

Department of Anesthesia, Intensive Care and Pain Management

Anesthesia Workstation Safety Features

Raafat Abdelazim

Intended Learning Outcomes

By the end of this lecture, the student will be able to understand :

1. *The hazards of the anesthesia workstation (AWS)*
2. *The safety features developed to avoid these hazards*
3. *The anesthesia machine obsolescence*
4. *Preuse checkout*

Anesthesia Machine (AM)

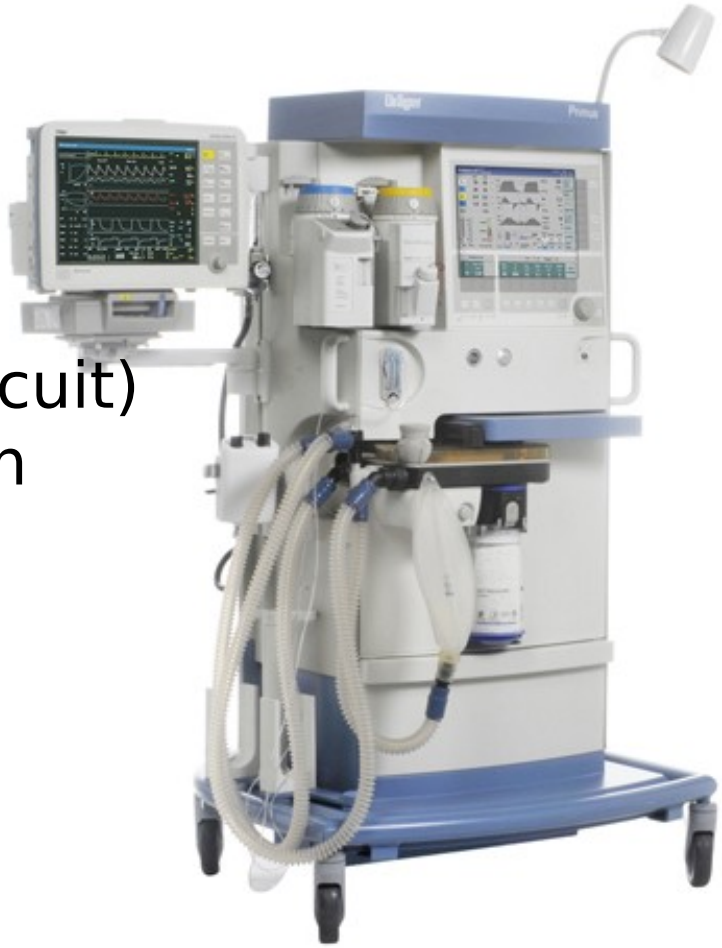


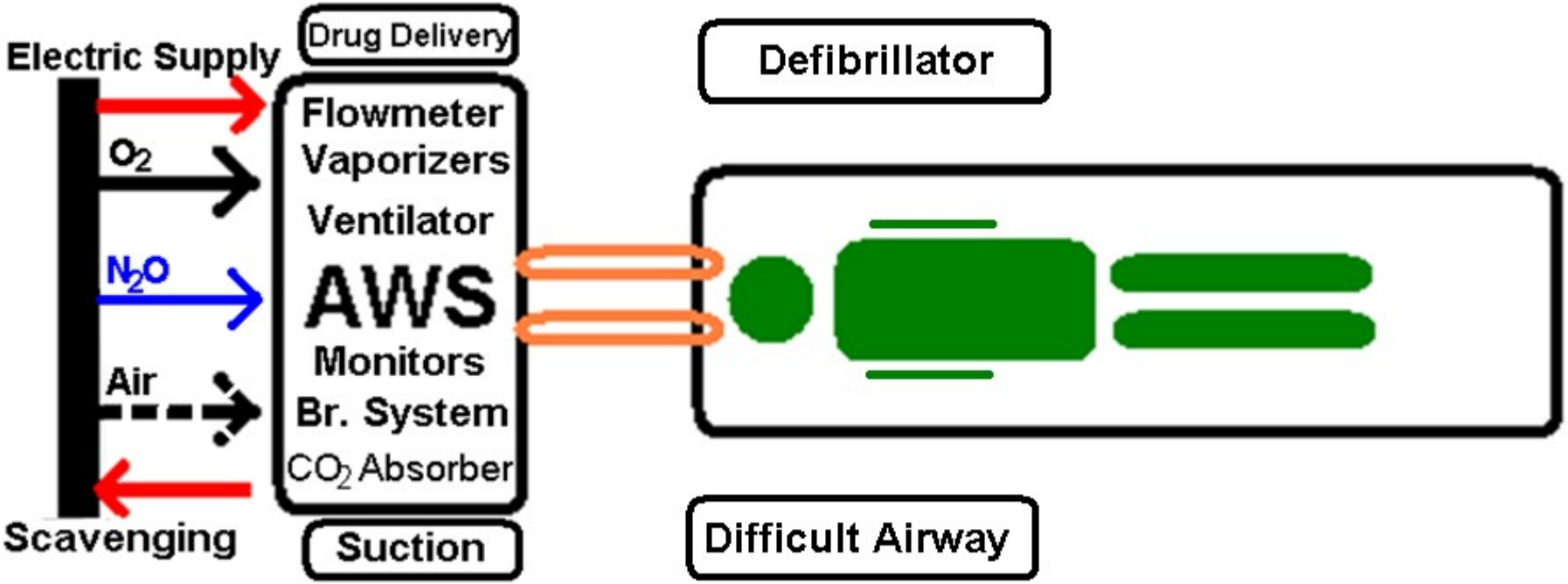
Anesthesia Workstation (AWS)



AWS Components

1. Anesthesia machine
2. Vaporizer(s)
3. Ventilator
4. Breathing system (patient circuit)
5. Waste gas scavenging system
6. Monitoring and alarm system
7. Drug delivery systems
8. Suction equipment
9. Data management system




Electric Supply
Drug Delivery
Defibrillator
Flowmeter
Vaporizers
Ventilator
AWS
Monitors
Br. System
CO_2 Absorber
O_2
N_2O
Air
Scavenging
Suction
Difficult Airway

AWS

- The **traditional** pneumatic anesthesia machine has **evolved** into **a complex electrical, mechanical, and pneumatic** multicomponent workstation.
- AWS **integrates** most of the **components** necessary for administration of anesthesia into **one unit**.
- **Monitoring and control functions** as well as **alarms** can be **integrated,** and **data displayed** on a single or multiple screens.
- **Reduced external connections** should reduce the likelihood of misconnections, disconnections, or kinked connections.
- A certain amount of the **preuse checking** procedure can be performed **automatically**.
- These workstations have **built-in safeguards** in case of machine failure.

System Components

I. Electrical Components
II. Data Communication Ports
III. Pneumatic System

Hazards of the Anesthesia Workstation

Analysis of Critical Incidents and Adverse Outcomes

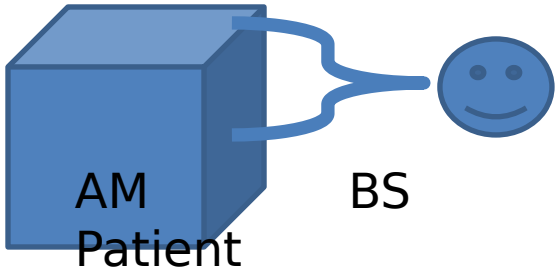
- **Human error** > equipment failure
- **Misuse** > pure failure
- **1ry anesthesia provider** > ancillary staff (technicians, nurses)
- **BS (breathing system)** > vaporizers > ventilators > gas tanks or gas lines > AM itself
- The use or better use of **monitoring** could have prevented an adverse outcome
- Problems are decreasing: 2000-2010 < 1990-2000
- The outcomes are less severe than earlier

Major Causes for Patient Injury from Anesthesia Equipment

- **Insufficient O_2 supply to the brain**
- Insufficient CO_2 removal
- Barotrauma (↑↑Paw)
- Excessive anesthetic concentration
- Foreign matter injuring the airway

How to avoid critical incidents?

1. Monitors and alarms:



2. Detailed education of caregivers and ancillary staff (anesthesia technicians and nurses):
   - safe use of equipment
   - management of hazardous situations
3. Development and adoption of **STANDARDS**
4. Regular service of all equipment
5. Equipment should be updated as necessary

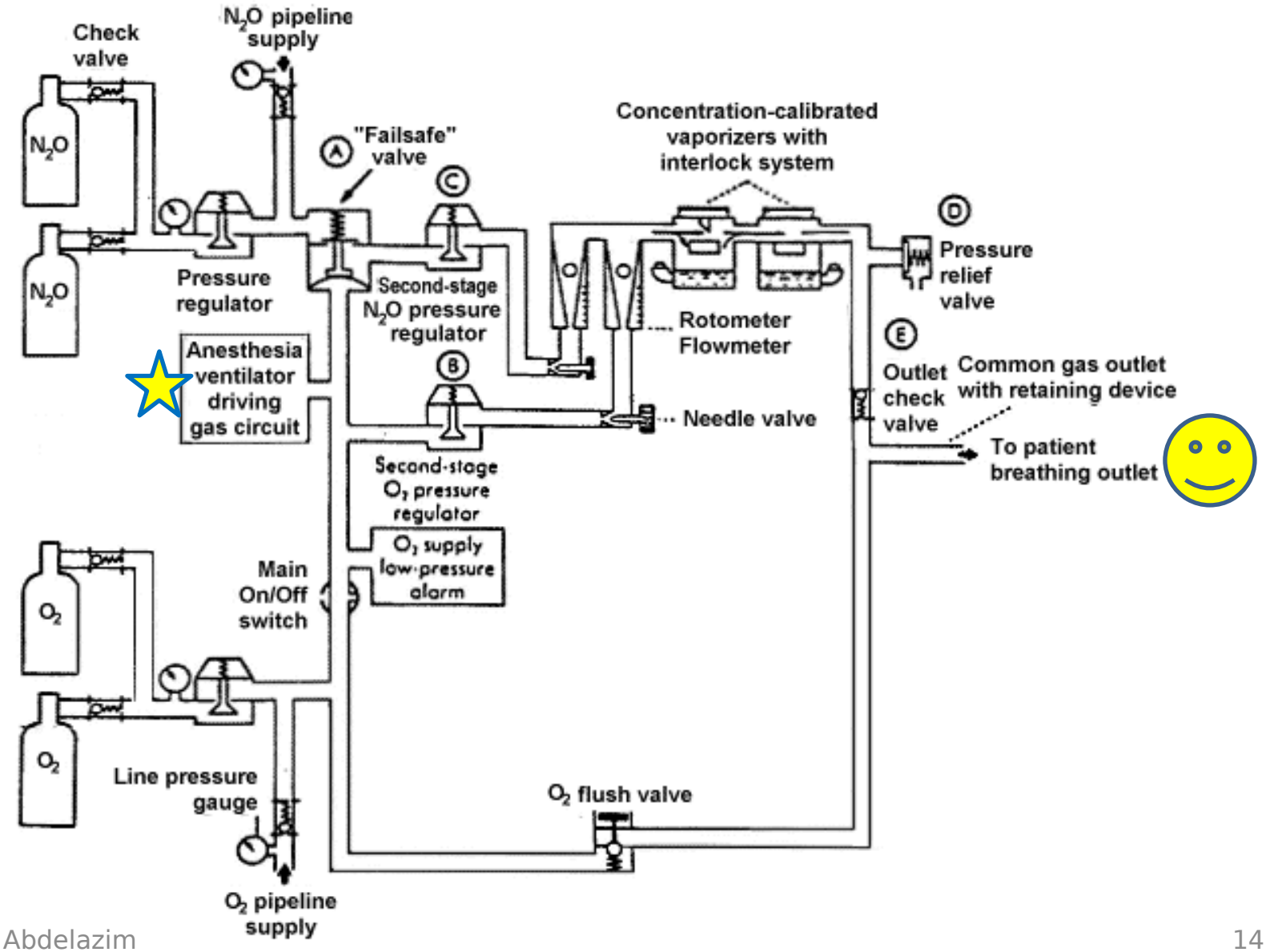
A safety feature is designed

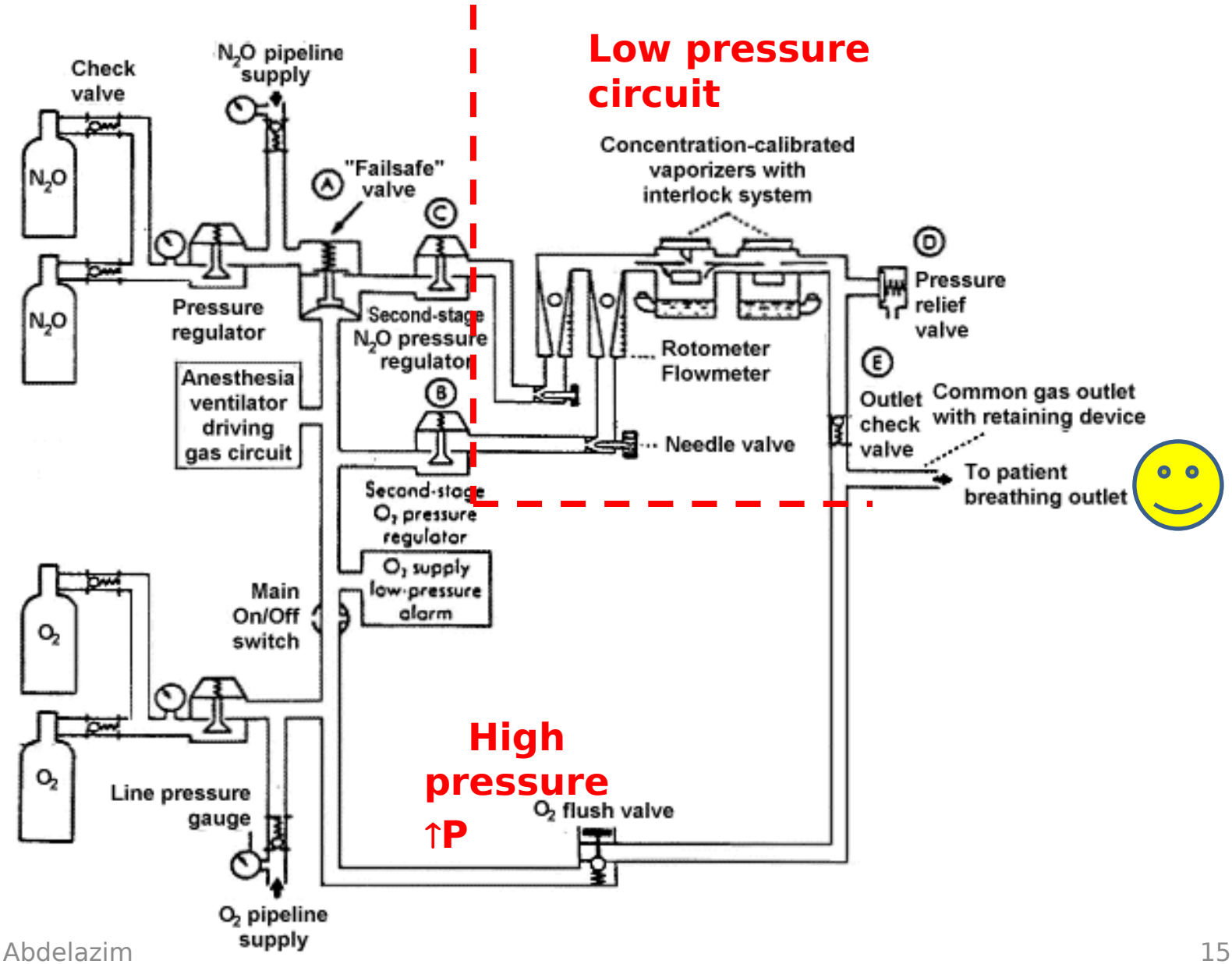
- to **prevent** the occurrence of a mistake
- to **correct** a mistake
- or to **alert** the anesthesia provider to a condition with a high risk.

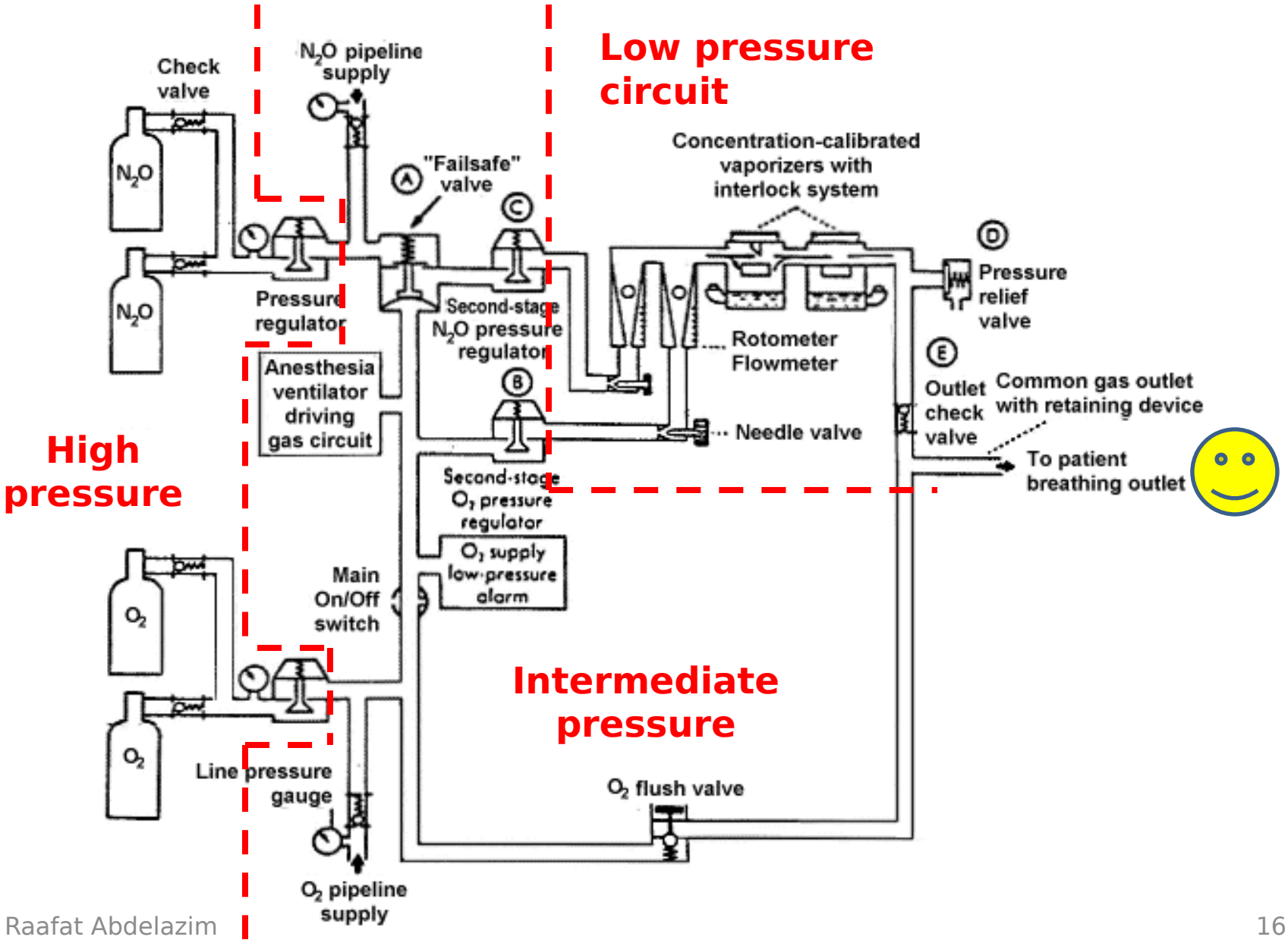
A chronology of the introduction of major safety features for the anesthesia machine

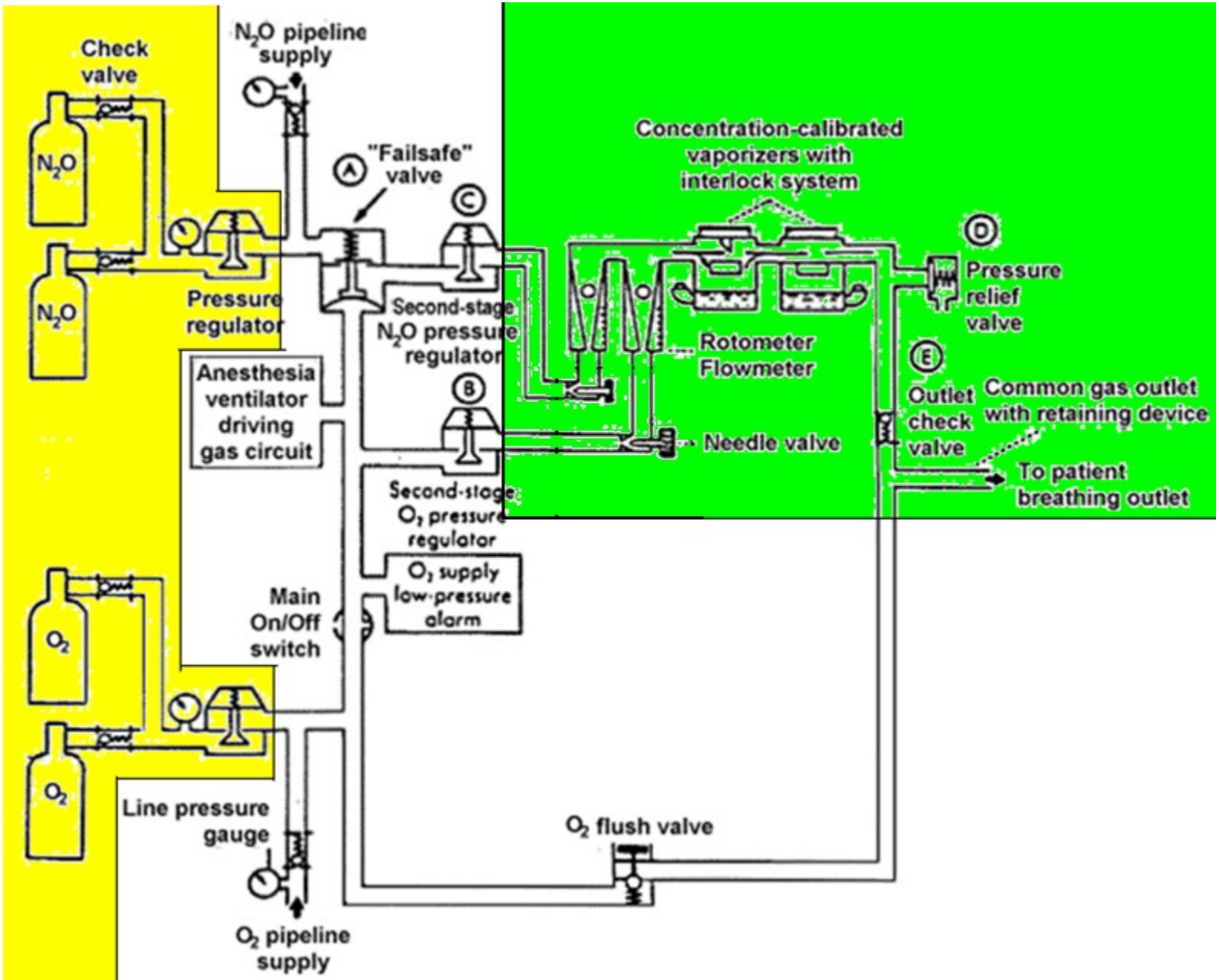
Years	feature
1950–1960	
	Pin index safety system for medical gas cylinders
	Oxygen flush valve delivering >35 L/min
	Temperature and flow compensated vaporizers
	Oxygen supply failure alarm system
	Oxygen failure protection device
	Vaporizer interlock system
1960–1970	
	Ventilator pressure relief system
	Check valve between vaporizer and fresh gas outlet
	Gate-style cylinder yokes
	Ascending-filling ventilator bellows
	Single-agent vaporizers
	Key index safety system for filling vaporizers
1970–1980	
	Ventilator low-pressure disconnect alarm
	Machine-mounted pipeline pressure gauges
	Diameter index safety system
	Minimum oxygen flow
	N_2O/O_2 proportioning device
	Recessed oxygen flush button
	Pin index safety system for flowmeter modules
	Oxygen analyzer
1980–1990	
	Antidisconnect fitting on fresh gas outlet
	Common manifold for breathing circuit components
	Volume disconnect alarm
	Master switch on/off for machine/patient monitors
	Airway pressure monitoring system
	Cable management arm
	Battery backup for power supply

