPOXIA)

3/- calculations show that with 40% and 30% mixes O2 partial pressure between 15m and surface is too low to sustain life.

4/- for those gas mixes, we must add an accessory which will add necessary oxygen . this accessory is the additional injector

supplemental injector brings directly tank mix and sends it in the breathing tube.

3/.- Diving with 40% mix.

1/- maximum depth:

40% mix shall only be used with DC55 fitted with injector.
It is usable from surface to 45m.

Each time depth is not greater than 25m 60% mix will be preferred.

2/- duration

data regarding scrubber duration for 60% mix are still applicable here.

a/- search dive

a search dive is limited to duration without deco stops.
Durations will vary with depth, you find here duration for these conditions of a DC55 (new sodalime, 2 tanks at 150 bar) and C coefficient for successive dives (marine nationale decompression tables)

Depth zone	Maximum duration without deco stops	C coef.	duration
25 to 30m	40 minutes	1.6	2 dives of 40 min
30 to 35m	35 minutes	1.5	2 dives of 35 min
35 to 40m	25 minutes	1.4	3 dives of 25 min
40 to 45 m	20 minutes	1.4	4 dives of 20 min

NOTE ascent speed must NOT be greater than 20m / minute.

b/- static dives – decompression

when dive occurs on a precise location on the bottom, materialized at surface by a buoy or the diving boat, one can afford longer work duration requiring deco stops.

Descent and ascent must be done along the cable from surface to bottom immediately near workplace.

Before entering water make pressure equalizing in both tanks
Whatever what was decided in surface before, it is mandatory to come up to surface opening left tank when right one is empty

Each mix needs a specific table, but a standard air table is usable by introducing equivalent air depth notion.

In fact, a gas mix containing X% of nitrogen breathed at a real P meters depth, regarding PpN2, behaves like air (79% N2) breathed at a fictions P' depth.

Partial pressure equality is:

$$(P + 10)\,x = (P' + 10)\,0.79$$

This formula gives "equivalent air depth"

P	:	real depth in meters
X	:	N2 percentage of effectively breathed mix
P'	:	"equivalent air depth"
0.79	:	nitrogen concentration in air.

Ascent must be done following decompression tables up to 40m from the air diving manual.

Enter the table with "equivalent air depth"

Ascent speed must not be greater than 20m /min

Effective depth with DC55 at 40%	"Equivalent air depth"
30 m	26 m
35 m	30 m
40 m	34 m
45 m	38 m

Any interpolation is forbidden . if the effective depth is not in this table, one must either make "equivalent air depth calculation or using the greater available depth .

3/- Safety recommendations

the only ones authorized to use DC55 with 40% mix are qualified de mining divers, authorized persons from GERS and l'ecole de plongee.

A decompression chamber must be reachable in the best delay.

During static dives 2 men team are linked by a safety rope.

For search dives , one can derogate to the rule if one of these:

- marked diver with a surface buoy.
- Diver linked to support by a line
- Diver linked to an other diver by "search line"

4.-diving with 30% mix (32.5% O2)

1/- maximum depth

30 mix is used with DC 55 for static dives at depth from 45 to 55m

it offers safety from surface to 45m but low oxygen percentage leads to deco stops fairly longer than 40mix.

2/- duration

since tiredness following deep dives and importance of perfect elimination of CO_2:

- maximum duration of dive is limited to 30min

- sodalime must be replaced each 2 hours.

3/- setting up

diving with DC55 using 30% mix is reserved to strictly determined conditions and selected and trained persons.

DC55 must be fitted with supplemental injector

Apparatus is fitted with:
- one tank of 30% mix at 150 bar (right side)
- one tank of pure oxygen at 150 bar (left side)

remark:
right tank is the right hand one when apparatus is on the diver's back.

A molded rubber valve protector is placed on oxygen tank valve to protect it from accidental or unwanted opening.

a/- tanks must never communicate together

when entering water diver opens right tank (M30) and breath normally in apparatus and descends along rope down to working place.

On ascent, just close right tank(pure O_2), remove valve protector, open left tank and stop at the first 10meter mark on the rope.

"Tank swapping is done without excessive time waste nor hurry between 25 and 20meters"

whatever deco stops are necessary, ascent speed will not be faster than 20m/min and 10meter stop is one minute (oxygen rinsing)

b/-following tables will be used until further notice

Plongée avec mélange à 30 Paliers à l'oxygène pur							
Barème exprimé en minutes							
Profondeur	Durée de la plongée Départ surface Départ fond	BAREME DE LA REMONTEE				Durée totale de la remontée	Coefficient C
		du fond à 10 m.	séjour à 10 m.	séjour à 6 m.	séjour à 3 m.		
45 m.	10	2	1		1	5	1,4
	15	2	1		3	7	1,4
	20	2	1	1	4	9	1,5
	25	2	1	2	9	15	1,7
	30	2	1	4	12	20	1,7
50 m.	10	2	1		1	5	1,4
	15	2	1	1	3	8	1,4
	20	2	1	2	8	14	1,5
	25	2	1	4	12	20	1,7
	30	2	2	7	13	25	1,7
55 m.	10	3	1		1	5	1,4
	15	3	1	2	3	10	1,5
	20	3	1	3	9	17	1,6
	25	3	2	5	12	23	1,7
	30	3	3	9	14	30	1,8

4/- safety recommendations

only allowed to use DC55 with 30 mix are:

- authorized persons of GERS
- authorized persons of "l'ecole de plongee"
- certified demining divers
- demining divers holding " brevet superieur" from regional groups, during own activities of these.

Since ascent procedures are strictly defined, ascent must be done along vertical buoy line from bottom place on which 3m, 6m and 10m are clearly marked.

The only authorized horizontal movement is circular search around bottom buoy weight on which diver will stay linked by a light line.

Except if not possible, divers are sent as a 2 men team linked by a safety rope.

For certain jobs, (for example: mine defusing) one can send single diver who will be in contact with surface by telephone each time it is possible.

Wearing PA is mandatory (bcd)

A decompression chamber must be reachable in the best delays.

5/- diving details

a/- setting up

- checked injector
- sodalime
- tanks at 150 bar (valve protector on left valve)
- general check

b/- equipment

diving suit, bcd, depth meter, compass, watch, safety rope, DC55

c/- entering water

- open right tank to avoid water entering by under pressure
- entering water quietly, do not jump
- attach safety rope
- mouthpiece valve on mix
- adjust watch external indicator

d/- descent

- Along the rope at 20m/min
- Max depth of 55m
- On bottom, adjust buoyancy (BCD)
- do not leave guiding rope

e/- ascent

- along guiding rope at 20m/min
- at 25m close mix tank
- remove valve protector
- at 20m open oxygen tank
- at 10m stop and rinse 2 times
- observe deco stops (see table)
- at surface : mouthpiece valve on “tuba” (snorkel)
- close oxygen valve

f/- mandatory:

- never let tanks communicate together
- keep an eye on buddy
- at the end of the dive used tanks must be emptied
- in the case of blow up, immediate recompression at half relative maximum pressure of the dive.

g/- external equipment

- weighted and marked rope (deco stops)
- guide rope on the bottom
- boat on the water

h/- safety

- physician or nurse
- one Cousteau-Gagnan for spare
- one decompression chamber ready for use

IMPORTANT NOTE:
Tank valves must be fully open to avoid any hesitation about closing direction.

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