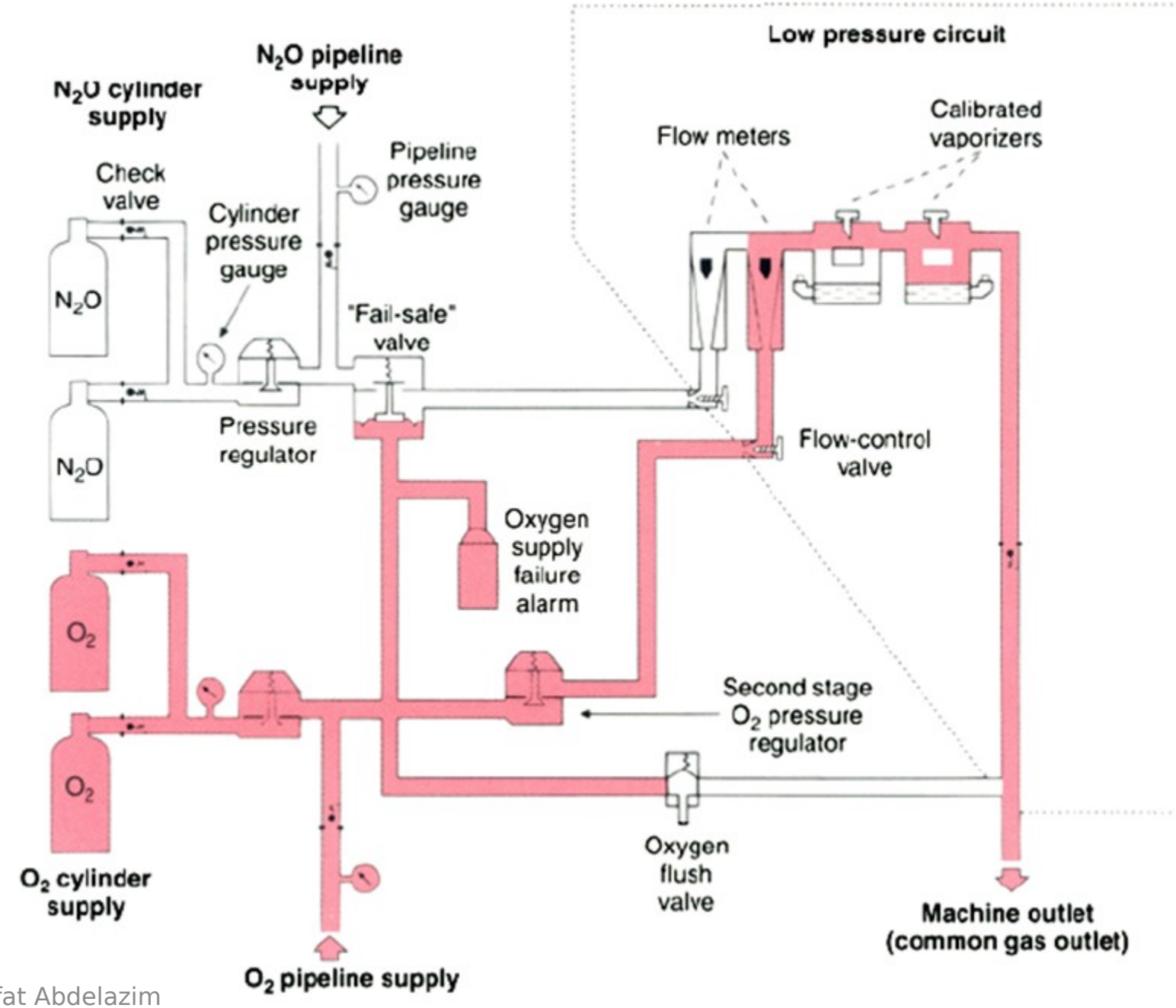
The flow arrangement of a basic two-gas anesthesia machine

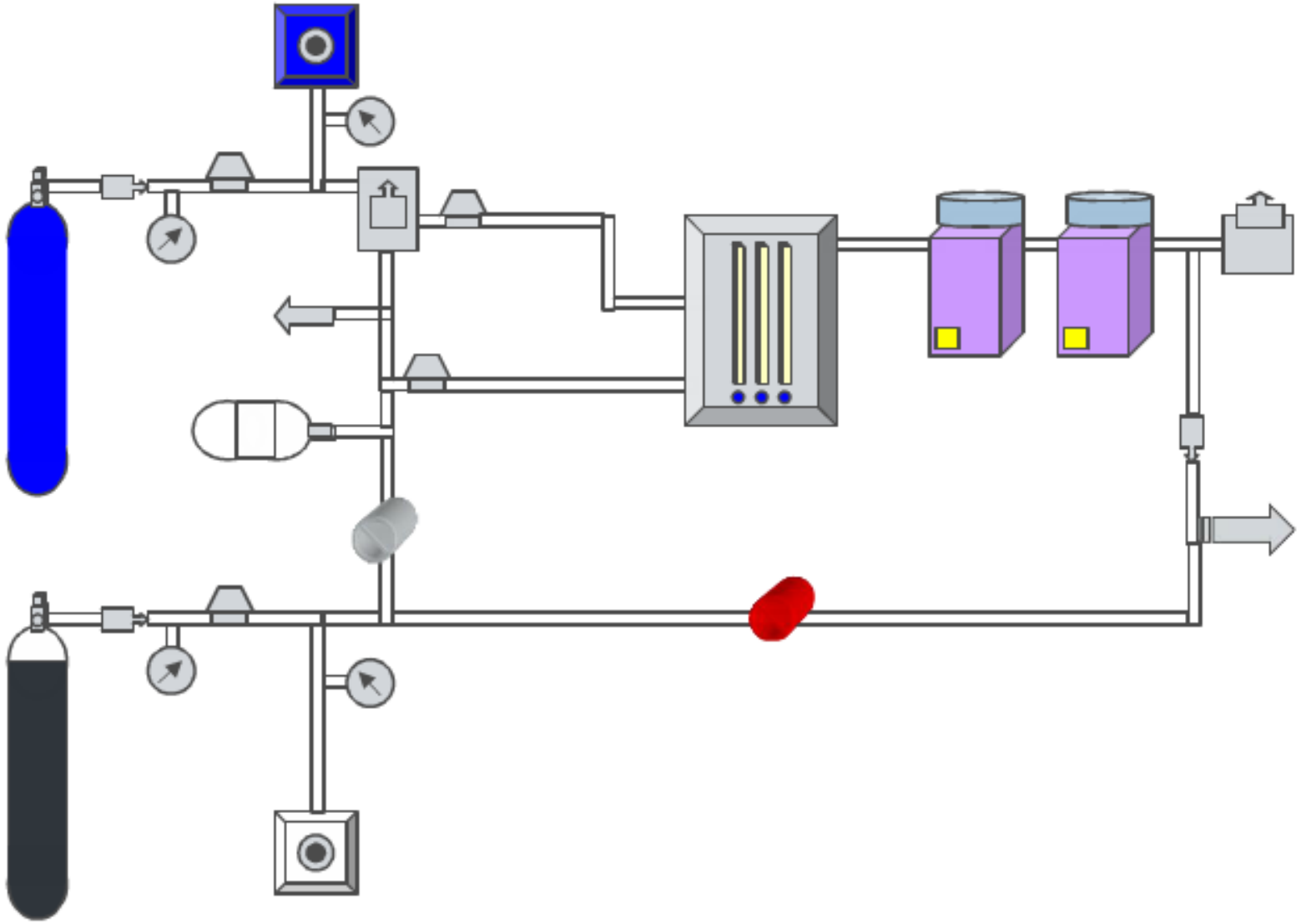



Low pressure circuit
Check valve
N_2O pipeline supply
"Failsafe" valve
Concentration-calibrated vaporizers with interlock system
Pressure relief valve
Pressure regulator
Second-stage N_2O pressure regulator
Rotometer Flowmeter
Anesthesia ventilator driving gas circuit
Needle valve
Outlet check valve
Common gas outlet with retaining device
To patient breathing outlet
Second-stage O_2 pressure regulator
O_2 supply low-pressure alarm
Main On/Off switch
High pressure
↑P
Line pressure gauge
O_2 flush valve
O_2 pipeline supply


Low pressure circuit
Check valve
N_2O pipeline supply
"Failsafe" valve
Concentration-calibrated vaporizers with interlock system
Pressure relief valve
Pressure regulator
Second-stage N_2O pressure regulator
Rotometer Flowmeter
Anesthesia ventilator driving gas circuit
Outlet check valve
Common gas outlet with retaining device
Needle valve
To patient breathing outlet
High pressure
Second-stage O_2 pressure regulator
O_2 supply low-pressure alarm
Main On/Off switch
Intermediate pressure
Line pressure gauge
O_2 flush valve
O_2 pipeline supply


Check valve
N_2O pipeline supply
N_2O
N_2O
"Failsafe" valve
A
C
Concentration-calibrated vaporizers with interlock system
D
Pressure relief valve
Pressure regulator
Second-stage N_2O pressure regulator
Rotometer Flowmeter
E
Outlet check valve
Common gas outlet with retaining device
Anesthesia ventilator driving gas circuit
B
Needle valve
To patient breathing outlet
Second-stage O_2 pressure regulator
O_2 supply low-pressure alarm
Main On/Off switch
O_2
O_2
Line pressure gauge
O_2 flush valve
O_2 pipeline supply


Low pressure circuit
N_2O pipeline supply
N_2O cylinder supply
Flow meters
Calibrated vaporizers
Pipeline pressure gauge
Check valve
Cylinder pressure gauge
N_2O
"Fail-safe" valve
N_2O
Pressure regulator
Flow-control valve
Oxygen supply failure alarm
O_2
Second stage O_2 pressure regulator
O_2
Oxygen flush valve
O_2 cylinder supply
Machine outlet (common gas outlet)
O_2 pipeline supply



Insufficient O_2 supply to the brain

- Hypoxic gas mixture (hypoxia)
  - Historical causes:
    - Crossing of **pipelines** in the hospital supply system
    - Inadvertent cross-connection of **gas supply hoses** to the AM

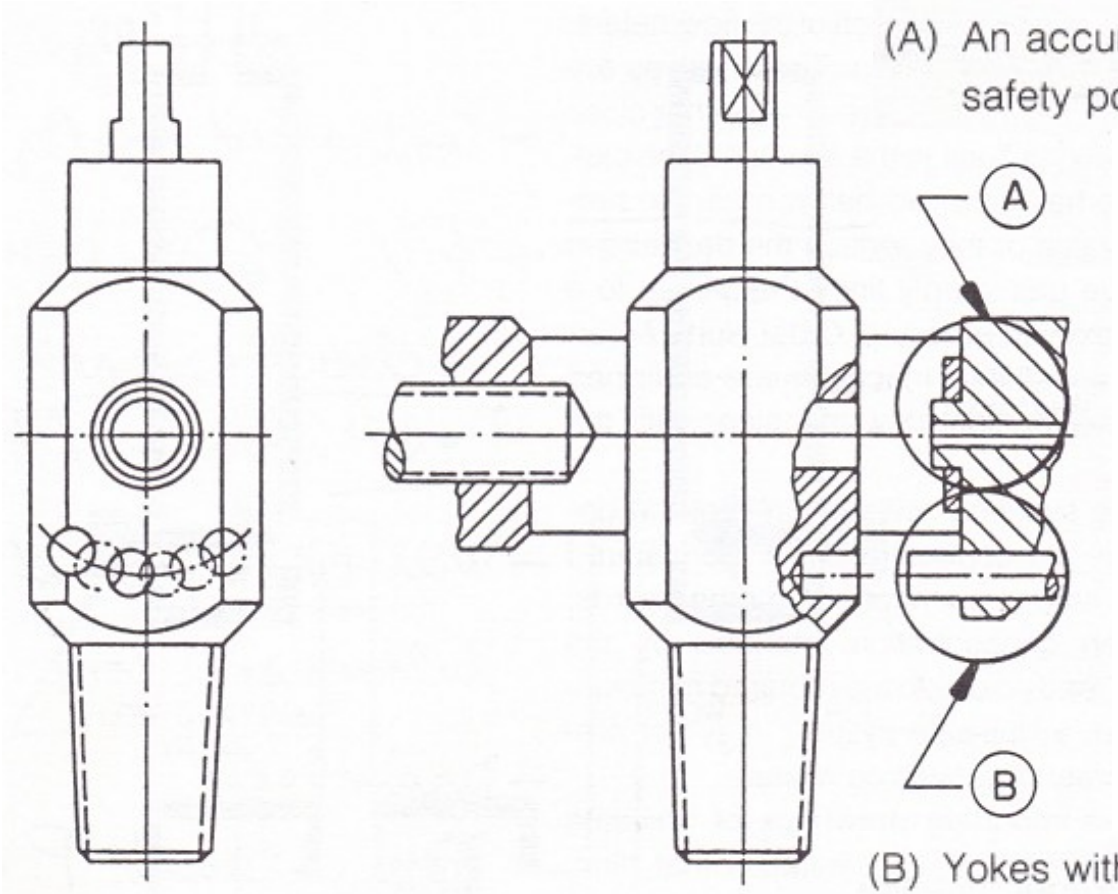
    This follows either:
    - New installation
    - Repair of the pipelines
    - Repair of the anesthesia system
    - Replacement of supply hoses at the AM
  - Errors incorrect **couplings** (various keyed couplings on wall outlets, AM inlets & supply hoses are dedicated to specific gases).
  - **Disconnection** of the FG hose during the use of a hanging bellows ventilator
  - The O_2 **flow** control valve is turned off
  - Malfunction of the **fail-safe** system
  - Failure of the N_2O-O_2 **proportioning** system
  - O_2 **leak** in the machine's low-P system
  - A closed circuit with an inadequate O_2 supply **inflow rate**
- Inadequate movement of the gas to and from the lungs (apnea)
- $\uparrow P_A$ (alveolar pressure) $\rightarrow \downarrow$ venous return & cardiac output

Safety Measures

- Contents of the cylinder = O_2
- Safety pins projecting from the yoke:
  - Sheared off
  - Fallen out

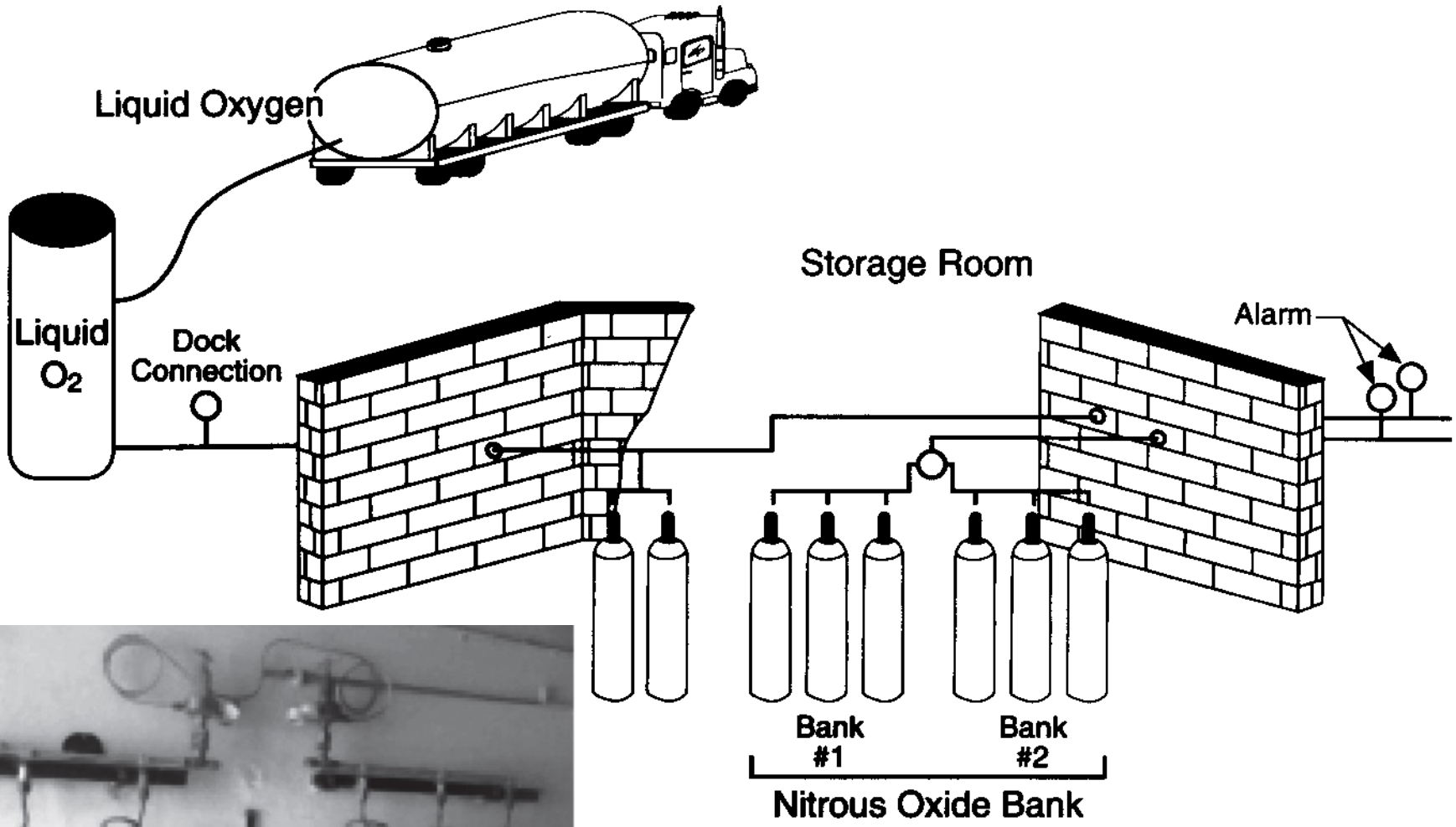
  → Permit the attachment of a wrong cylinder
- Gasket (seal): never > 1

  → Accumulation of several gaskets on the inlet nipple of the yoke may compromise the safety potential of the pins
- Pipeline pressure gauge
- Cylinder pressure gauge
  - If 2 cylinders of the same gas are open, the gauge will display the higher pressure of the two
  - In the event of a tight check valve in the yoke, the pressure at the contents gauge may continue to display a reading even after the cylinder has been removed from the yoke, thus indicating a reserve O_2 supply which does not exist



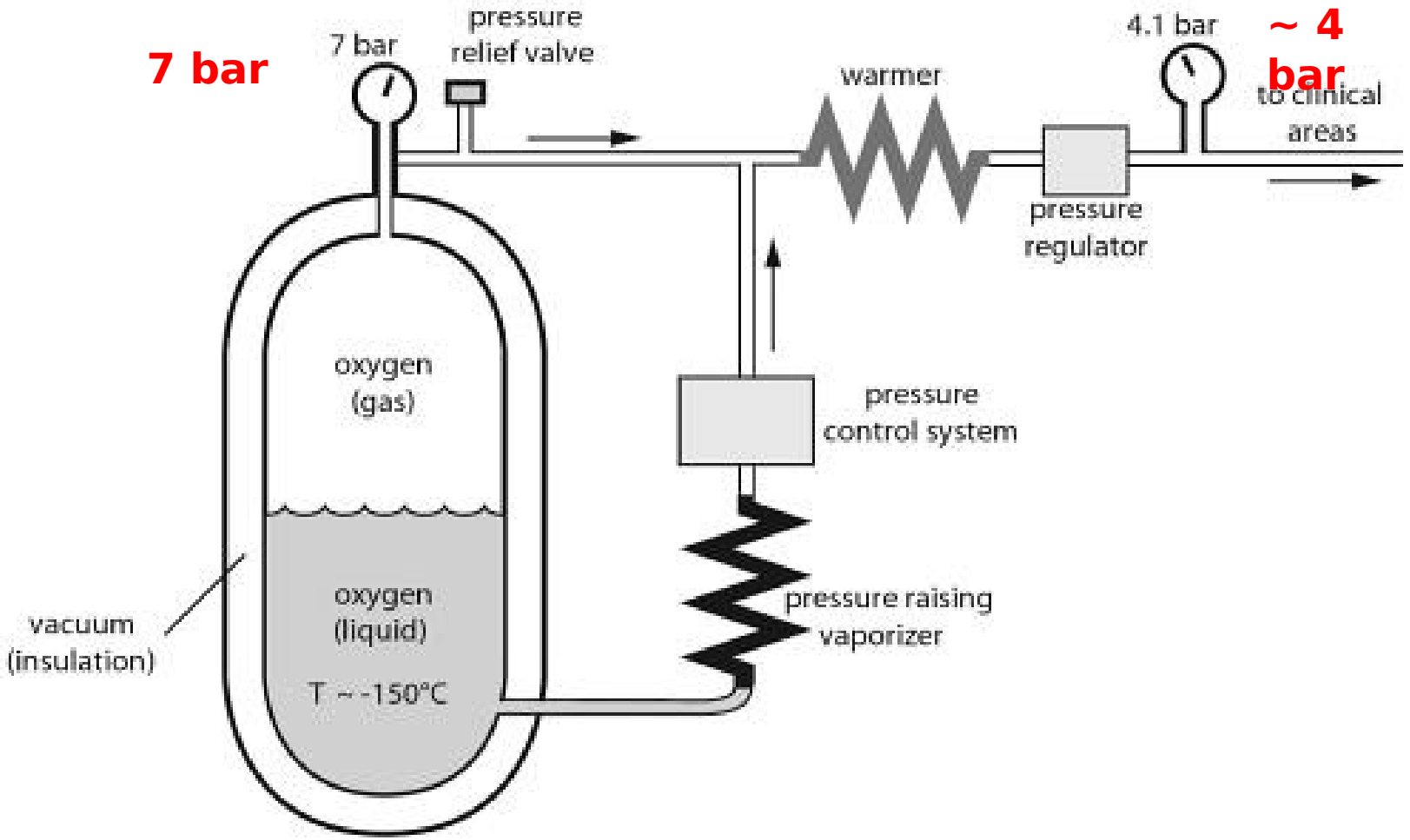
(A) An accumulation of gaskets jeopardizes the safety potential of the pins

(B) Yokes without pins permit the attachment of a wrong cylinder

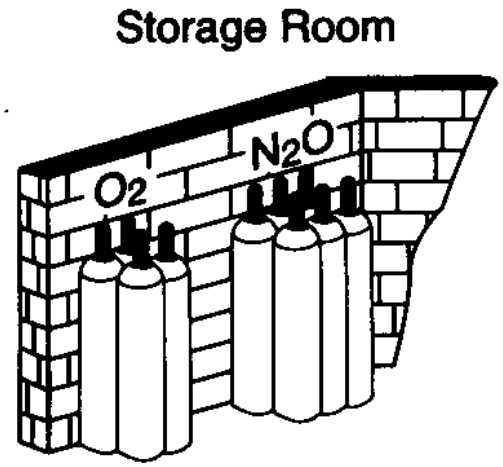

Liquid Oxygen
Liquid
O_2
Dock
Connection
Storage Room
Alarm
Bank
#1
Bank
#2
Nitrous Oxide Bank

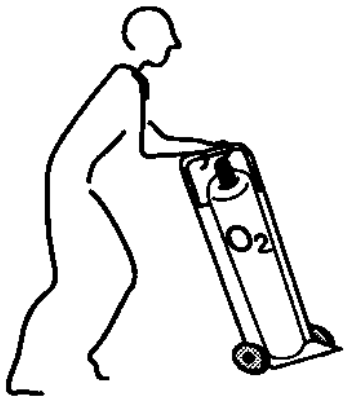


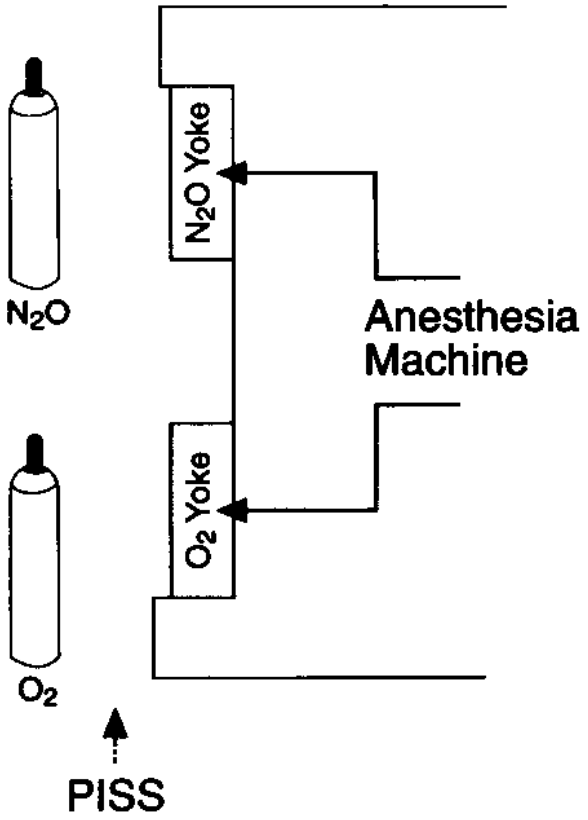
Liquid O_2 (cryogenic) storage tank. Behind the large tank is a smaller liquid O_2 tank. To the left of this are two vaporizers



A vacuum insulated evaporator (VIE) as used in hospitals with a high oxygen demand.







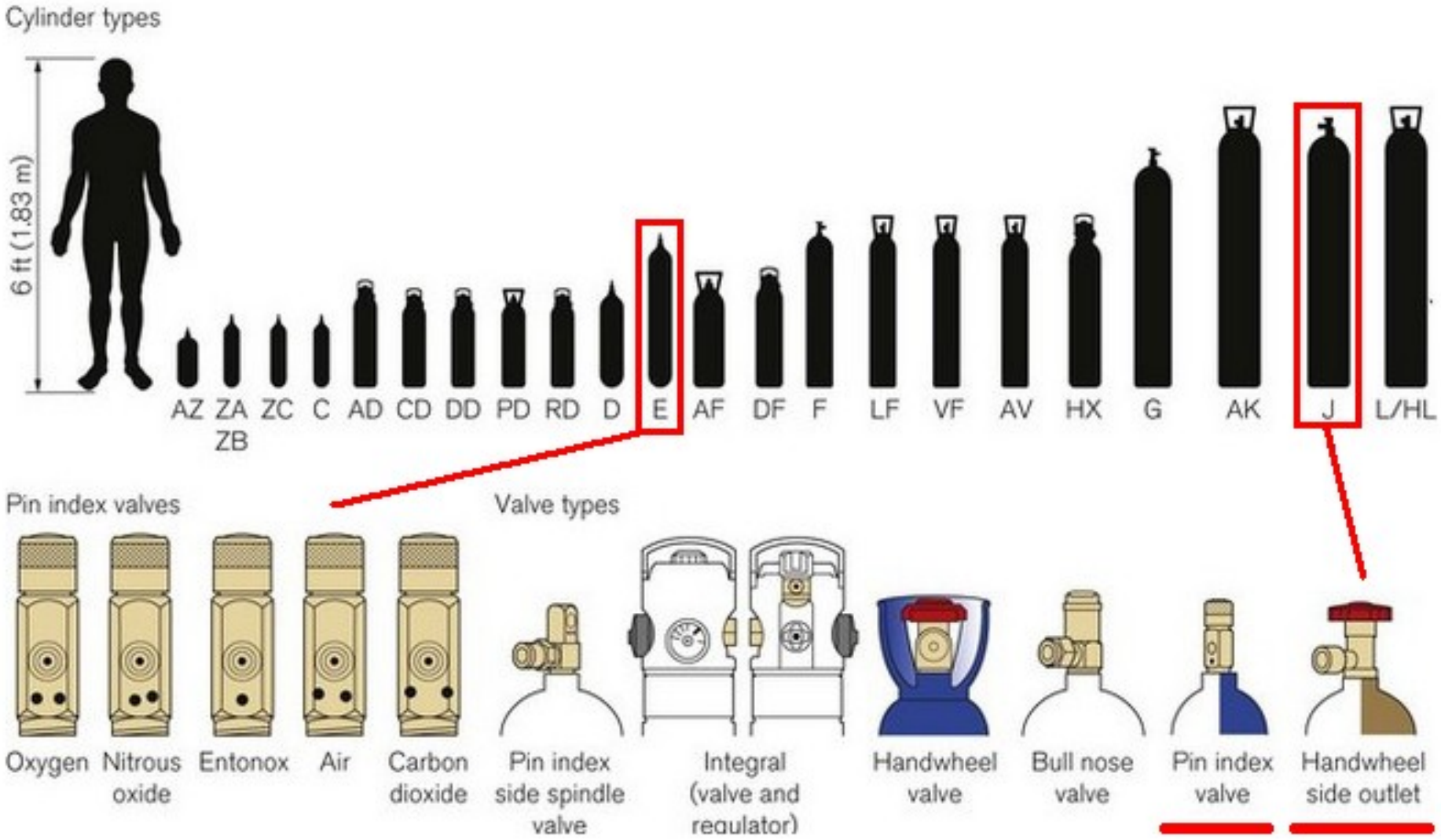
Small cylinders (Size E)



PISS= Pin Index Safety System



Oxygen

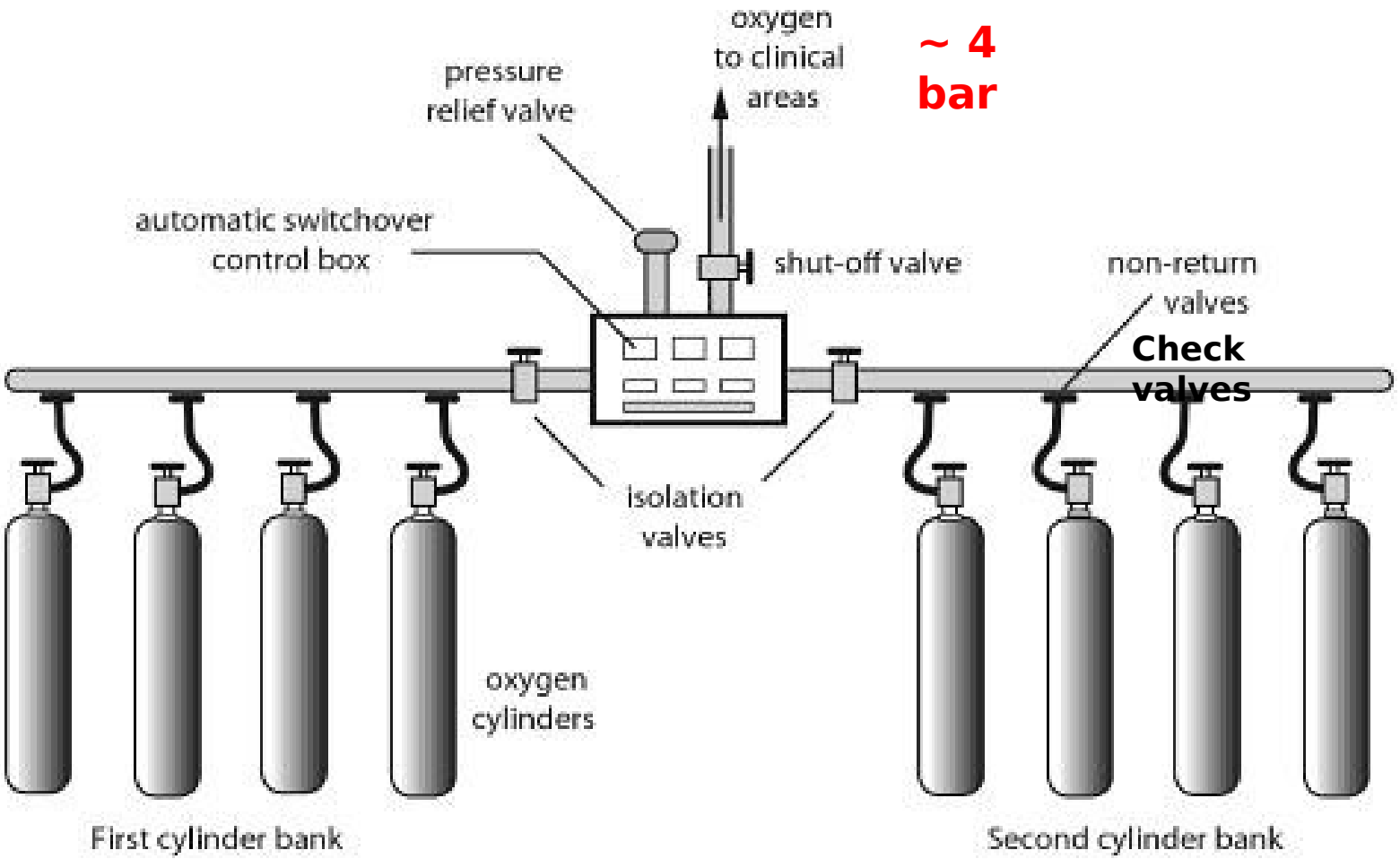

Cylinder types
6 ft (1.83 m)
AZ
ZA
ZB
ZC
C
AD
CD
DD
PD
RD
D
E
AF
DF
F
LF
VF
AV
HX
G
AK
J
L/HL
Pin index valves
Oxygen
Nitrous oxide
Entonox
Air
Carbon dioxide
Valve types
Pin index side spindle valve
Integral (valve and regulator)
Handwheel valve
Bull nose valve
Pin index valve
Handwheel side outlet



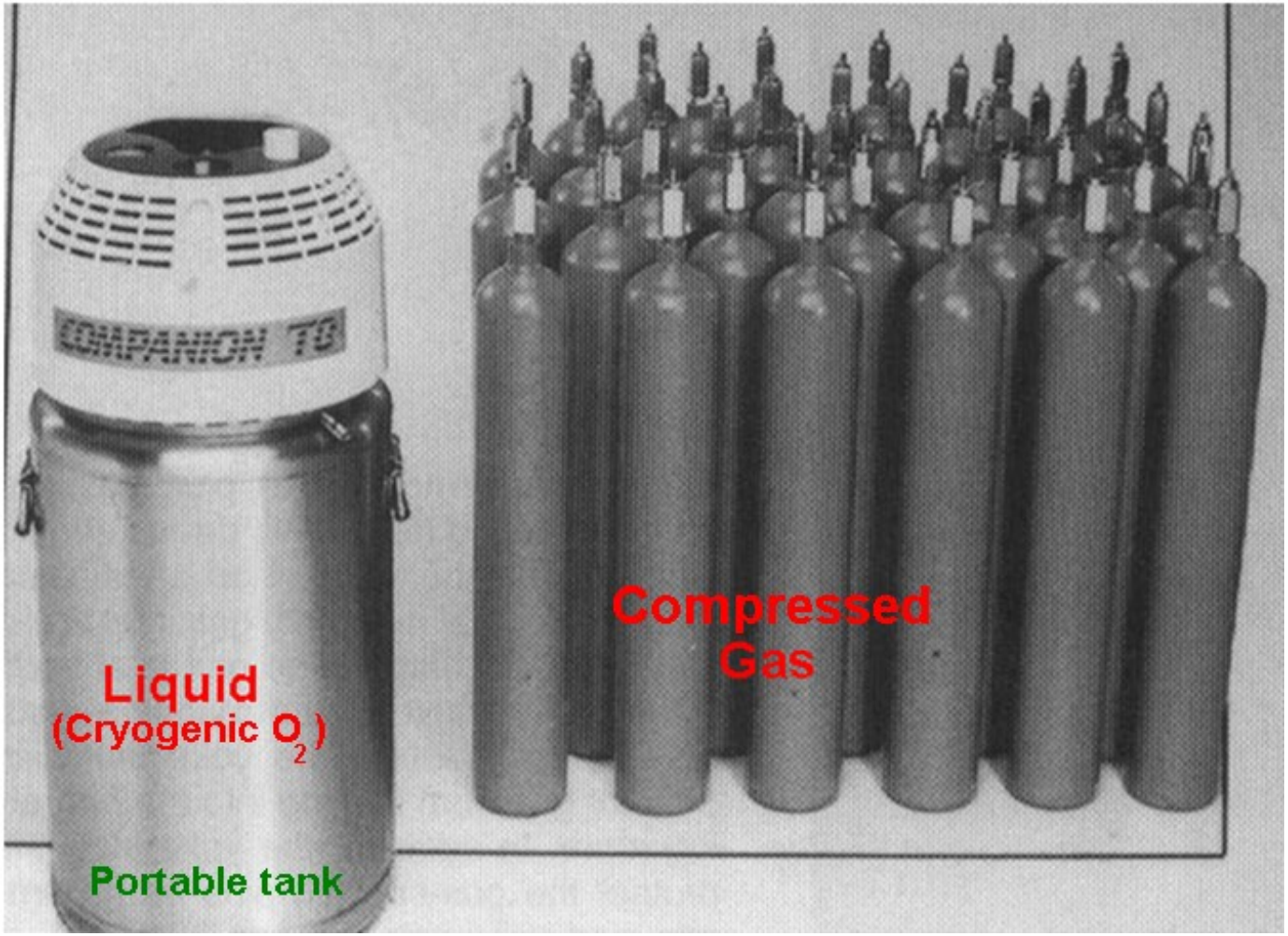




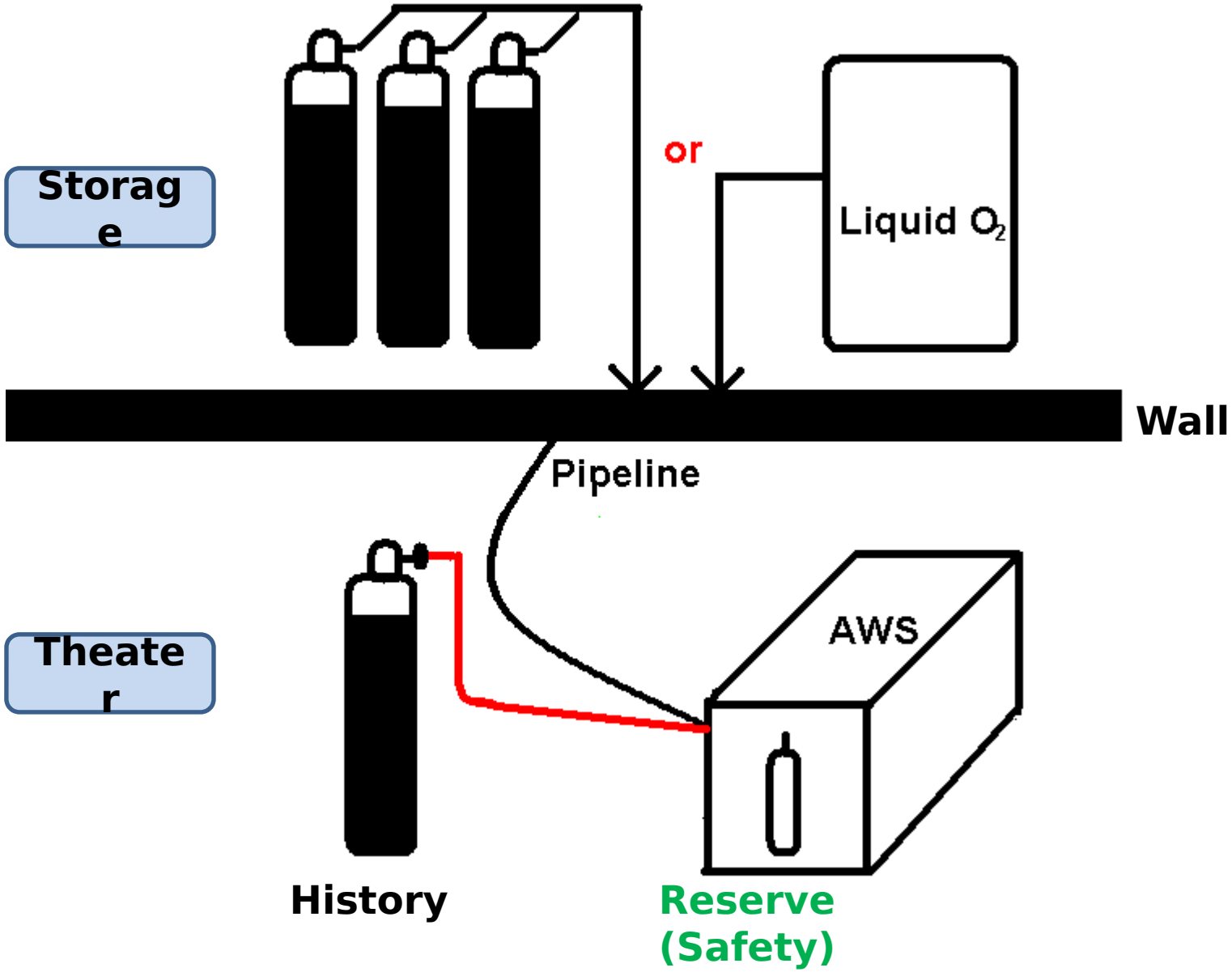
Cylinder supply system. This shows both the primary and secondary supplies with switching mechanism.



Oxygen cylinder manifold as used in smaller hospitals.

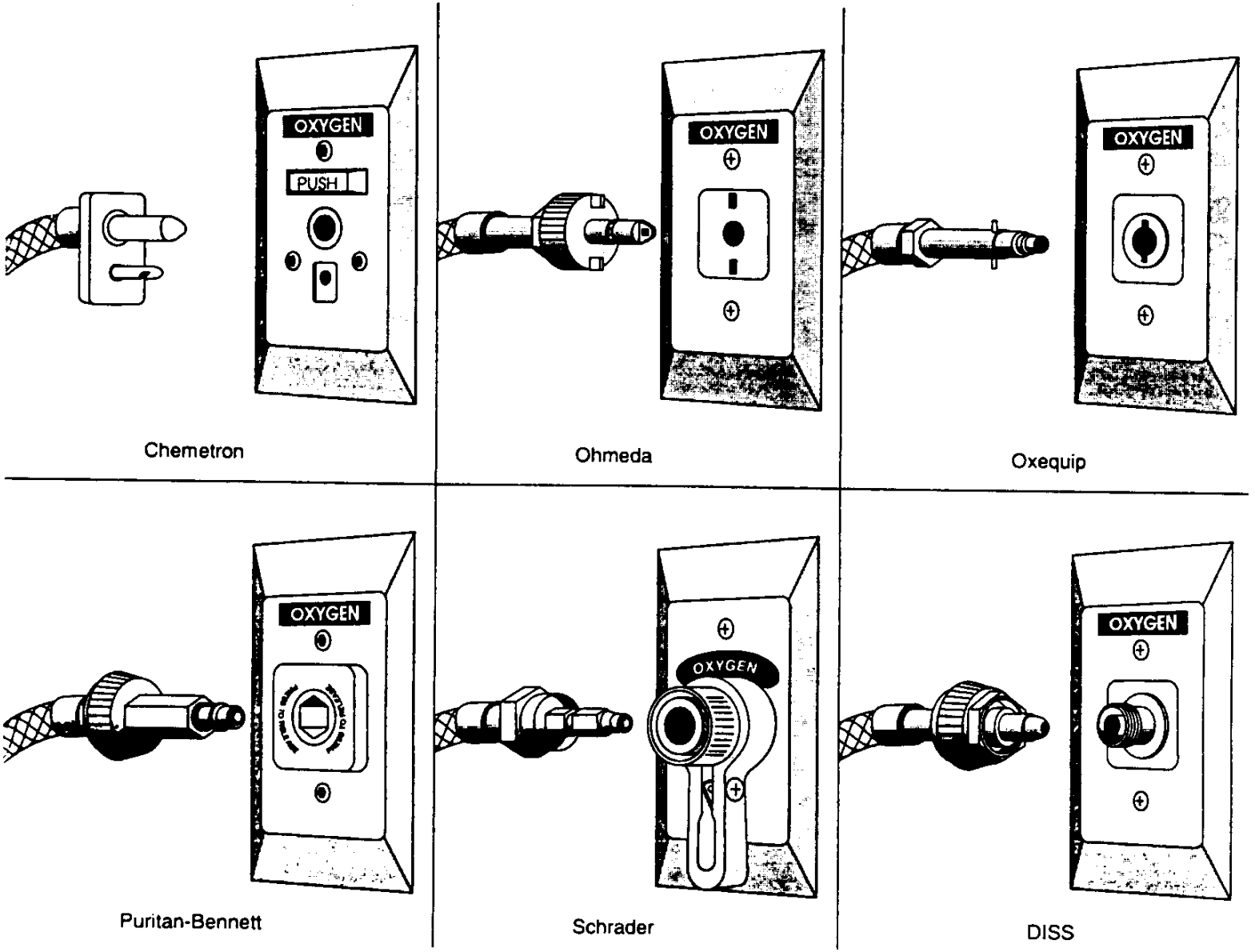


O_2 may be stored as a refrigerated liquid (Cryogenic O_2) or as a compressed gas. The portable liquid O_2 tank (left) can deliver as much O_2 as the 38 compressed gas cylinders (right)

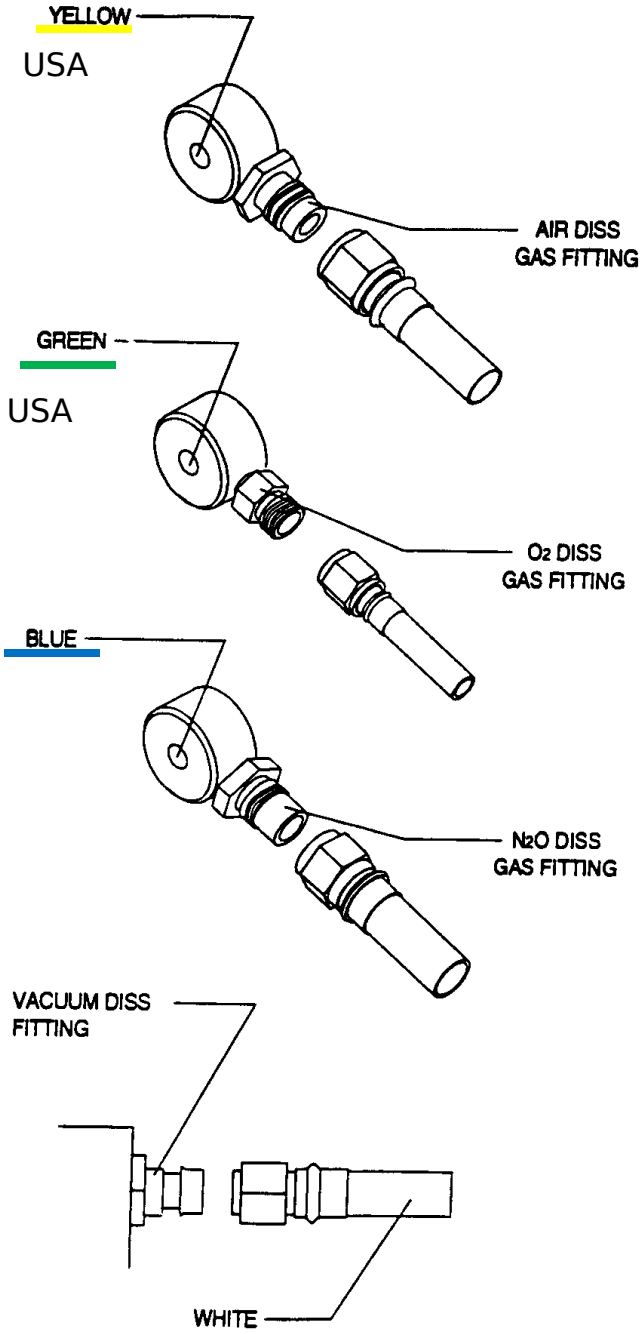


2 independent gas sources: (1) Pipeline (2) Reserve cylinder

Wall connections



DISS= Diameter Index Safety System



- The DISS is designed to prevent misconnection of the medical gases.
- The end of the hose for each type of medical gas is assigned a unique diameter and thread that is used to connect the pipeline gas supplies to the anesthesia machine

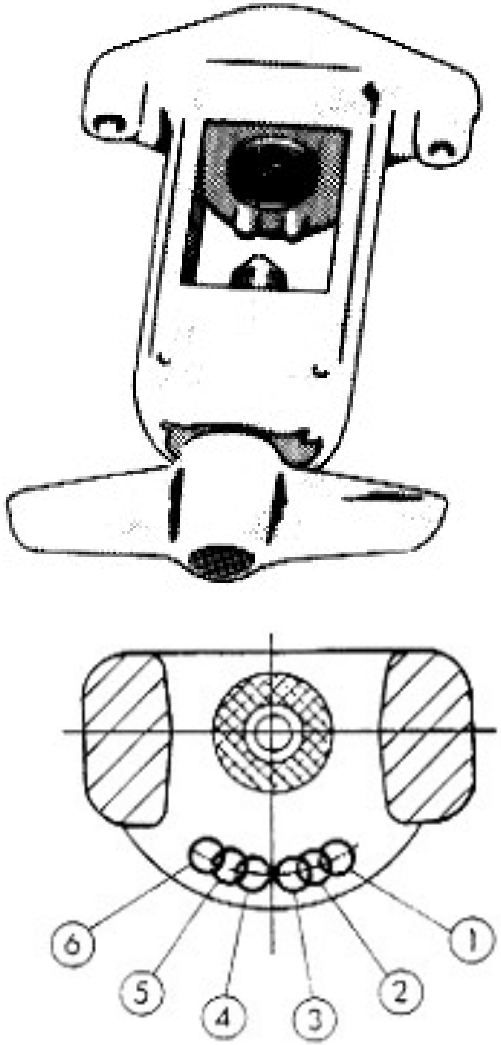


Wrong color coding

Cylinder Yokes

Mechanical system for fitting cylinders securely to the machine.
Components usually include:

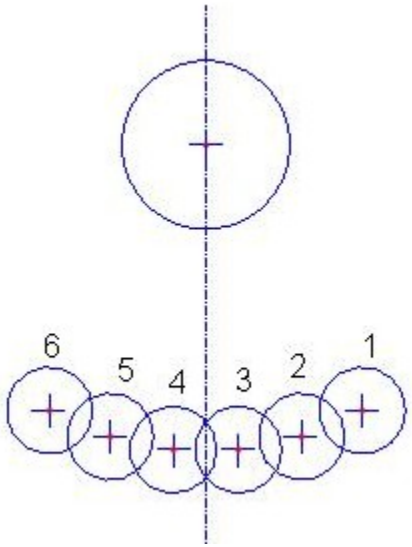
1. Pins for the indexing system
2. Bodok seal - neoprene (synthetic rubber) disk with aluminium or brass ring - generates airtight seal
3. Check valve to prevent retrograde loss of gas on cylinder disconnection
4. Filter - 34 micron - to prevent dust entering and blocking needle valves etc



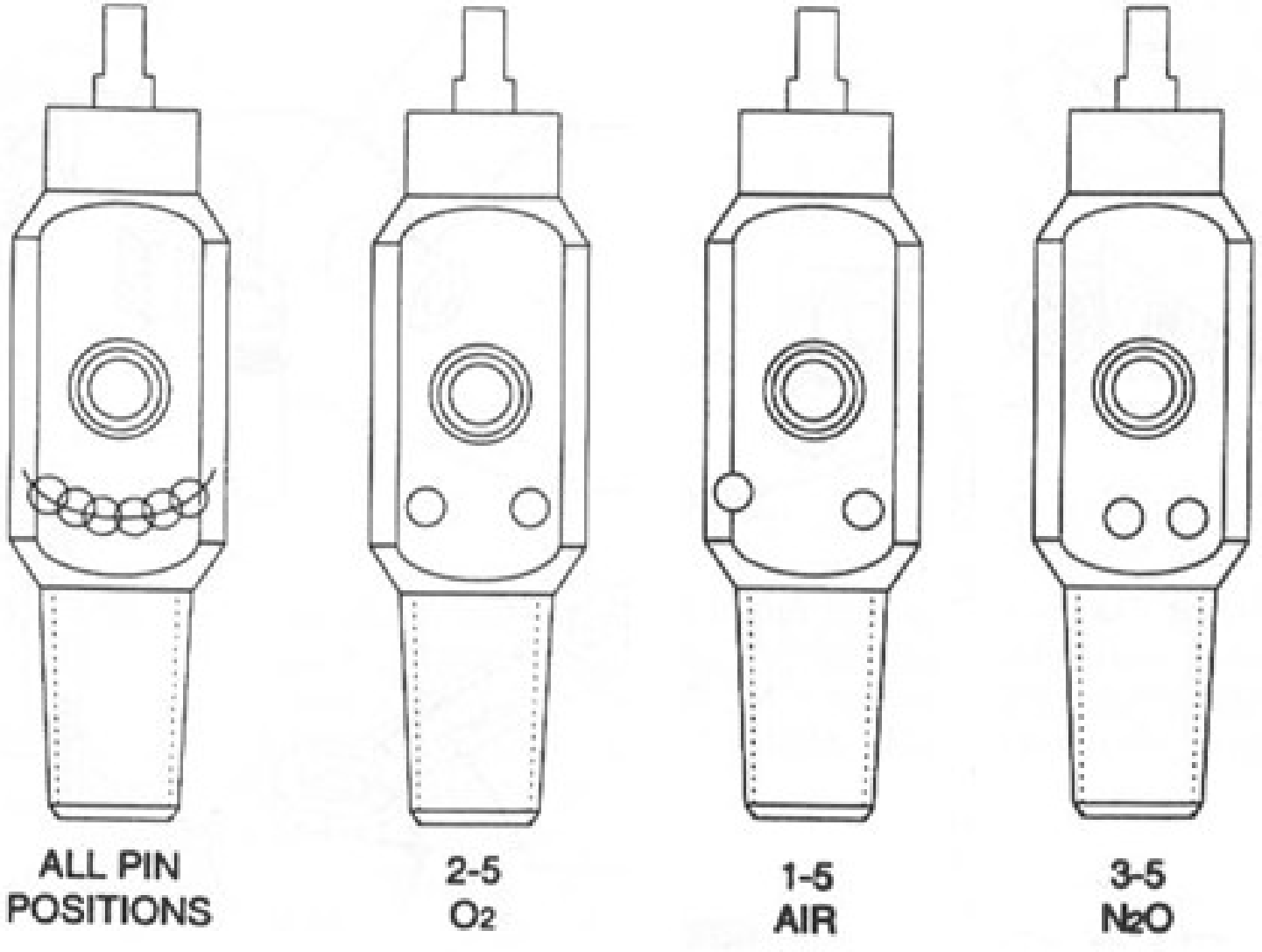

N_2O
PIPELINE
OXYGEN
PIPELINE
N_2O
N_2O
O_2
O_2

The **Pin Index Safety System (**PISS)

- It uses geometric features on the yoke to ensure that pneumatic connections between a gas cylinder and AM are not connected to the wrong gas yoke.
- Each gas cylinder has a pin configuration to fit its respective gas yok
  - O_2: 2-5
  - N_2O: 3-5
  - Air: 1-5
  - CO_2: 1-6
  - Heliox : 2-4



PISS




N_2O
O_2

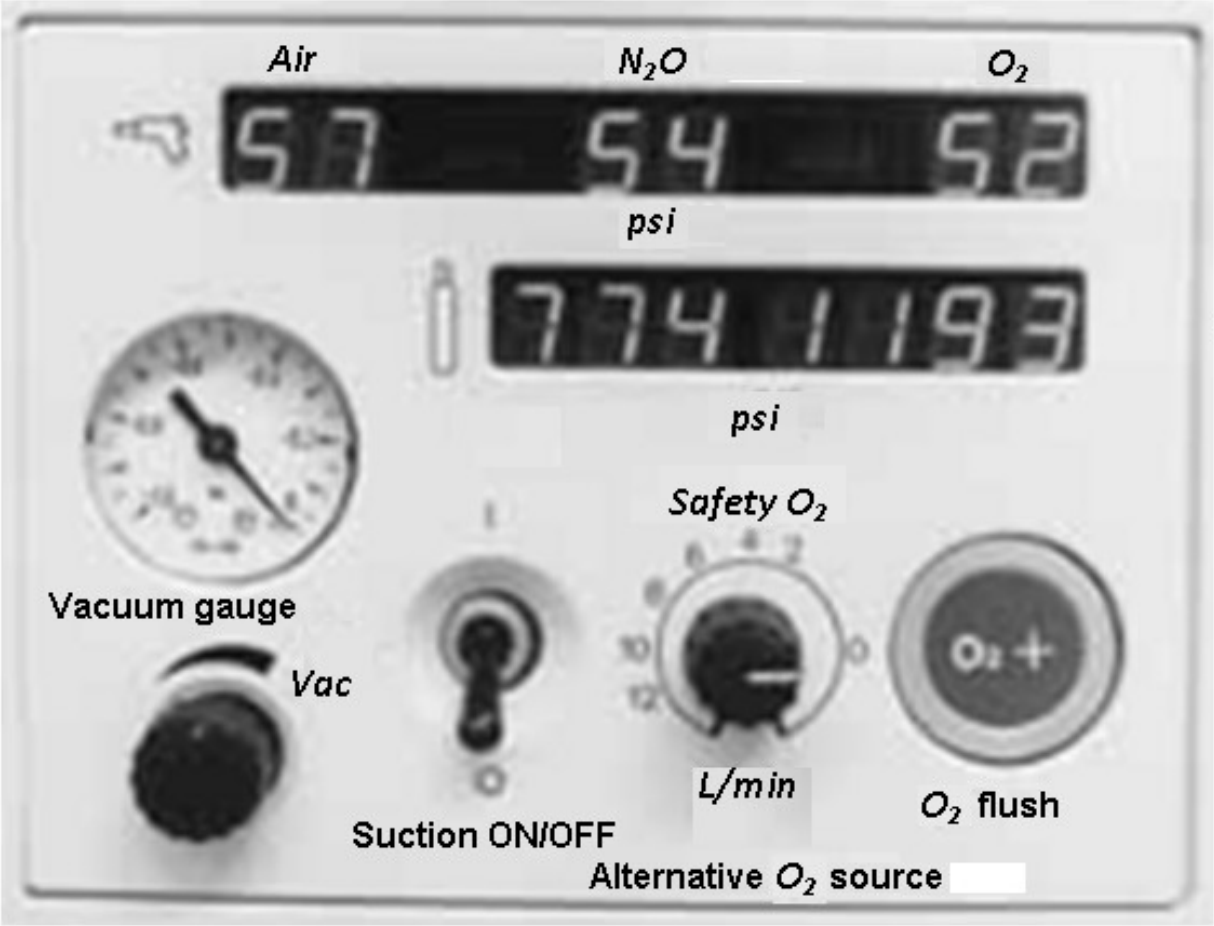
Pressure gauges



Pressure gauges



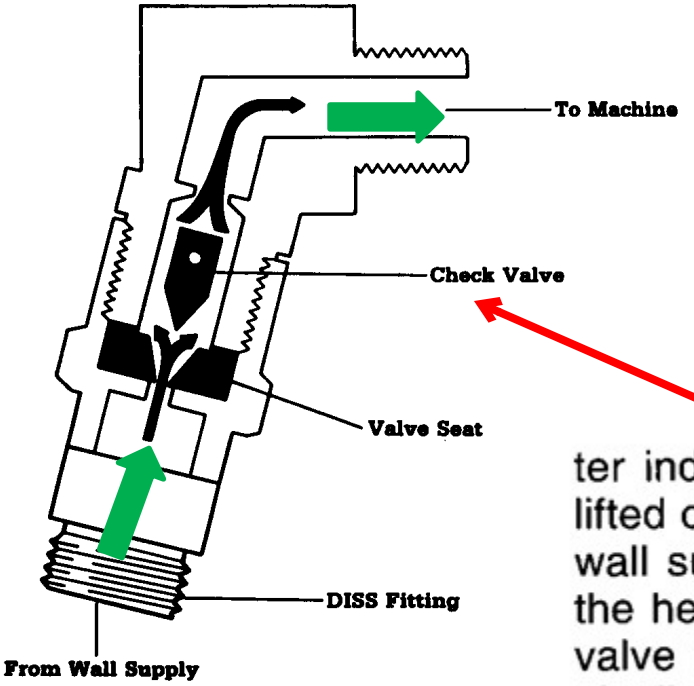
Digital pressure indicators

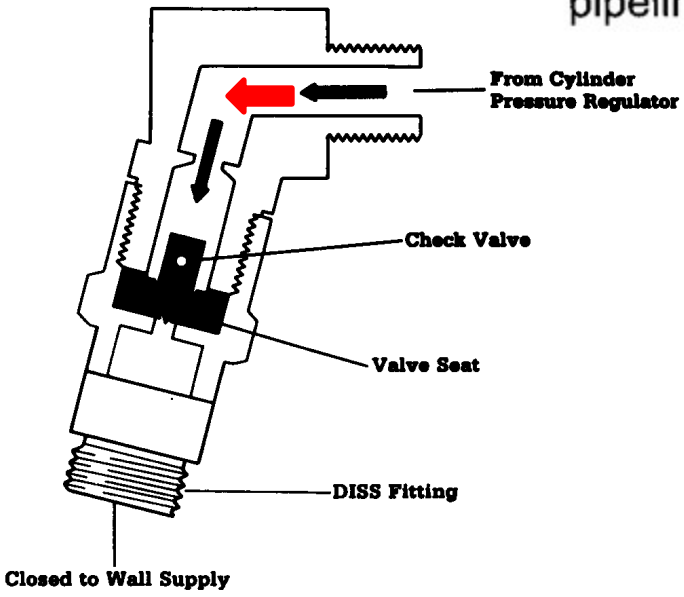


Pipeline pressures

Cylinder pressures

Vacuum regulator



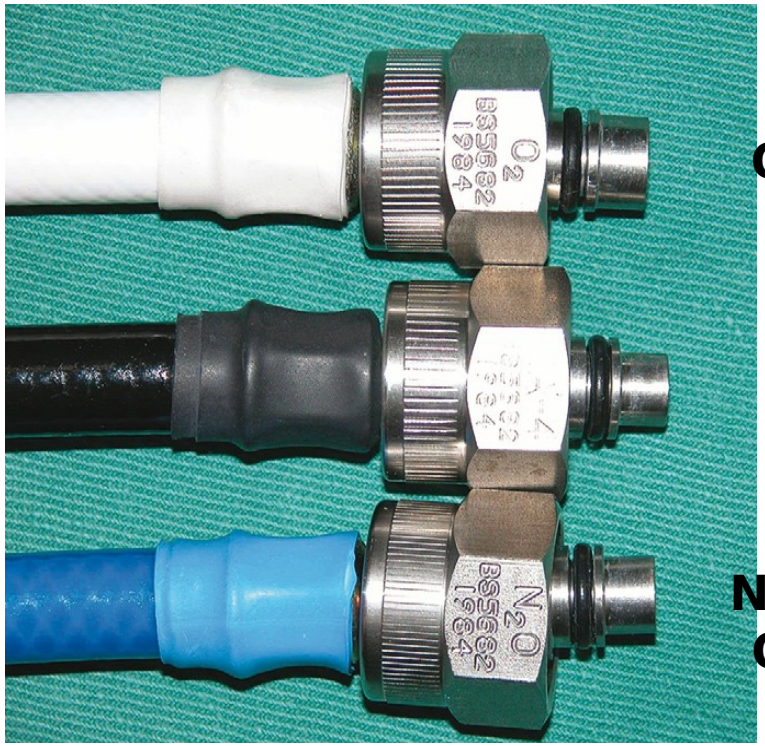


Check valve used in the connections of the diameter index safety system. **Top:** The check valve has been lifted off the valve seat by the pressure of the gas from the wall supply. **Bottom:** The gas supply from the pipeline of the health care facility has been disconnected. The check valve has been closed by the pressure in the anesthesia pipeline. This prevents loss of gas into the operating room.



Nitrous Oxide (N_2O)

Oxygen (O_2)



Oxygen

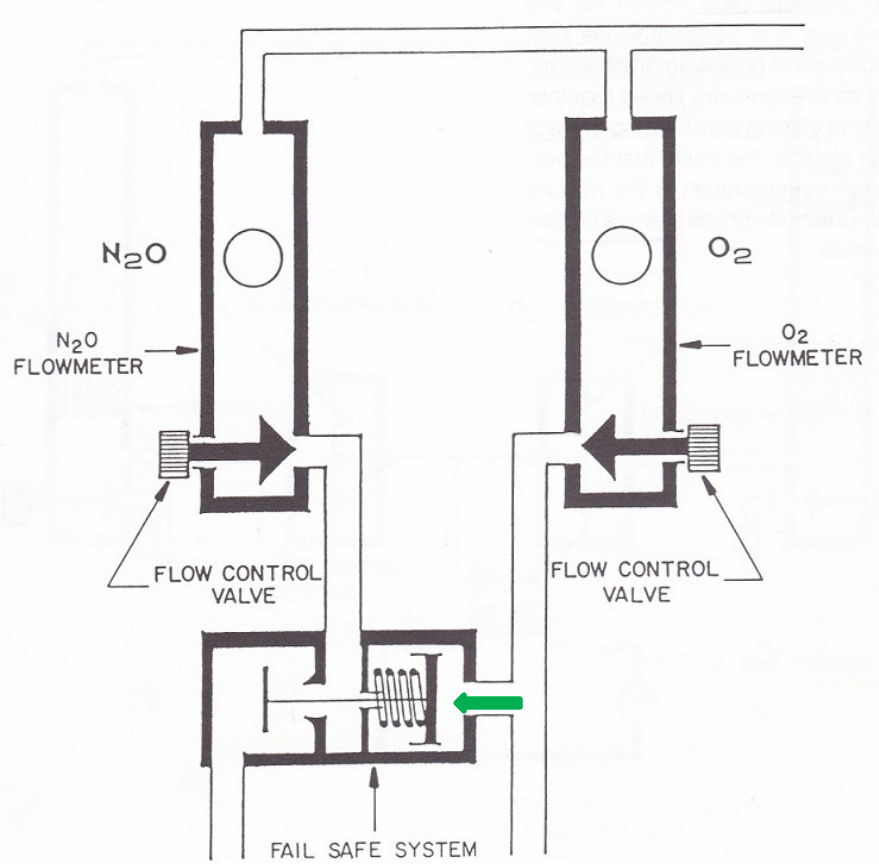
Air

Nitrous Oxide


N_2O
Air
O_2

Fail-Safe System (O_2 pressure failure protection device)

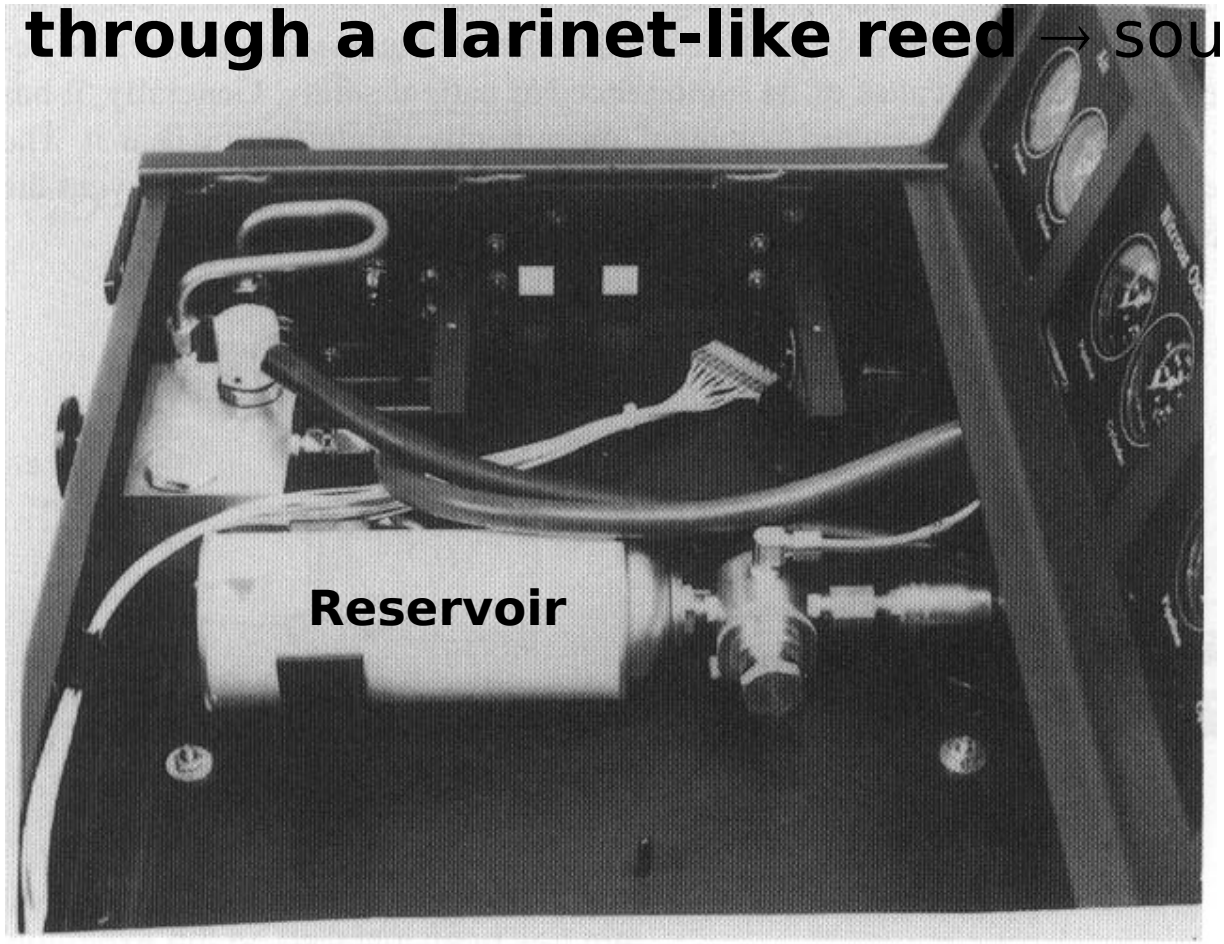
- Valves inserted in all gas lines upstream of each of the flowmeters except O_2
- Controlled by O_2 pressure
- ↓ O_2 P →
  - Close the respective gas line (old)
  - ↓P in the respective gas line (new)
- Will not prevent ↓O_2 conc <safe levels
- Drawbacks:
  - Sensitive to P only, will not analyze the supplied gas
  - Closing O_2 flow-control valve → O_2 P will maintain all other gas lines open → hypoxic mixture



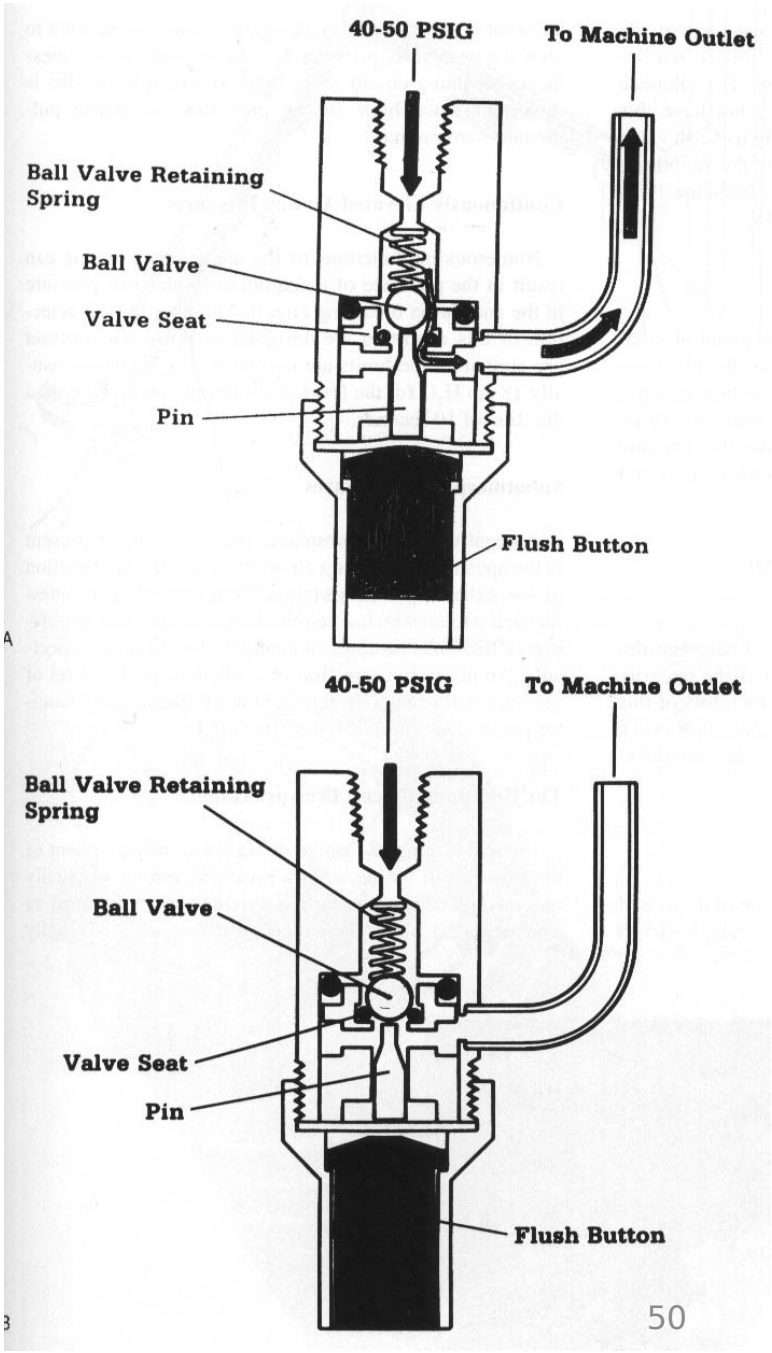
Its safety potential is overestimated (limited)

he Oxygen Whistle Alarm

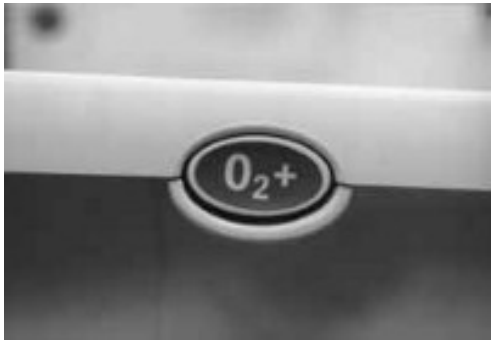
A reservoir is filled with O2 when the machine is turned on. **When the** O2 **pressure ↓ < 30-35 psig, the gas in the reservoir will pass through a clarinet-like reed** → sound



he Oxygen Flush Valve



Oxygen Flush



The O_2 flush (O_2 bypass, emergency O_2 bypass) receives O_2 from the pipeline inlet or cylinder P regulator and directs a **high unmetered flow** directly to the common gas outlet.

It is commonly labeled "O_2+"

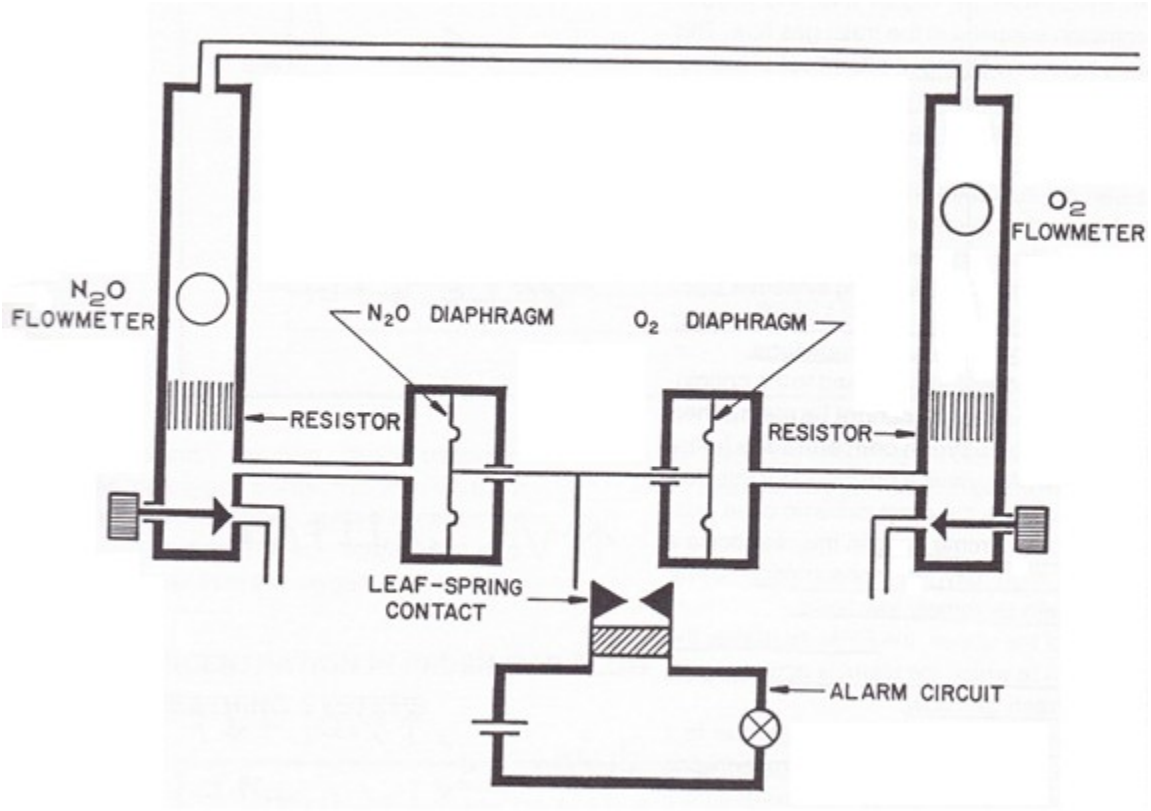
On most AMs, the O_2 flush can be activated regardless of whether the master switch is turned ON or OFF.

The AWS requires that the O_2 flush be a single-purpose, self-closing device operable with one hand and designed to minimize unintentional activation.

No safety measure other than an **OXYGEN ANALYZER** will reveal the hazard of the supply of N_2O into the O_2 inlet of the AM

ORM, Oxygen Ratio Monitor

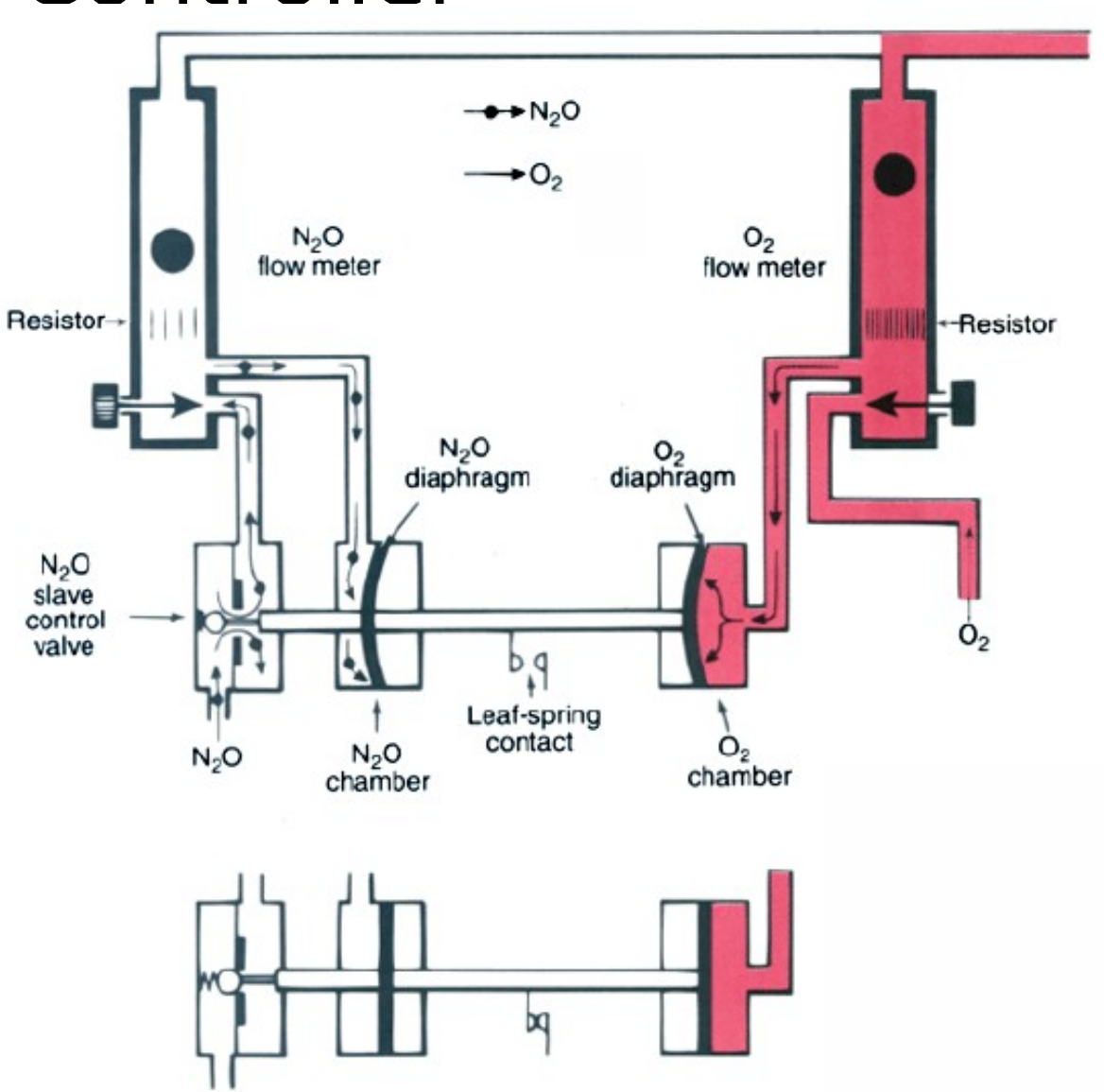
- A set of linear resistors inserted between the O_2 & N_2O flow-control valves & their associated flowmeters
- The P↓ across the 2 resistors is monitored & transmitted via pilot lines to an arrangement of opposing diaphragms
- These diaphragms are linked together with the capability of closing a leaf-spring contact & actuating



It does not actively control the gas flow. It will not sound an alarm if a hypoxic gas mixture is administered when the O2 piping system contains a gas other than O2

ORMc, Oxygen Ratio Monitor Controller

- North American Drager ORMc not only generates an alarm but also controls the N_2O flow automatically in response to the O_2 flow
- Basic design: similar to ORM with the exception that a slave regulator is additionally controlled
- Advantage: automatically responding to ↓O_2 P or operator error
- Disadvantage: the operator can't



Mandatory Minimum Oxygen Flow

- Some AMs require a minimum (50 to 250 mL/minute) flow of O_2 before other gases will flow. This is preset by the manufacturer.
- On some machines, the minimum flow may be deleted at the user's request.
- Some machines activate an alarm if the O_2 flow goes below a certain minimum, even if no other gases are being used.
- The minimum flow is activated when the master switch is turned ON.
- On some machines, it is disabled when air is used.


ENSURE BACKLIGHT IS
SWITCHED OFF BEFORE
REMOVING FRONT COVER
MINIMUM PRE-SET FLOW OF O_2 INCORPORATED.
DO NOT FORCE O_2 FLOW CONTROL KNOB.
TO TURN MINIMUM O_2 FLOW OFF, USE ON/OFF SWITCH.
O_2
N_2O
AIR

Minimum Oxygen Ratio

AM is provided with a **device** to protect against an operator-selected delivery of a mixture of O_2 and N_2O having an O_2 concentration < **25% O_2** (V/V)

By:

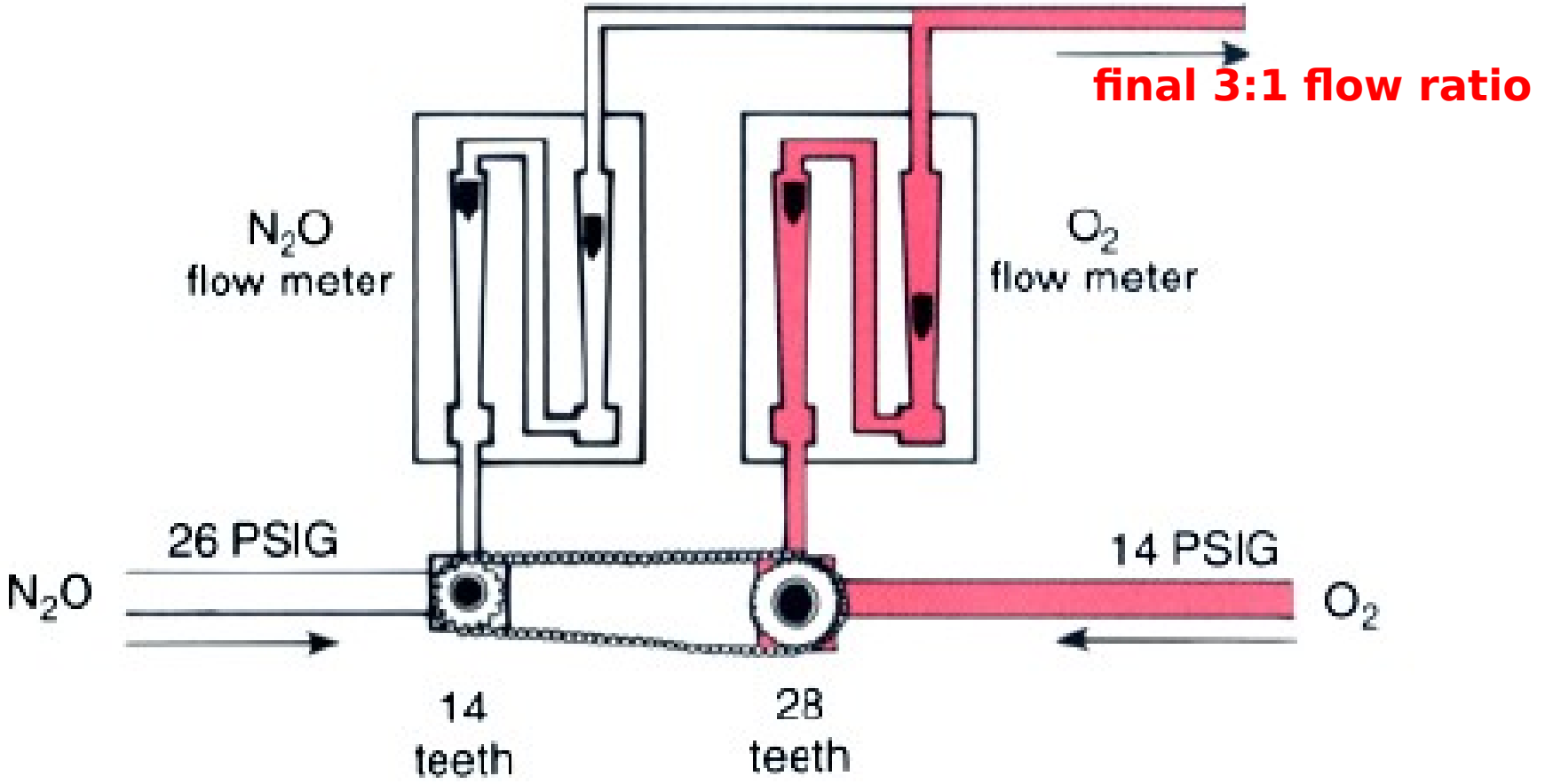
- Mechanical Linkage
- Electronic Linkage
- Mechanical and pneumatic

Alarms:

Alarms are available on some AMs to alert the operator that the O_2: N_2O flow ratio has ↓ < a preset value.

Datex-Ohmeda Link-25 Proportion Limiting Control (Proportioning) System

A system that *↑O_2 flow when necessary to* prevent delivery of a fresh gas mixture with an O_2 concentration of <25%



The combination of the mechanical and pneumatic aspects of the system yields the final oxygen concentration

Proportioning Systems

Manufacturers have equipped newer machines with proportioning systems in an attempt to prevent delivery of a hypoxic mixture. Nitrous oxide and oxygen are interfaced mechanically or pneumatically so that the minimum oxygen concentration at the common gas outlet is between 23% and 25%, depending on manufacturer

1. **Datex-Ohmeda Link-25 Proportion Limiting Control System**
2. **North American Dräger Oxygen Ratio Monitor Controller**

Alternative Oxyge



When using an AM, there is always the **possibility that the electronics will fail**.

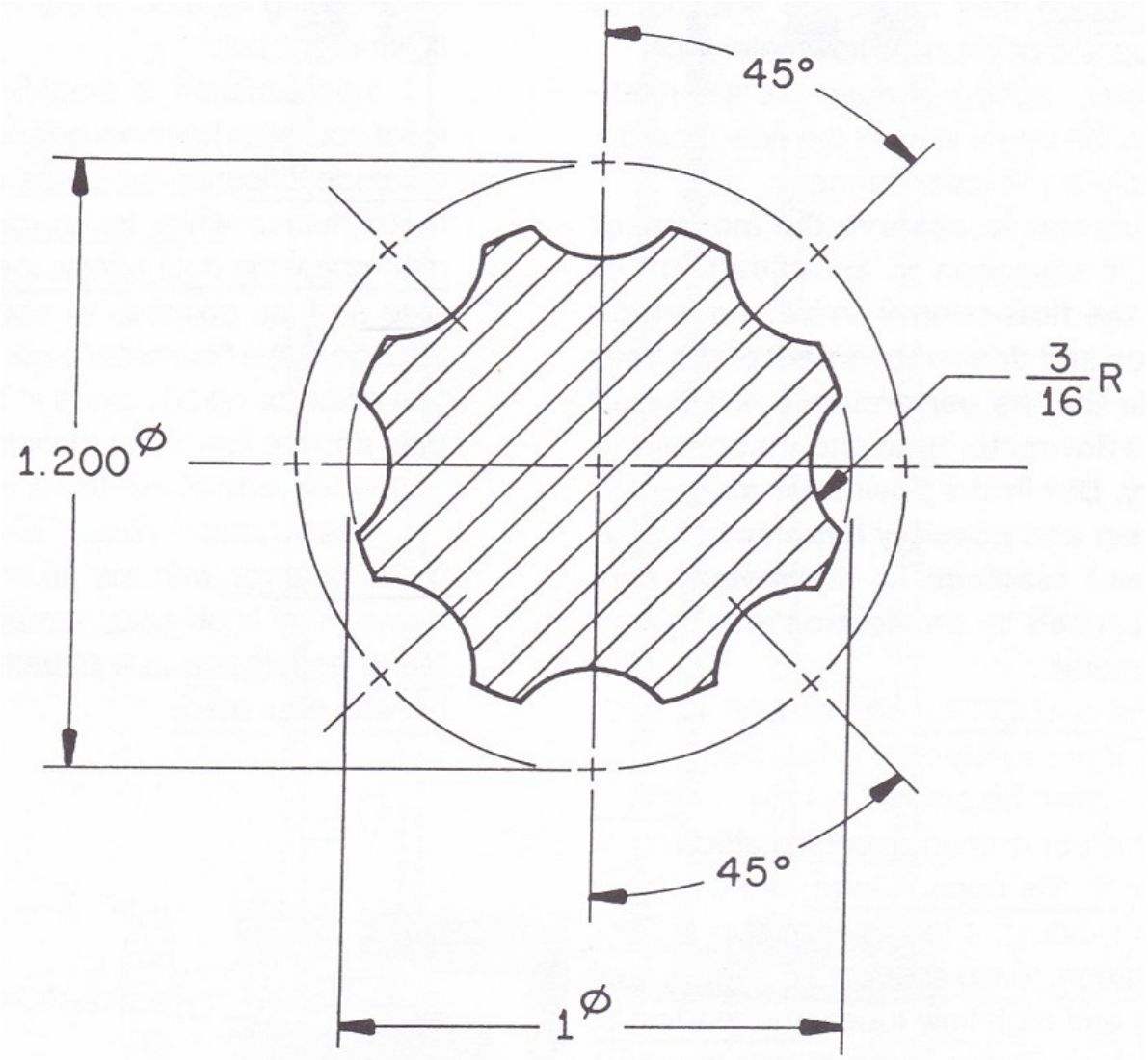
Different machines deal with this problem in different ways.

Some machines provide an alternative means to administer O_2 . This is separate from the auxiliary (courtesy) flowmeter.

If there is a mechanical total flow flowmeter, it can be used to measure the delivered O_2. Anesthesia can be administered with **intravenous** agents.

Touch-Coded O_2 Flow-Control Knob

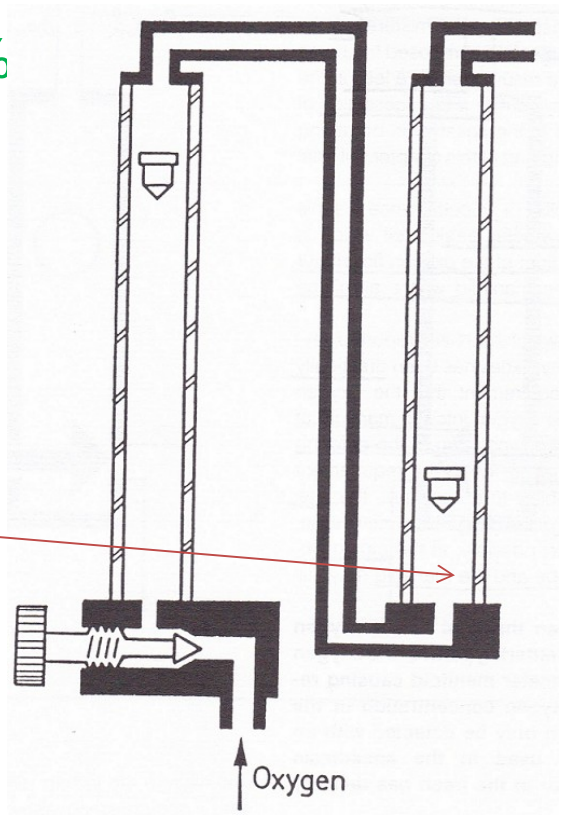
OLD



O_2 Flowmeters Arranged in Tandem

OLD

↑Accuracy
(deviation 3%



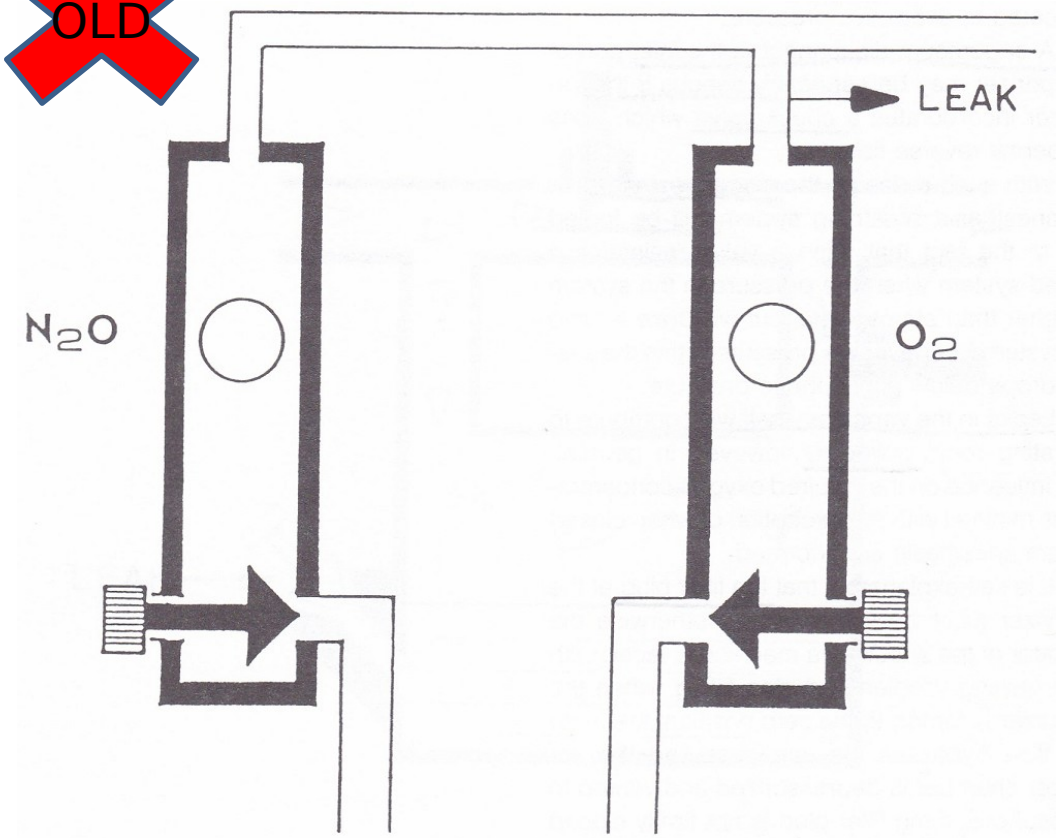
↓Accuracy
(deviation
20%)

- ↓ Diameter
- Condensation → small particles of dust or moisture may cause the float not to move freely

Leaks at Flowmeter Tubes

Leak → same effect of ↓ fresh gas flow (FGF) → ↓ O_2 concentration

OLD

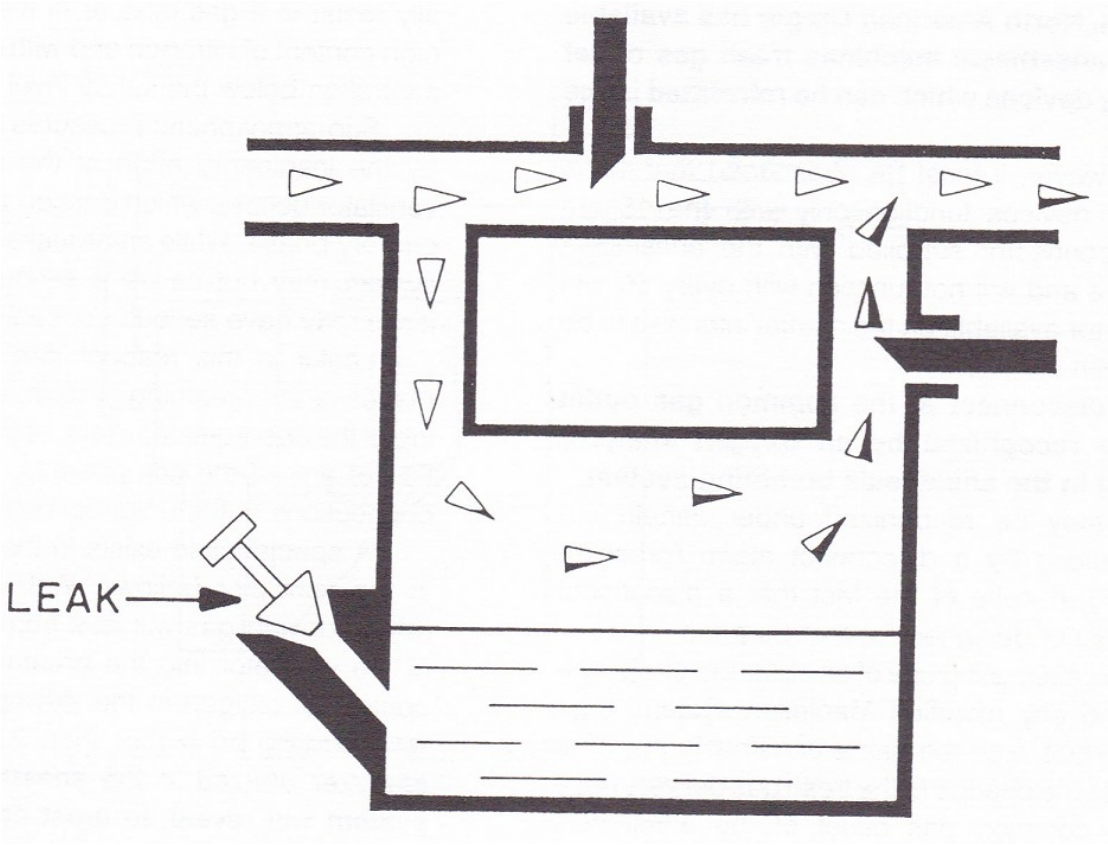


Possible sites of leak:

- Upper gasket of the O_2 flowmeter tube
- Sealing screw
- The piping between flowmeter tube & the manifold

Leaks at Vaporizers

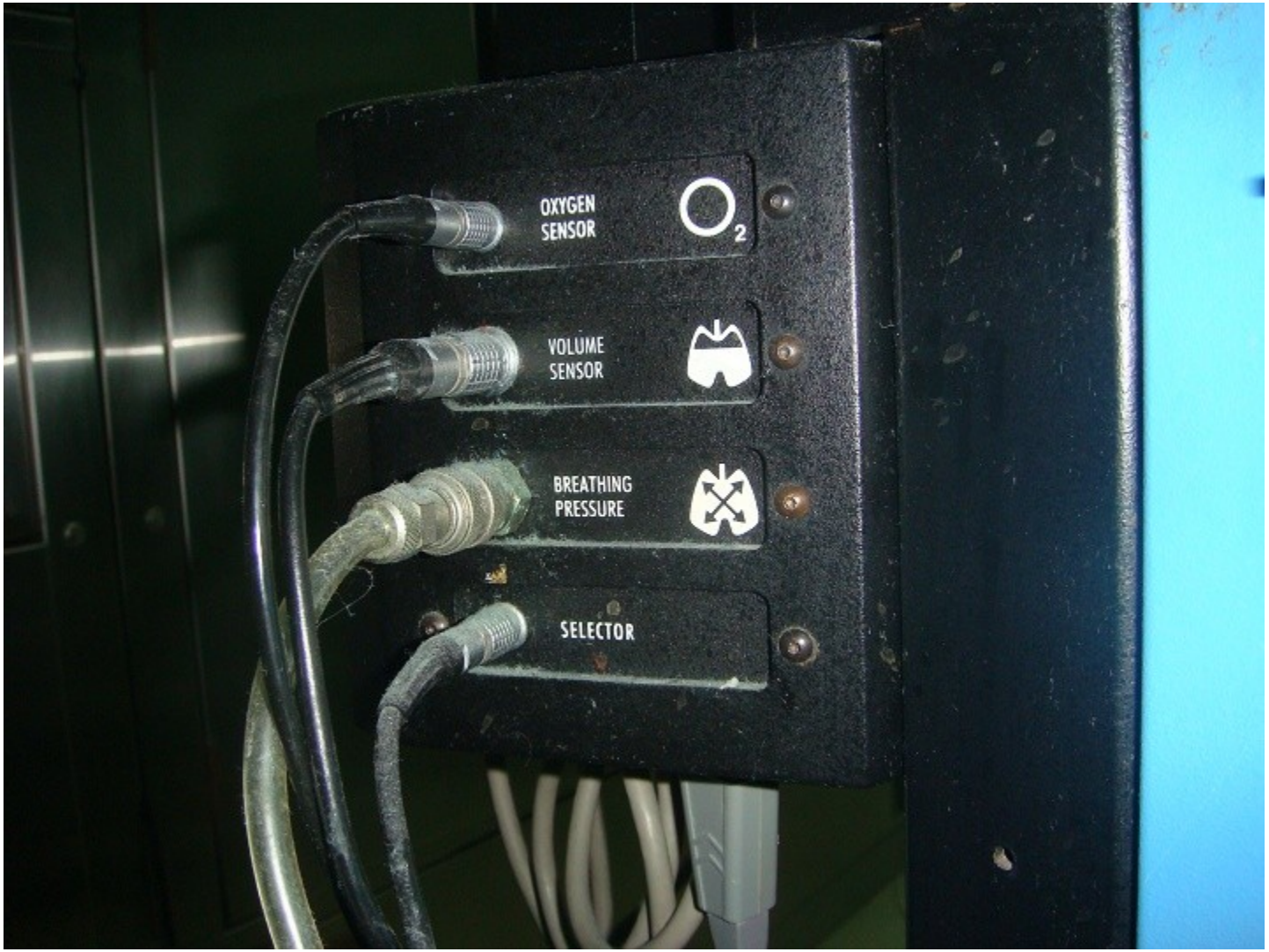
- At the inlet & outlet connections when standard cagemount fittings are used
- At the filler plug (funnel)
- At the draining device



Any ↓ of O_2 % due to leaks at any of the above-referenced points will be recognized if an **OXYGEN ANALYZER** is used in the breathing system


APL
APL
OXYGEN
SENSOR


PEEP OFF
ON PEEP
PEEP ON
OXYGEN SENSOR

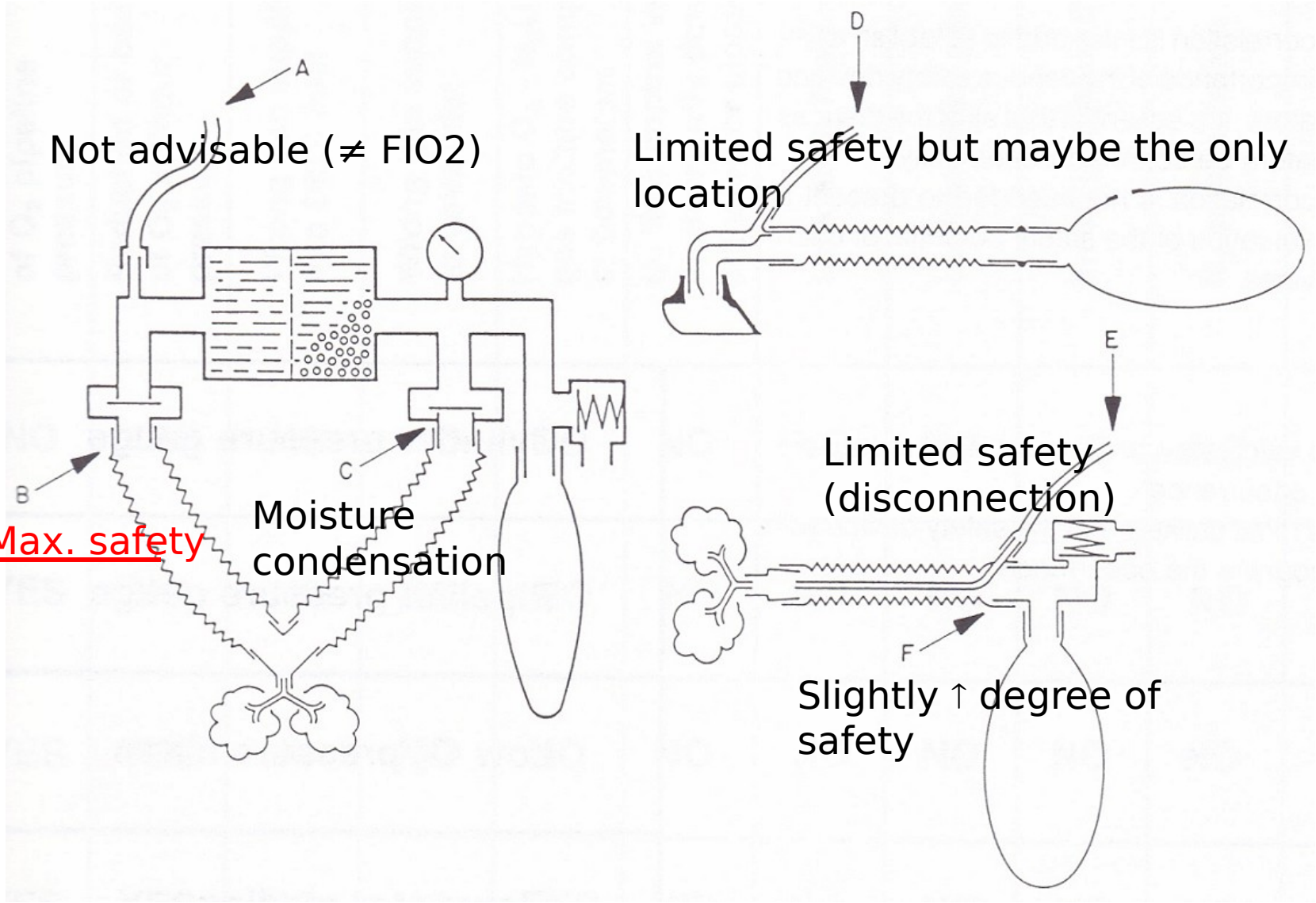

OXYGEN
SENSOR
O_2
VOLUME
SENSOR
BREATHING
PRESSURE
SELECTOR

Oxygen Analyzer

- What design?
  - Polarographic sensor (Clark Cell)
  - Paramagnetic sensor
  - Electrochemical sensor (galvanic fuel cell)
- How to calibrate?
  - Using O_2 % either:
    - 21% (air): preferable
      - The accuracy of an O_2 analyzer is the greatest around the concentration which is used for its calibration. The operator should be more concerned with a hypoxic gas mixture.
      - Using room air → ↓ risk of an error in the calibration gas
    - 100% (AM): Possibility of air entering the gas mixture exists → calibration gas with < 100% O_2
  - Expose the sensor to a stable calibration media during the whole period of calibration (45 sec).
- High & low O_2 alarm limits. Low alarm limit always returns to 30% when the unit is initially turned on.
- It does not monitor the movement of gas to the patient
- Where to place?

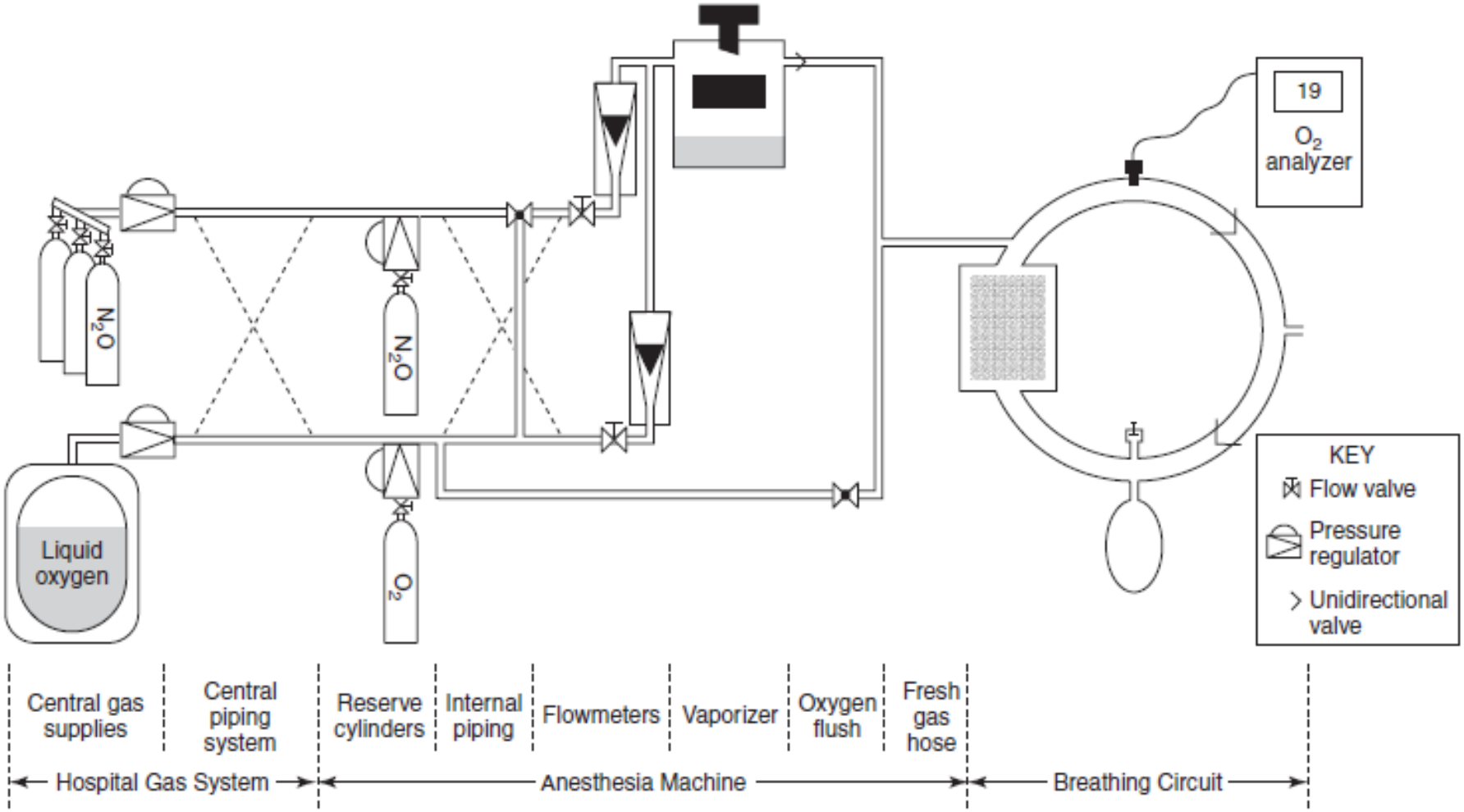

Volume Control
11:05 AM
02 SENSOR FAIL !
FLOW SENSOR CAL DUE !
02
100
18
12
8
4
2
1
.5
0
02
Air
N20
Freq
VT
MV
12.0
12
713
8.5
2.0
PEEP
PLAT
PEAK
40
2
19
22
0
PMAX
VT
Freq
TI:TE
TIP:TI
PEEP

Location of O_2 Sensor



	↓ or cessation of O_2 pipeline pressure	↓ or cessation of O_2 cylinder pressure	Wrong gas supply into DISS inlet	Wrong gas supply to ypke inlet	Hypoxic O_2-N_2O gas mixture composed at flowmeters	O_2 flow control valve inadvertently downward adjusted or closed	Leak at O_2 flowmeter	Leak in fresh gas line	Fresh gas hose disconnect	N_2 accumulation	Rate
Cylinder P gauge	-	+	-	-	-	-	-	-	-	-	1
Pipeline P gauge	+										1

↓ or cessation of O_2 pipeline pressure
↓ or cessation of O_2 cylinder pressure
Wrong gas supply into DISS inlet
Wrong gas supply to ypke inlet
Hypoxic O_2-N_2O gas mixture composed at flowmeters
O_2 flow control valve inadvertently downward adjusted or closed
Leak at O_2 flowmeter
Leak in fresh gas line
Fresh gas hose disconnect
N_2 accumulation
Rate

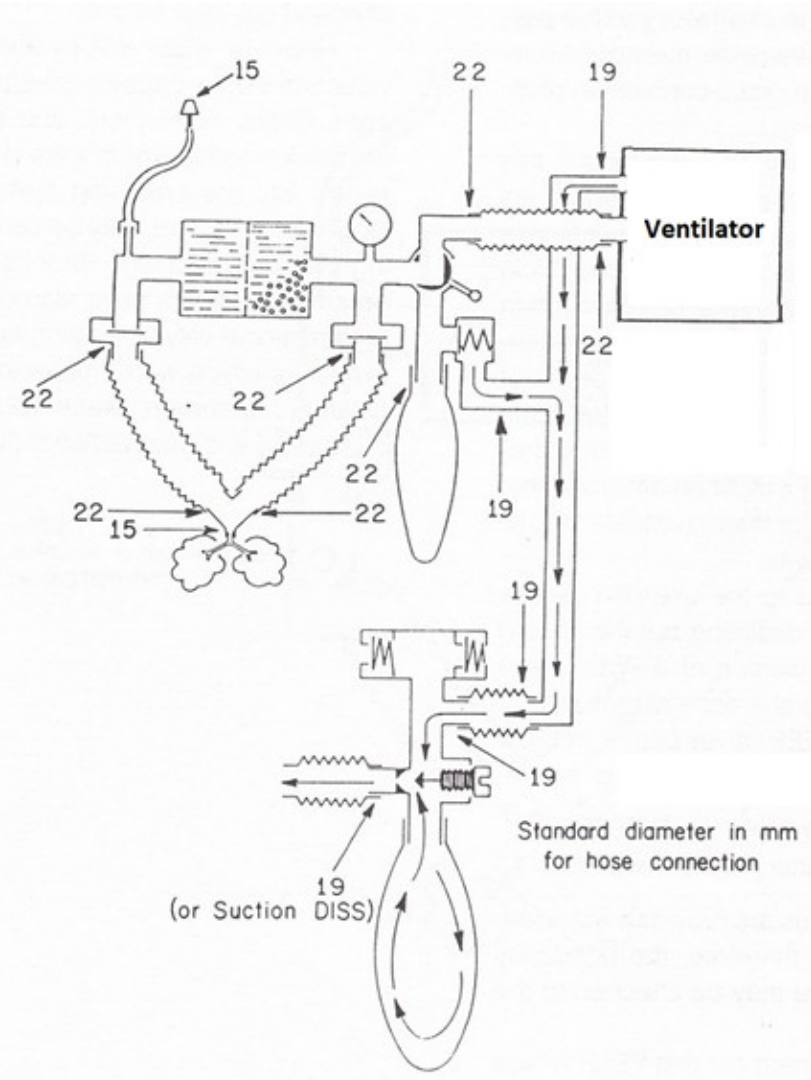


A low inspired oxygen concentration can result from problems anywhere along the path from the central gas supplies to the breathing circuit. The central or reserve oxygen supplies may be contaminated. Cross-connections (dashed *X's*) can occur within the hospital's central piping or the anesthesia machine internal piping. Oxygen flow may be disrupted owing to leaks, obstructions, or regular failures. Air may be entrained into the breathing circuit. Note that the oxygen flush system bypasses the anesthesia machine's internal piping, flowmeters, and vaporizers.

Standard Diameters in Millimeters for Hose Connections (15, 19 & 22 mm)

Different diameters for hose terminals → ↓ the possibility of misconnection

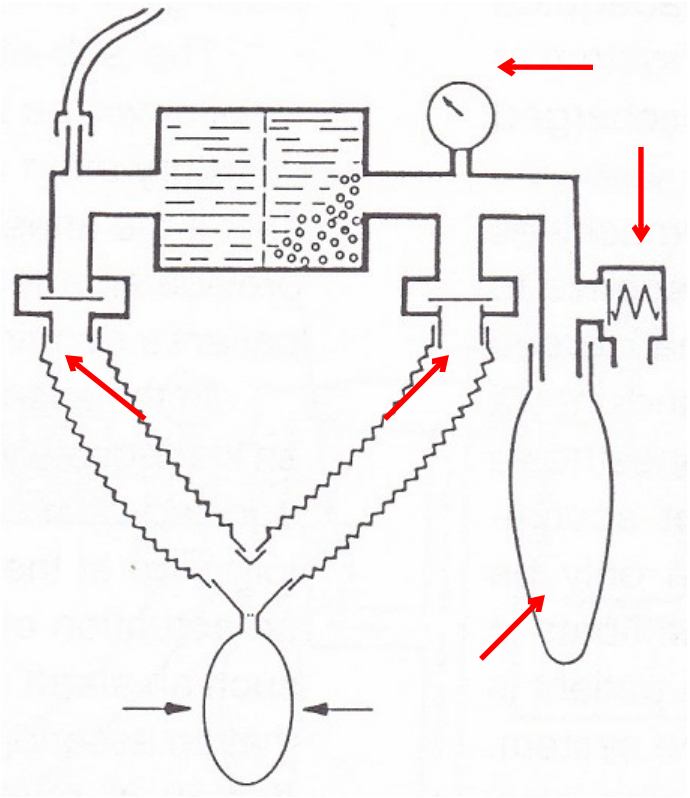
Misconnection → occlusion in BS



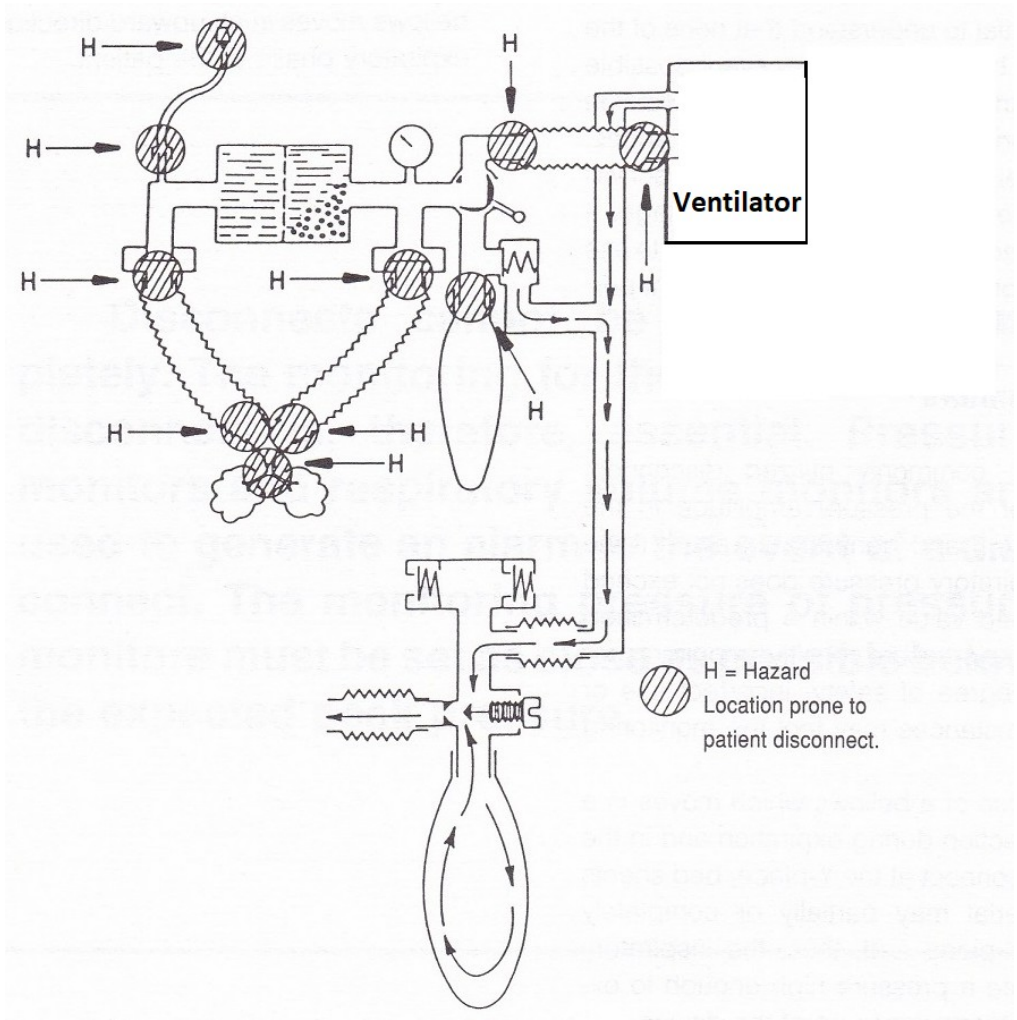
The Use of a Bellows or Self-Inflating Resuscitation Bag for Checking Out the Breathing System before Use

Observe:

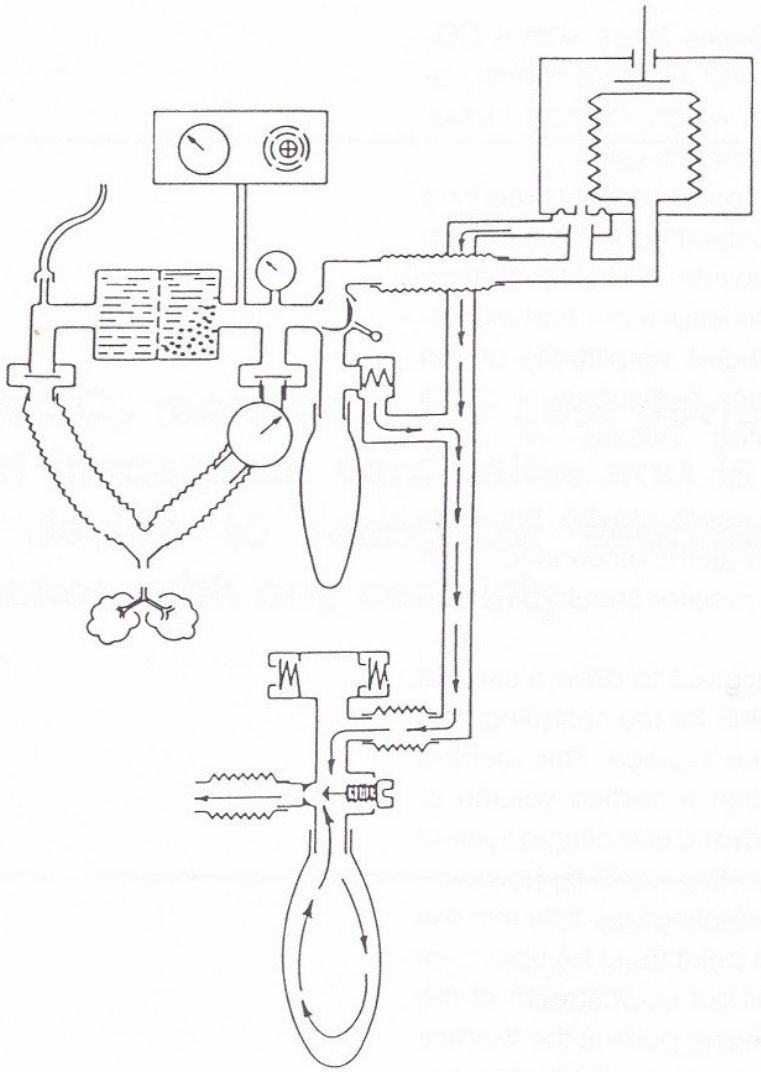
- Function of I & E valves
- System P gauge
- Movement of rebreathing bag
- Function of APL valve



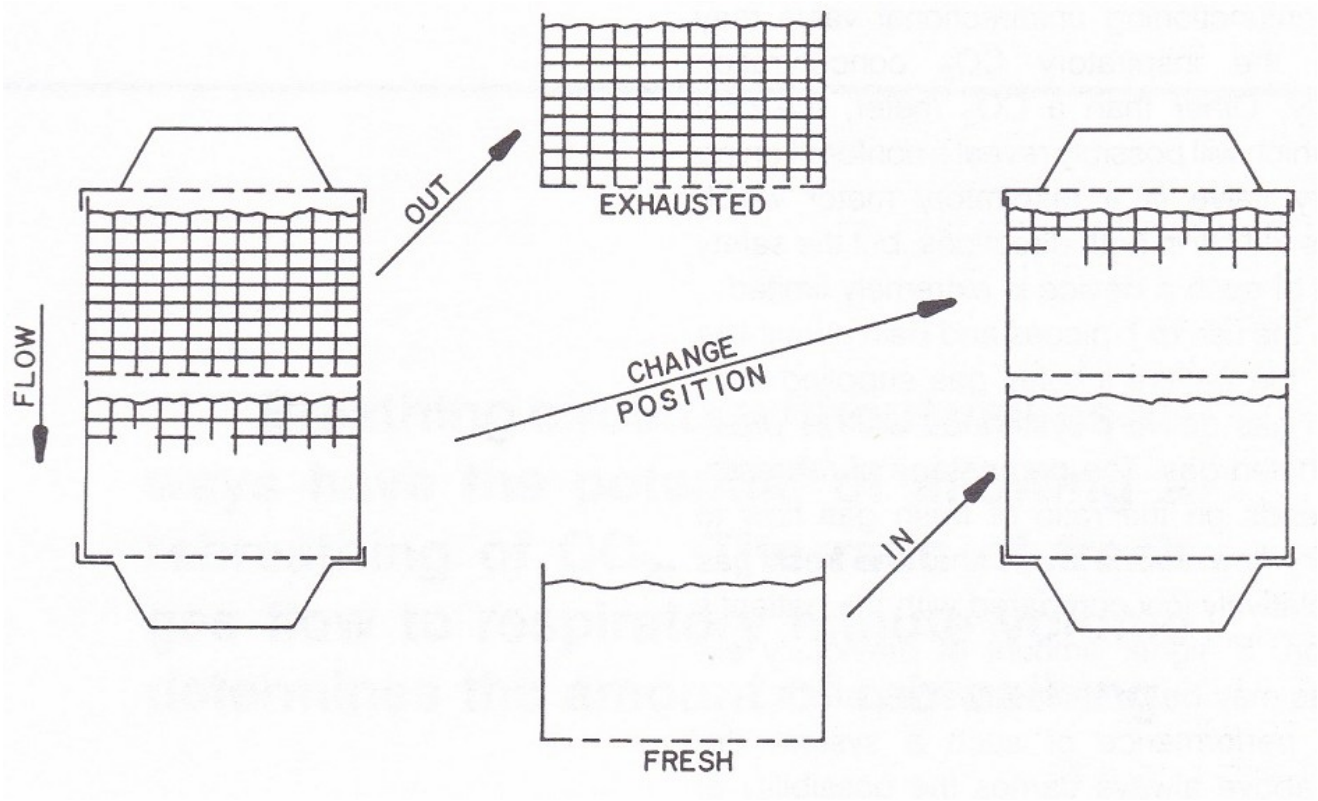
Connecting Points with a Potential for Disconnects in Breathing Systems



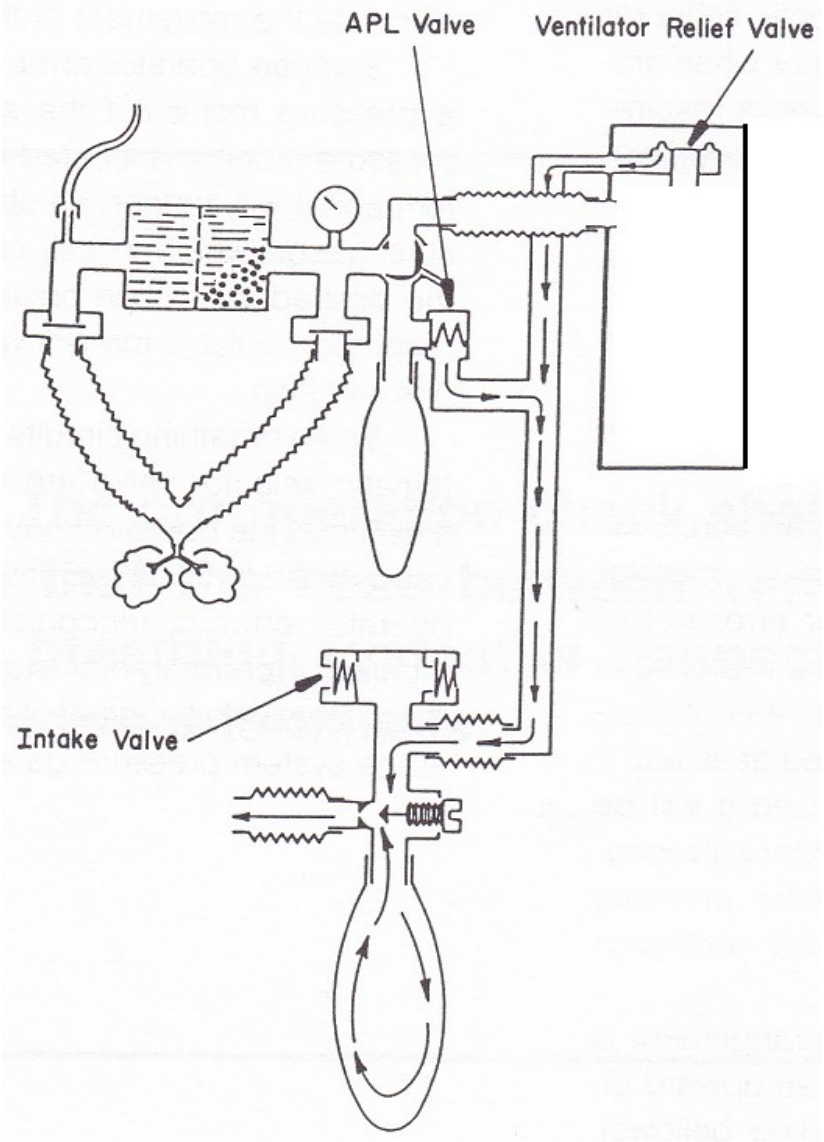
Safety Potential in an Ascending Ventilator Bellows Arrangement



Switching of Absorber Canisters



Malfunctioning of Scavenger Systems



Anesthesia Machine Obsolescence

Absolute criteria:

1. Lack of essential safety features such as:
   A. O_2/N_2O proportioning system
   B. O_2 failure safety device (‘‘fail--safe’’ system)
   C. O_2 supply failure alarm
   D. vaporizer interlock device
   E. noninterchangeable, gas-specific pinindexed and diameter-indexed safety systems for gas supplies.
2. Presence of unacceptable features such as:
   A. measured flow vaporizers (e.g., Copper Kettle)
   B. more than one flow control knob for a single gas delivered to the common gas outlet
   C. vaporizer with a dial such that the concentration increases when the dial is turned clockwise
   D. connections in the scavenging system that are the same (15 or 22mm diameter) as in the breathing system.
3. Adequate maintenance no longer possible

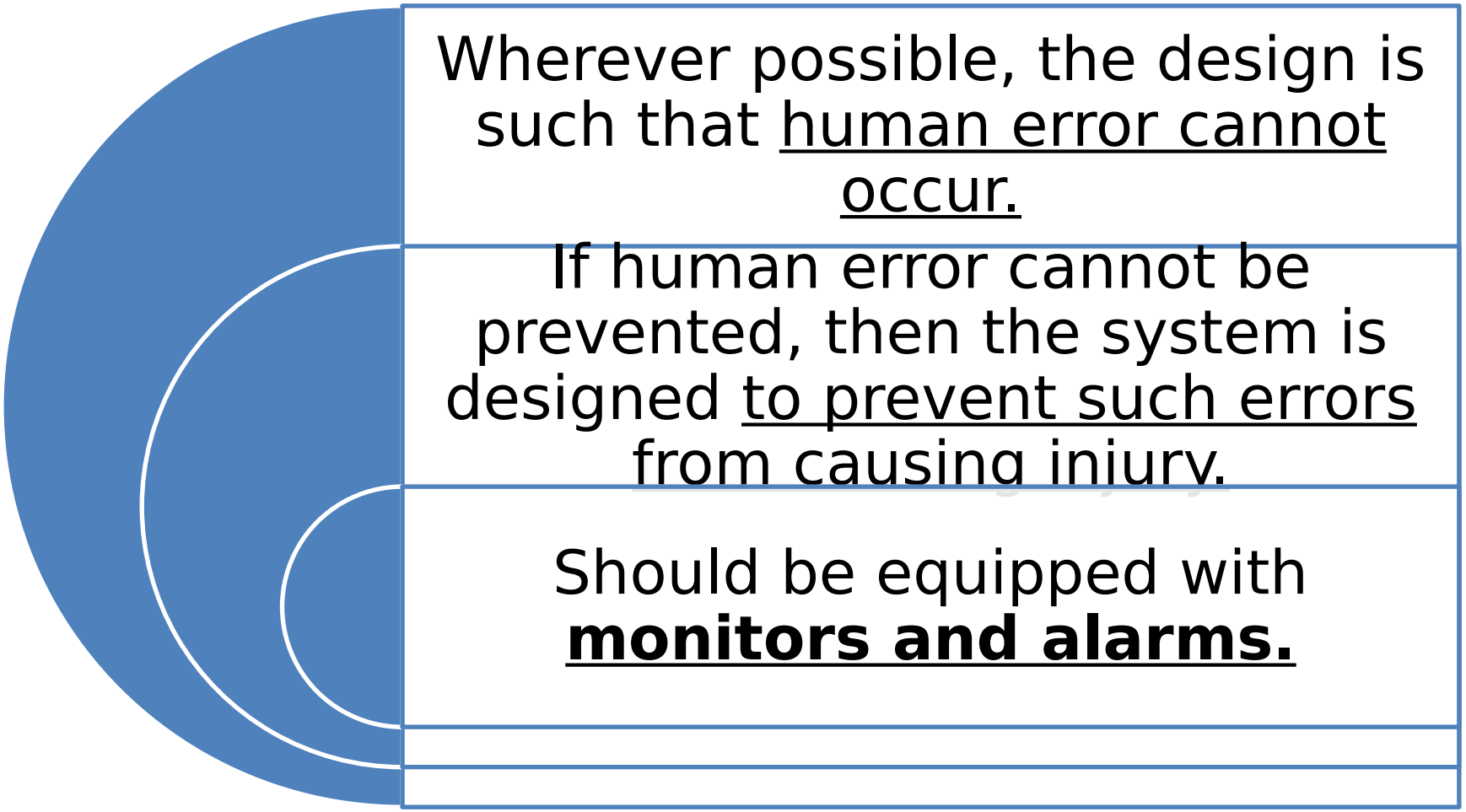
Relative criteria:

1. Lack of certain safety features such as
    A. a manual/automatic bag/ventilator selector switch
    B. a fluted O_2 flow-control knob that is larger than the other gas flow-control knobs
    C. an O_2 flush control that is protected from unintentional activation
    D. an antidisconnection device at the common gas outlet
    E. an airway pressure alarm.
2. Problems with maintenance.
3. Potential for human error.
4. Inability to meet practice needs such as
    A. accepting vaporizers for newer agents
    B. ability to deliver low fresh gas flows (FGFs)
    C. a ventilator that is not capable of safely ventilating the lungs of the target patient population.

Design Features of New Workstations

Modern anesthesia delivery systems and workstations contain pneumatic, mechanical, and electronic components that are extremely reliable so that unexpected ‘‘pure’’ failure of equipment is rare in a system that has been well maintained and properly checked before use.

Approach in the design for increased safety



The Anesthesia Breathing System

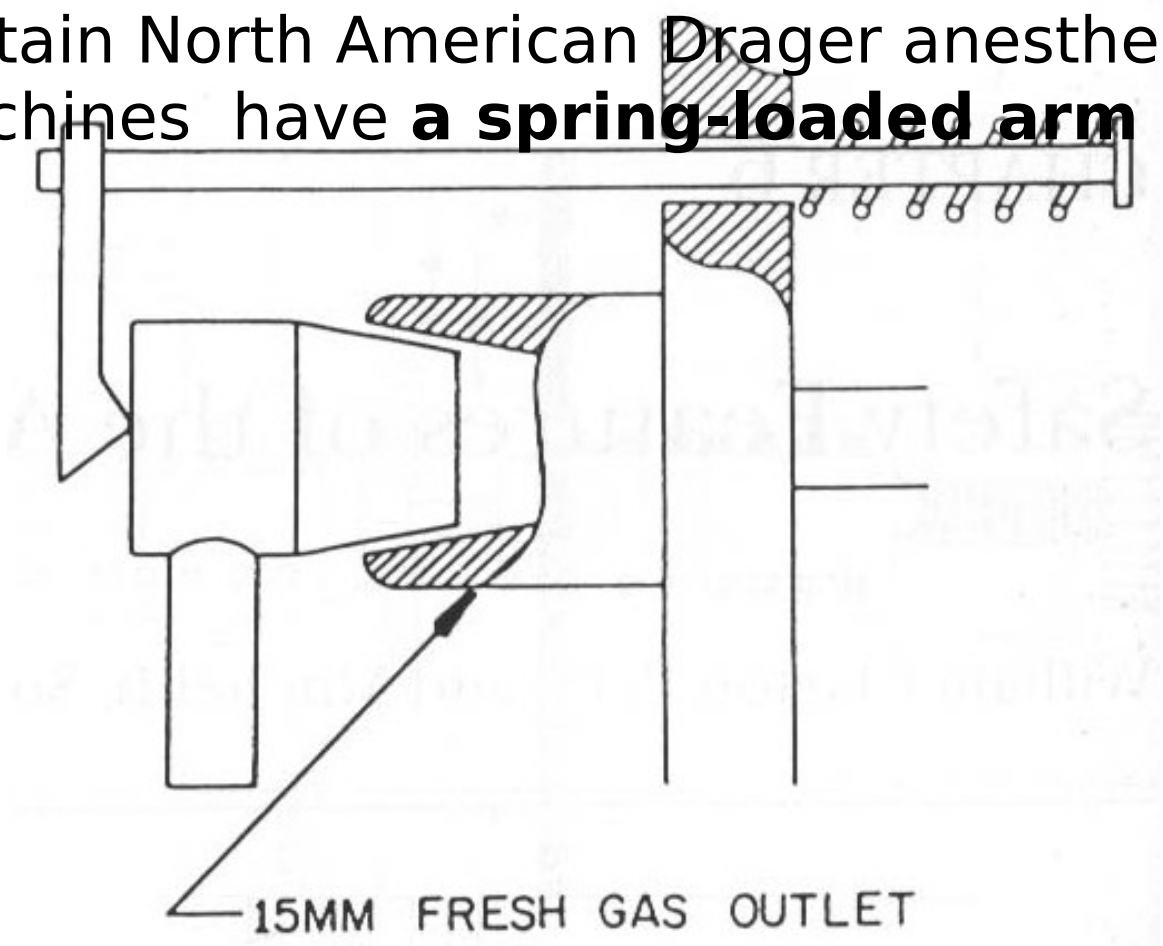
- The bag-ventilator selector switch (older design: 5 steps, each step→ error)
- PEEP valve: integrated component of the BS or built into the ventilator (older design: freestanding→ mistakenly placed into the inspiratory limb→ complete obstruction)
- Hoses and connections (new design ↓ their number)
- Fresh gas hose disconnection: prevented by:
  - Retaining devices
  - Connection is not accessible
- Filters and humidifiers can become blocked
- Failure to remove the plastic wrapping from facemasks or breathing circuits

Design changes made

Preventing fresh gas hose disconnection

OLD

1. Certain North American Drager anesthesia machines have **a spring-loaded arm**

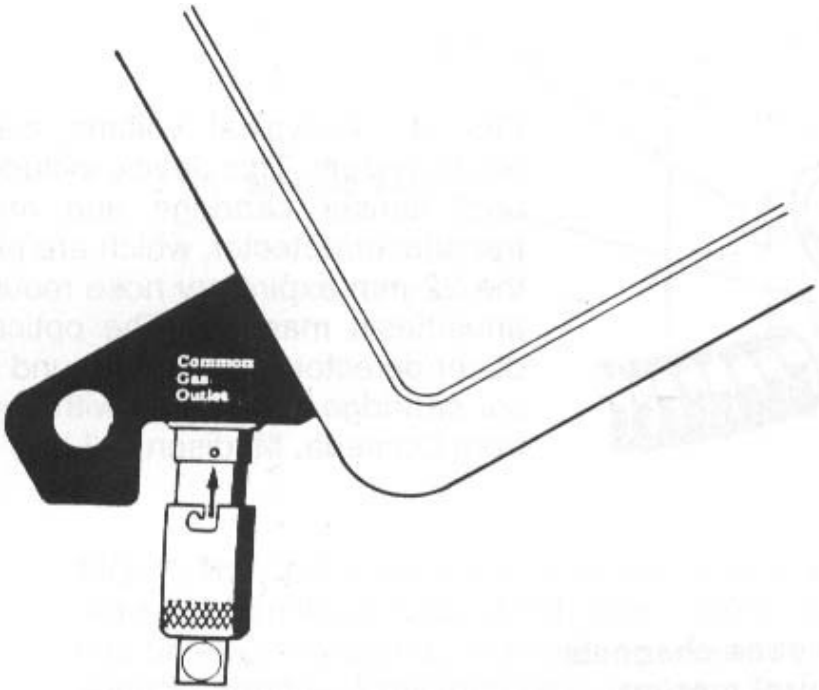


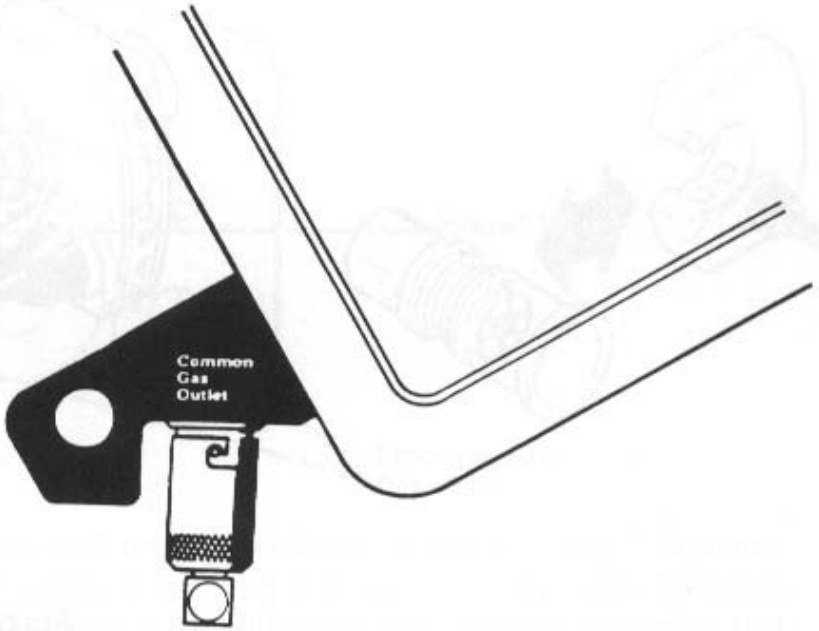

FRESHGAS OUTLET


FRESHGAS OUTLET

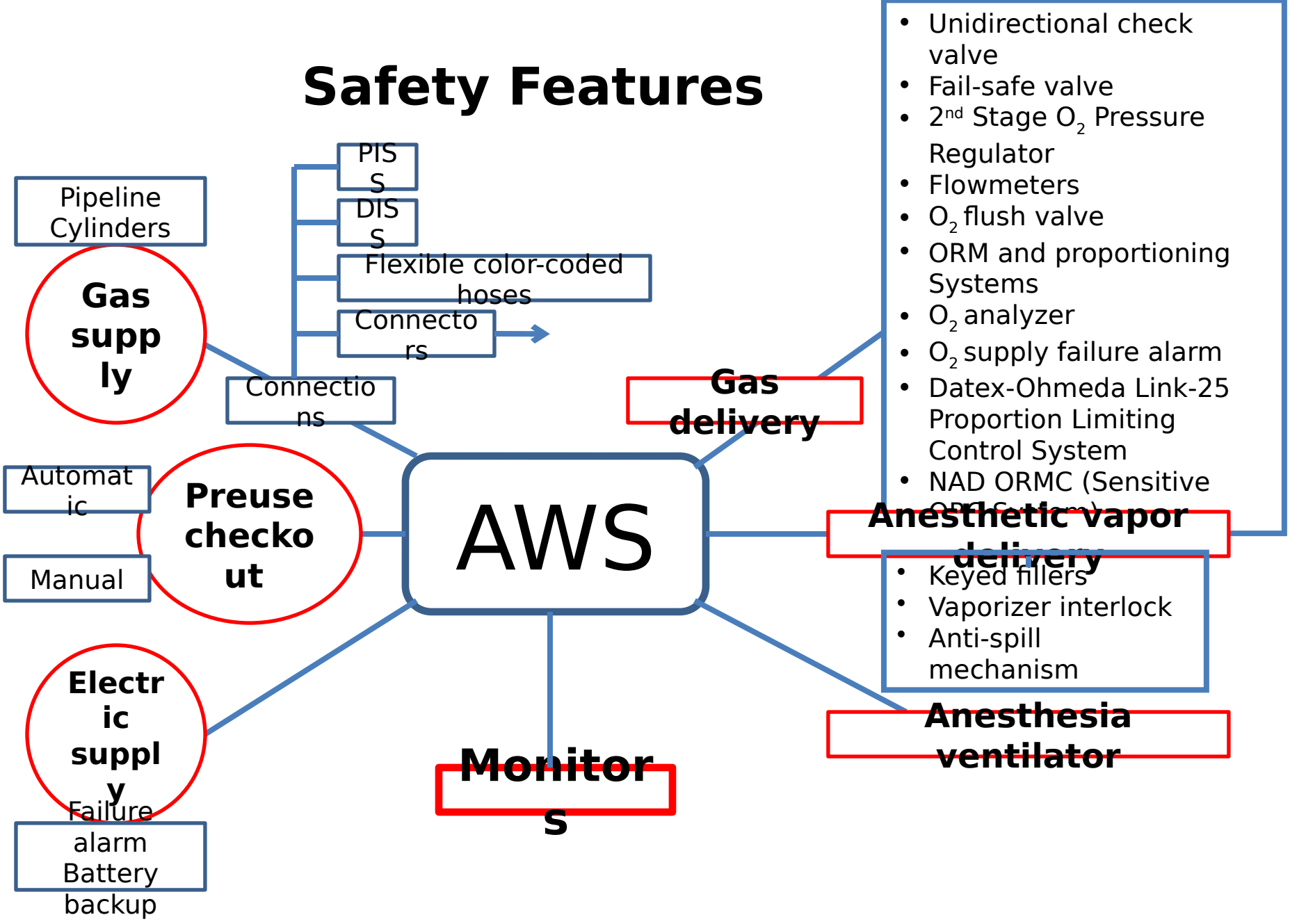
2. Certain Ohmeda anesthesia machines have **a locking connector** which includes a coiled spring, an L-shaped slot and a mating pin for this purpose

OLD





Safety Features



Monitoring the Breathing System

- Perhaps the greatest advance in the design of modern anesthesia gas delivery systems has been the incorporation of integrated monitoring and prioritized alarm systems.
- With appropriate monitors, alarm threshold limits, and alarms enabled and functioning, such monitoring should detect most, but not all, delivery system problems

Monitoring the Breathing System

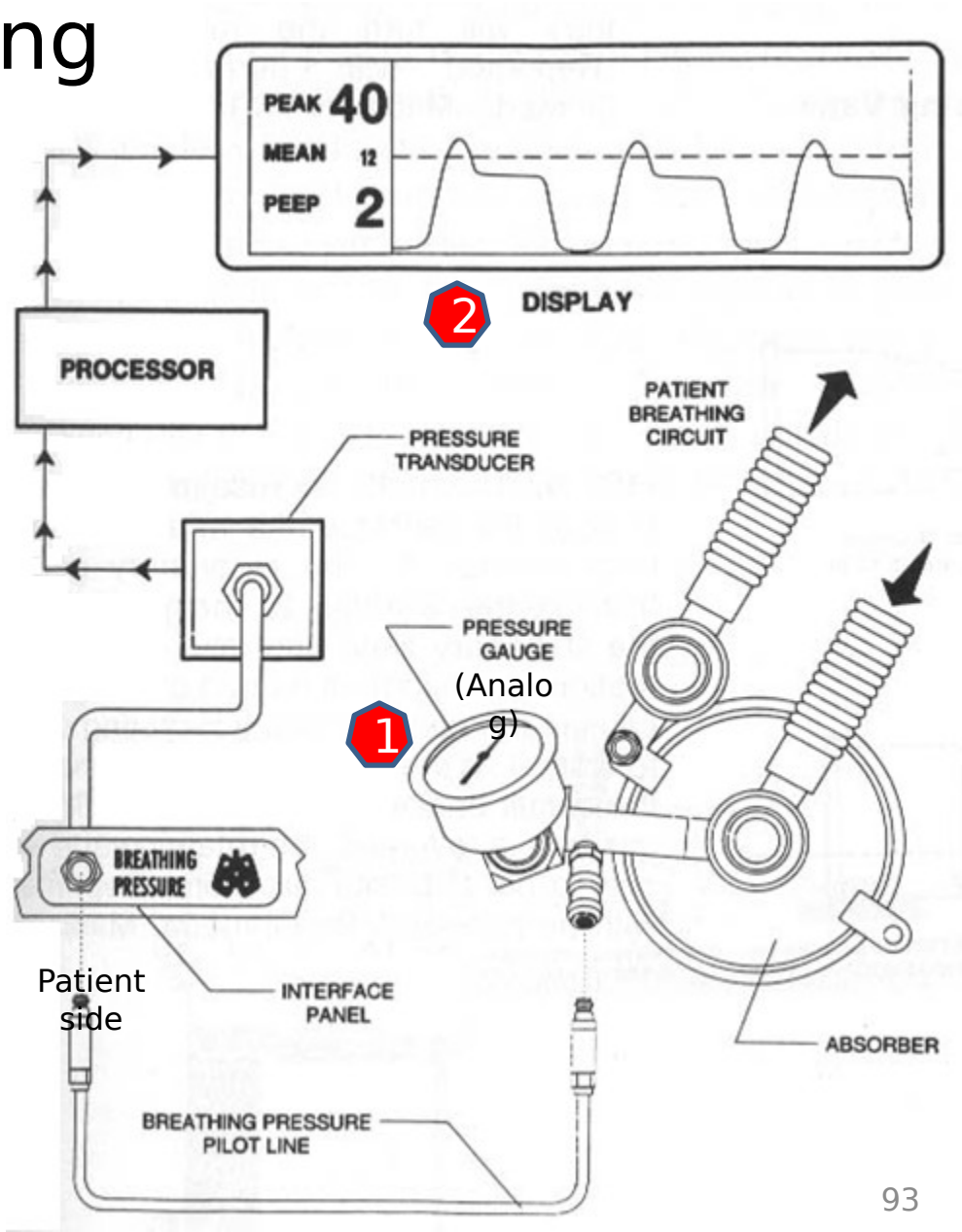
1. Pressure
   a) P monitoring
   b) Alarms: low P, continuing P, high P, subatmospheric P
2. Volume (spirometry)
3. $P_{ET}CO_2$
4. Respiratory gas composition
5. Gas flows

Pressure Monitoring

1. Mechanical analog P gauge
2. Electronic display:

The pressure waves are converted to **electrical impulses** that are analyzed by a **microcomputer**.

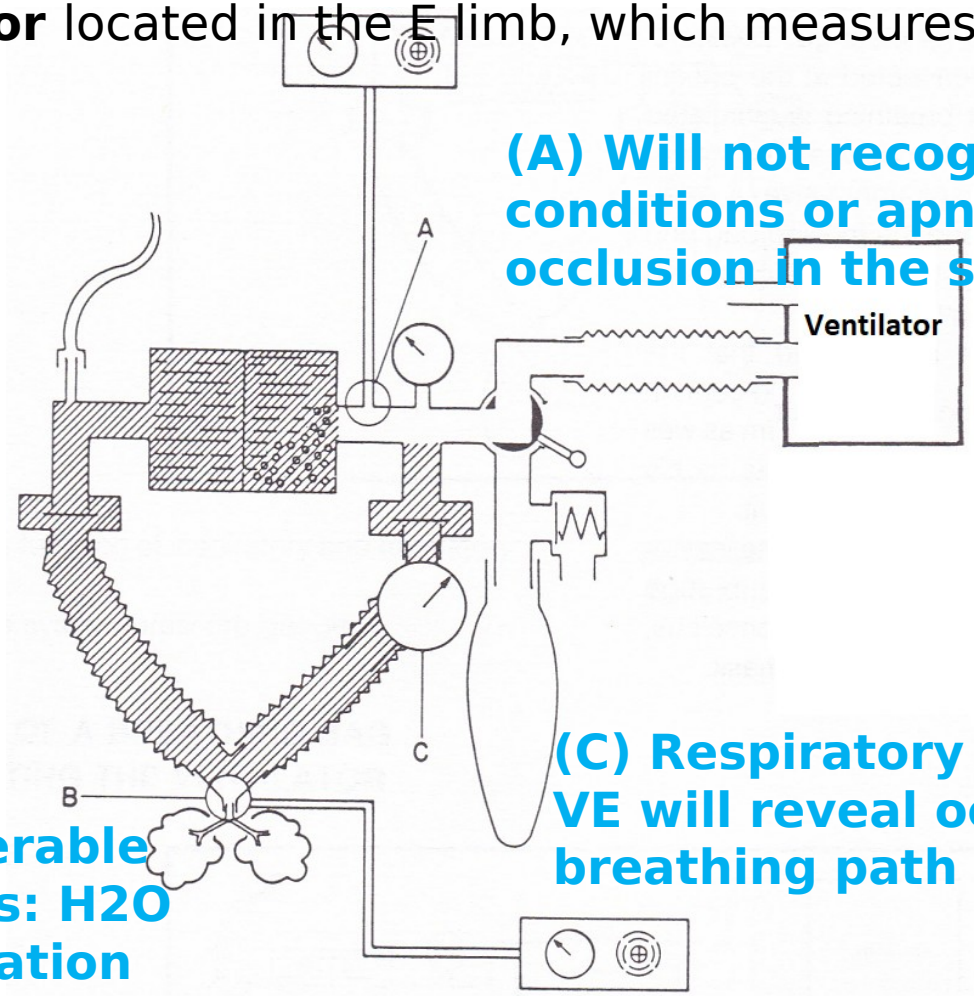
If the user has altered the manufacturer's original breathing **circuit configuration**, the system may fail to detect certain cases of abnormal Paw. Monitoring of circuit integrity and correct configuration is essential.



Sensing Points for Pressure Alarms

A pressure monitor is not designed to warn of occlusion or misconnections in the BS & should not be relied upon for that purpose

Occlusion in the BS will be recognized by a **respiratory flow monitor** located in the E limb, which measures VT, f & VM

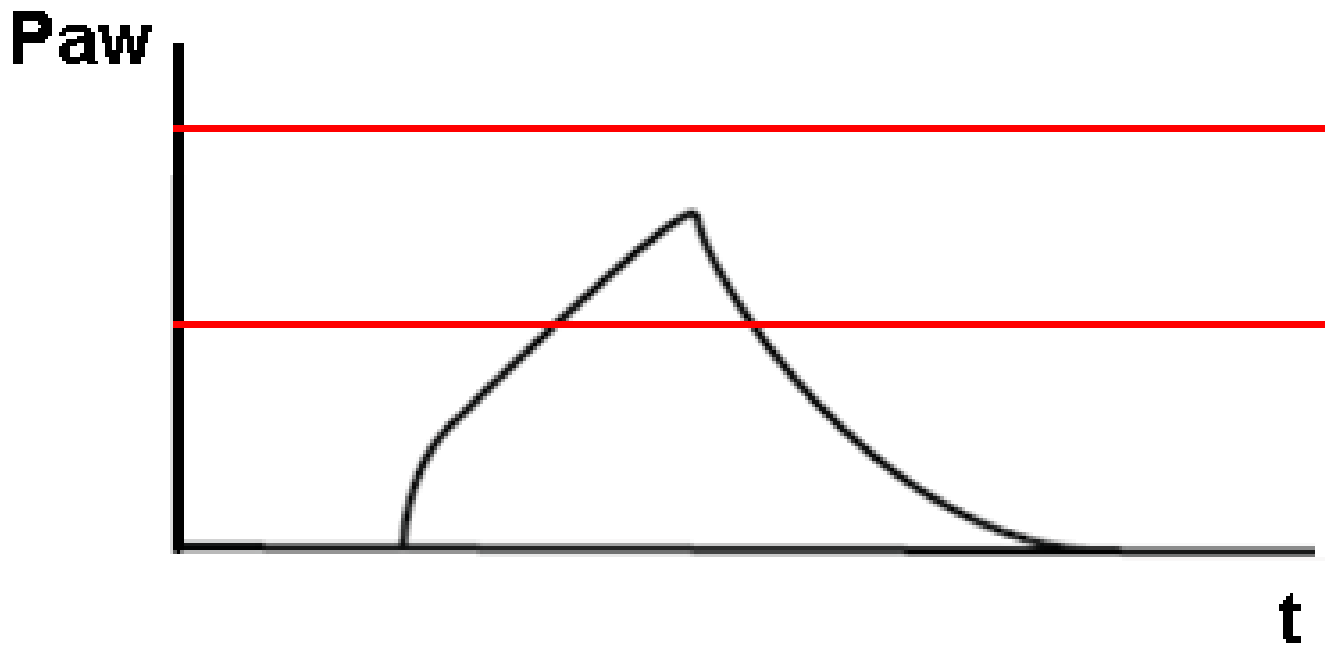


(A) Will not recognize adverse P conditions or apnea in the event of an occlusion in the shaded area

(C) Respiratory meter measuring VE will reveal occlusion in the breathing path

(B) Preferable
Problems: H2O condensation
Difficult

PIP Alarms

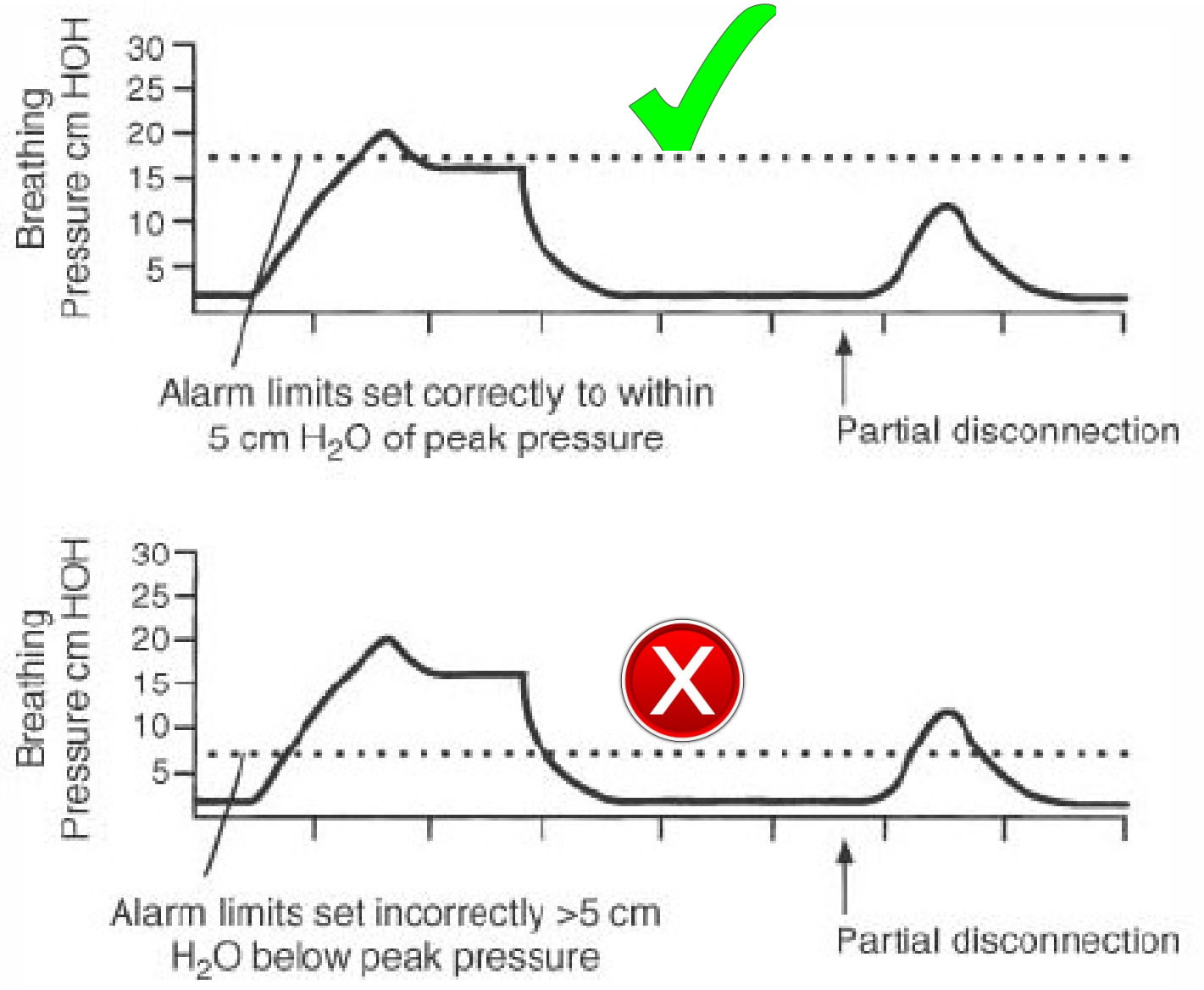


High-Pressure Alarm

- In new AWS, threshold can be adjusted by the user, with a default setting of 40 cm H_2O
  - The ability to set the high-P limit to values of 60-65 cm H_2O may be necessary to permit adequate ventilation of patients whose lungs have ↓C (stiff)
- In some older models, it is not user-adjustable & have a threshold of 65 cm H_2O → too high to detect an

Low-pressure Alarm (Low-pressure Monitor)

- Sometimes have been called Disconnect Alarm (monitor). This is a misnomer because it monitors P.
- An **audible and visual alarm** will be activated within 15 seconds when **a minimum P threshold is not exceeded** within the circuit.
- This minimum P threshold should be adjusted to be **just < PIP** so that any slight ↓ will trigger the alarm (if not close to PIP → a circuit leak or disconnect may go undetected).
- A small-diameter ETT (e.g., 3-mm) might be pulled out. Because the tube has a high R (& P= RxF), the P↑ in the circuit with each PPV may satisfy the low-P alarm threshold & the disconnect may go undetected by P monitoring.
- **Thus, NOT all disconnections can be detected with pressure actuated disconnect alarms.**


Breathing
Pressure cm HOH
30
25
20
15
10
5
Alarm limits set correctly to within
5 cm H_2O of peak pressure
Partial disconnection
Breathing
Pressure cm HOH
30
25
20
15
10
5
Alarm limits set incorrectly >5 cm
H_2O below peak pressure
Partial disconnection

- Display:
  - The circuit P waveform
  - High- and low-pressure alarm thresholds
  - The high-P alarm threshold can be adjusted by the user
  - The low-P alarm threshold can be:
    1. Automatically enabled whenever the ventilator is turned on (new AWS)
    2. Bracketed automatically to the existing PIP by pressing one button (auto limits) (new AWS)
    3. Adjusted by the user (user-variable) (old models)
    4. Provided by a limited choice of settings (manual set) (e.g., 8, 12, or 26 cm H_2O) (older models) → may limit the monitor's sensitivity to detect small decreases in PIP → readjust the ventilator settings such that the PIP just exceeds one of the available low-P alarm limits

Continuing Pressure Alarm

- When > 10 cm H_2O > 15 sec
- Causes (gradual ↑ in circuit P):
  - Malfunction of the ventilator P-relief valve (stuck closed)
  - Waste gas scavenging system occlusion: the rate of P↑ will depend on FGF rate

Subatmospheric Pressure Alarm

- Activated when P < -10 cm H_2O
- $\rightarrow$
  - -ve P barotrauma
  - -ve P pulmonary edema
- May be the result of:
  - Spontaneous respiratory efforts (under MV)
  - Malfunctioning scavenging system
  - A side-stream sampling respiratory gas analyzer or capnography when FGF is inadequate
  - A suction catheter is passed into the airway
  - Suction is applied through the working channel of a fiberscope

Spirometry/Volume Monitoring

- Exhaled V_T & V_M
- Location: near the E unidirectional valve
- Used to monitor:
  - Ventilation
  - Circuit integrity
- Circuit disconnect → low V_T alarm if appropriate limits have been set
- In some older units the low-V alarm limit threshold may not be user-adjustable (e.g., fixed at 80 ml).
- Hanging bellows → disconnection may fail to trigger a low V_T alarm

- Because the spirometry sensor is usually placed by the E valve at the CO_2 absorber → it does not measure the actual I or E V_T. It measures V_E + V that has been compressed in the circle system tubing during I
- High V_T alarm is also useful. In older AWS: ↑GF entering the BS during I (when the BS is closed by closing the ventilator P-relief valve) → ↑V_T.
- This ↑may be due to:
  - FGF
  - ↑I:E
  - Through a hole in the bellows

  This is particularly hazardous for the pediatric patient

- Modern electronic AWS incorporate features designed to ensure that the patient will always receive the intended V_T
- Automated checkout is performed to ensure that there are no leaks and to measure the C (compliance) of the BS
- FGD (fresh gas decoupling) ensures that FGF (fresh gas flow) does not $\uparrow V_T$
- A spirometer that senses GF (gas flow) direction can alert to a situation of reversed GF (incompetent E valve, leak in the BS between the E valve and the spirometer)

Gas Composition in the Breathing System

- O_2 analyzer
- Capnography
- N_2O
- Anesthetic agents
- Nitrogen

Monitoring Gas Flows and Side Stream Spirometry

- Side stream sampling (or diverting) gas analyzers are used to monitor I & ET % of CO_2, O_2, N_2O & the anesthetic agent.
- Gas is sampled from an adaptor close to the patient's airway →sampling tube →analyzer →BS or scavenging system
- The addition of Pitot tube flow sensors → monitoring of P, F, V & respired gas composition at the patient's airway = side stream spirometry

- V_T and V_M: I *vs* E → detection of a leak distal to the airway adapter

  I-E difference may be due to:
  - Deflated TT (tracheal tube)cuff
  - Poorly fitting LMA
- Loops:
  - F/V
  - P/V
- With appropriate alarm limits → greater patient safety because it is less likely to be deceived than are monitors whose sensors are remote from the patient's airway

- Rather than using the disposable Pitot tube F (flow) sensor placed by the airway, many AWSs use F sensors placed in the vicinity of the I & E unidirectional valves in the circle system.
- These sensors measure the F into the I limb of the circle system during I and the F from the E limb during E.
- The output of these sensors is compared and a difference may indicate a leak in the circuit.
- In some AWSs, the sensors' output is used to correct V_T for changes in FGF and other aspects of ventilator control.

Alarms

- Problems with monitors or alarms:
  - Absent
  - Broken
  - Disabled
  - Ignored
  - Led to an inadequate response by the caregiver

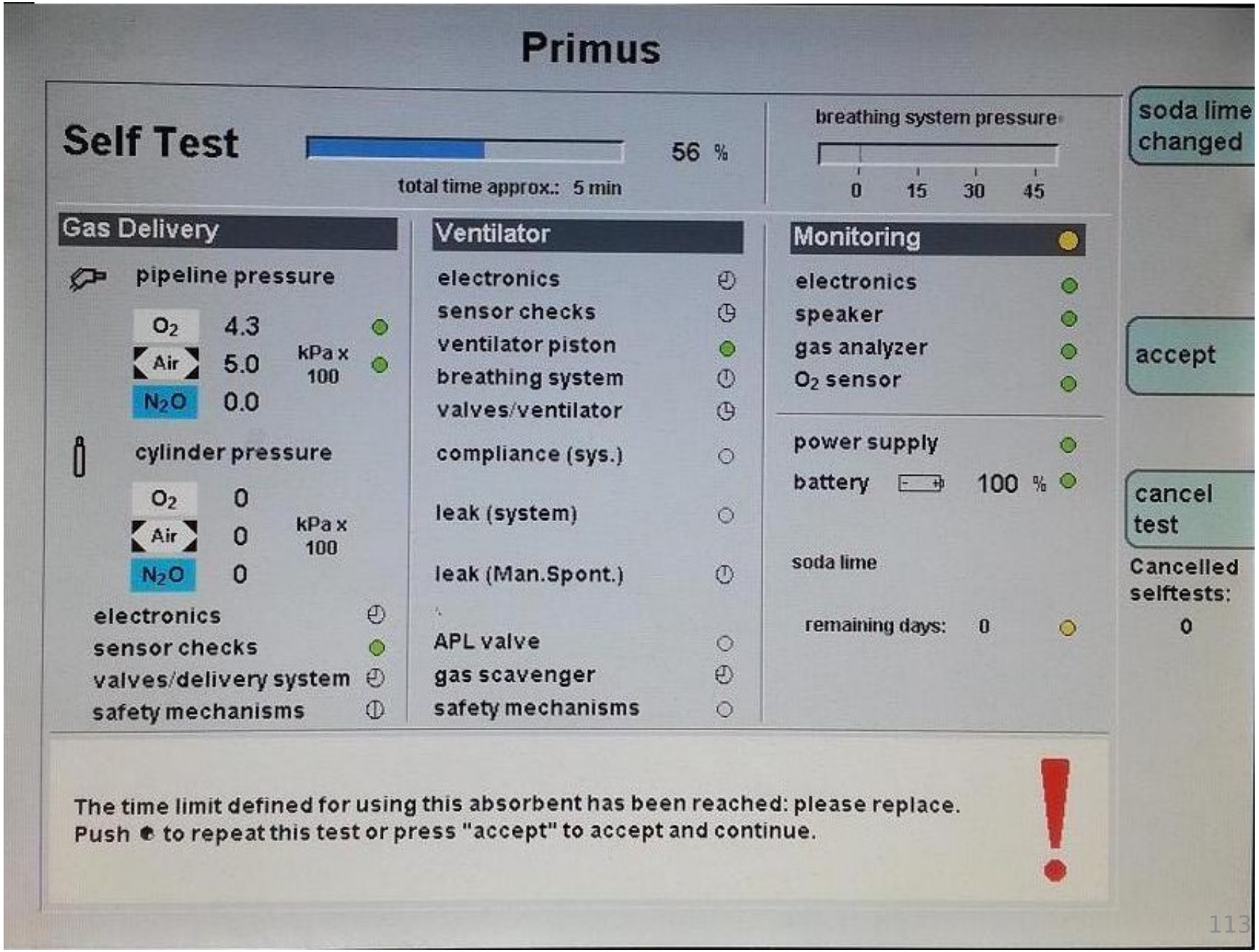
- Monitors should be:
  - User friendly
  - Automatically enabled when needed
  - Have alarm thresholds easily bracketed to prevailing “normal” conditions
  - Intelligent (smart)
  - Alarm signal should be appropriate in terms of:
    - Urgency
    - Specificity
    - Audibility (volume): should be tested & adjusted. The silencing of audible alarms (because “false alarms are annoying”) should be discouraged

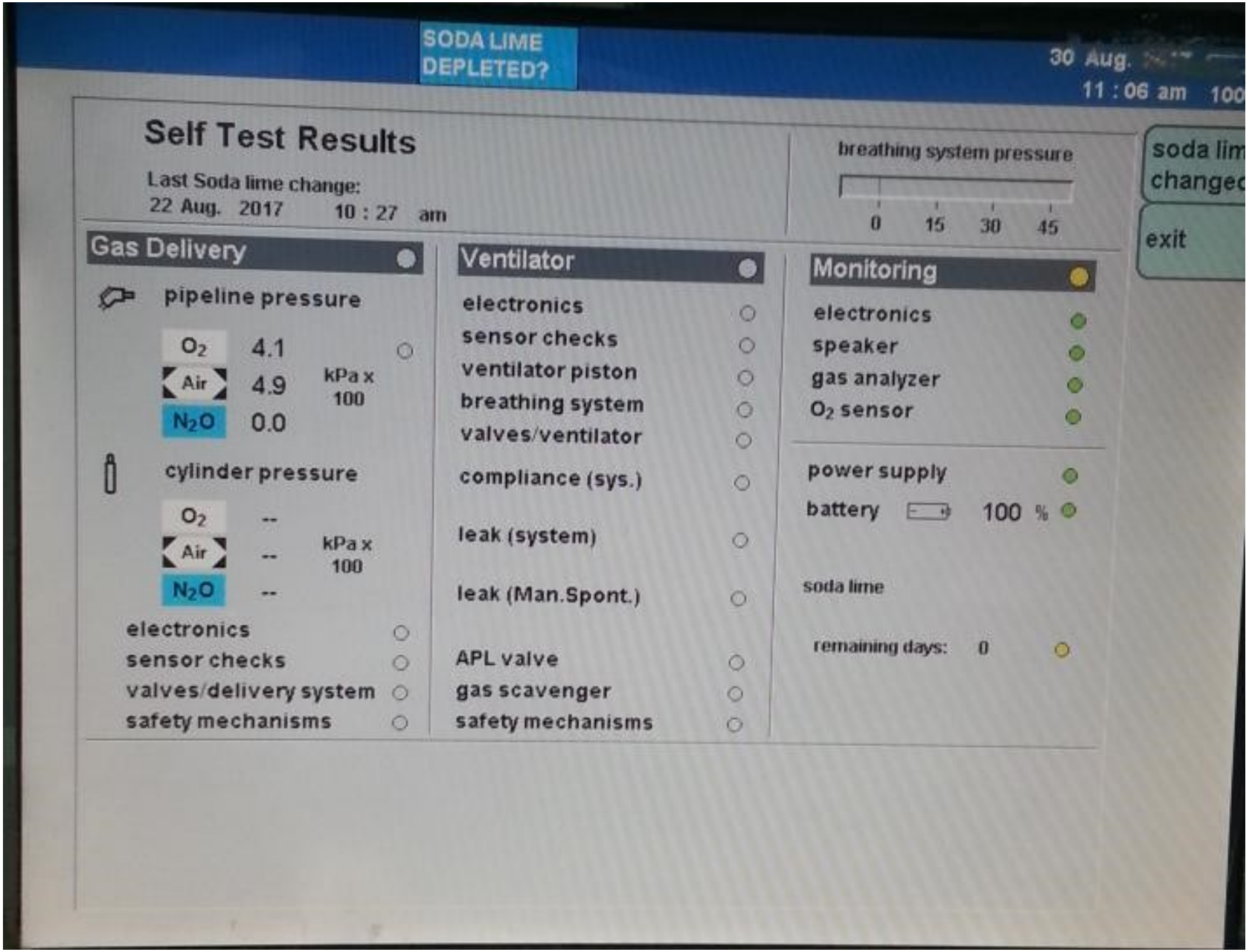
Other Potential Problems: Fires from interactions of anesthetics with desiccated absorbent

- Sevoflurane → CO & flammable gases
- Baralyme +:
  - Sevoflurane → >200 ℃ → fire
  - Desflurane & Isoflurane → 100 ℃

  So, baralyme has been withdrawn from the market
- Soda lime: ↓strong base than baralyme → ↓hazard
- Less basic CO_2 absorbents are now available; e.g., Amsorb:
  - No strong base (Na, K, or Ba hydroxides)
  - It changes color from white to pink when desiccated

Preuse Checkout


Primus
Self Test
56 %
total time approx.: 5 min
breathing system pressure
0
15
30
45
soda lime changed
Gas Delivery
pipeline pressure
O2 4.3
Air 5.0
N2O 0.0
kPa x 100
cylinder pressure
O2 0
Air 0
N2O 0
kPa x 100
electronics
sensor checks
valves/delivery system
safety mechanisms
Ventilator
electronics
sensor checks
ventilator piston
breathing system
valves/ventilator
compliance (sys.)
leak (system)
leak (Man.Spont.)
APL valve
gas scavenger
safety mechanisms
Monitoring
electronics
speaker
gas analyzer
O2 sensor
power supply
battery 100 %
soda lime
remaining days: 0
accept
cancel test
Cancelled selftests:
0
The time limit defined for using this absorbent has been reached: please replace.
Push to repeat this test or press "accept" to accept and continue.


SODA LIME DEPLETED?
30 Aug.
11 : 06 am
Self Test Results
Last Soda lime change:
22 Aug. 2017 10 : 27 am
breathing system pressure
0 15 30 45
soda lim changed
exit
Gas Delivery
pipeline pressure
O2 4.1
Air 4.9
N2O 0.0
kPa x 100
cylinder pressure
O2 --
Air --
N2O --
kPa x 100
electronics
sensor checks
valves/delivery system
safety mechanisms
Ventilator
electronics
sensor checks
ventilator piston
breathing system
valves/ventilator
compliance (sys.)
leak (system)
leak (Man.Spont.)
APL valve
gas scavenger
safety mechanisms
Monitoring
electronics
speaker
gas analyzer
O2 sensor
power supply
battery 100 %
soda lime
remaining days: 0

FDA 1993

FDA anesthesia apparatus checkout recommendations

This checkout, or a reasonable equivalent, should be conducted before the administration of anesthesia. These recommendations are valid only for an anesthesia system that conforms to current and relevant standards and includes an ascending bellows ventilator and at least the following monitors: capnograph, pulse oximeter, oxygen analyzer, respiratory volume monitor (spirometer), and breathing system pressure monitor with high- and low-pressure alarms.

This is a guideline which users are encouraged to modify to accommodate differences in equipment design and variations in local clinical practice. Such local modifications should have appropriate peer review. Users should refer to the operator's manual for the manufacturer's specific procedures and precautions, especially the manufacturer's low-pressure leak test (step 5).

Emergency ventilation equipment

Step 1.[a] Verify that backup ventilation equipment is available and functioning.

High-pressure system

Step 2.[a] Check oxygen cylinder supply.

a. Open oxygen cylinder and verify at least half full (about 1,000 psig, pounds per square inch gauge).
b. Close cylinder.

Step 3.[a] Check central pipeline supplies.

a. Check that hoses are connected and pipeline gauges read ~50 psig.

Low-pressure system

Step 4.[a] Check initial status of low-pressure system.

a. Close flow control valves and turn vaporizers off.
b. Check fill level and tighten vaporizers' filler caps.

Step 5.[a] Perform leak check of machine low pressure system.

a. Verify that the machine master switch and flow control valves are off.
b. Attach "suction bulb" to common (fresh) gas outlet.
c. Squeeze bulb repeatedly until fully collapsed.
d. Verify that bulb stays *fully* collapsed for at least 10 seconds.
e. Open one vaporizer at a time and repeat steps c and d as above.
f. Remove suction bulb and reconnect fresh gas hose.

Step 6.[a] Turn on machine master switch and all other necessary electrical equipment.

Step 7.[a] Test flowmeters.

a. Adjust flow of all gases through their full range, checking for smooth operation of floats and undamaged flowtubes.
b. Attempt to create a hypoxic oxygen/nitrous oxide mixture and verify correct changes in flow and/or alarm.

FDA
1993

Scavenger system

Step 8.[a] Adjust and check scavenging system.

a. Ensure proper connections between the scavenging system and both adjustable pressure-limiting (APL, pop-off) valve and ventilator relief valve.
b. Adjust waste gas vacuum (if possible).
c. Fully open APL valve and occlude Y-piece.
d. With minimum oxygen flow, allow scavenger reservoir bag to collapse completely and verify that absorber pressure gauge reads about zero.
e. With the oxygen flush activated, allow the scavenger reservoir bag to distend fully, and then verify that absorber pressure gauge reads less than 10 cm H_2O.

Breathing system

Step 9.[a] Calibrate oxygen monitor.

a. Ensure that monitor reads 21% in room air.
b. Verify low oxygen alarm is enabled and functioning.
c. Reinstall sensor in circuit and flush breathing system with oxygen.
d. Verify that monitor now reads greater than 90%.



Step 10. Check initial status of breathing system.

a. Set selector switch to "Bag" mode.
b. Check that breathing circuit is complete, undamaged and unobstructed.
c. Verify that carbon dioxide absorber is adequate.
d. Install breathing circuit accessory equipment (e.g., humidifier, positive end expiratory pressure valve;) to be used during the case.

Step 11. Perform leak check of the breathing system.

a. Set all gas flows to zero (or minimum).
b. Close APL (pop-off) valve and occlude Y-piece.
c. Pressurize breathing system to about 30 cm H_2O with oxygen flush.
d. Ensure that pressure remains fixed for at least 10 seconds.
e. Open APL (pop-off) valve and ensure that pressure decreases.

FDA
1993

Manual and automatic ventilation systems

Step 12. Test ventilation systems and unidirectional valves.

a. Place a second breathing bag on Y-piece.
b. Set appropriate ventilator parameters for next patient.
c. Switch to automatic ventilator (Ventilator) mode.
d. Turn ventilator on and fill bellows and breathing bag with oxygen flush.
e. Set oxygen flow to minimum and other gas flows to zero.
f. Verify that during inspiration bellows delivers appropriate tidal volume and that during expiration bellows fills completely.
g. Set fresh gas to about 5 L/min.
h. Verify that ventilator bellows and simulated lungs fill *and empty* appropriately without sustained pressure at end expiration.
i. *Check for proper action of unidirectional valves.*
j. Examine breathing circuit accessories to ensure proper function.
k. Turn ventilator off and switch to manual ventilation (Bag/APL mode).
l. Ventilate manually and assure inflation and deflation of artificial lungs and appropriate feel of system resistance and compliance.
m. Remove second breathing bag from Y-piece.

Monitors

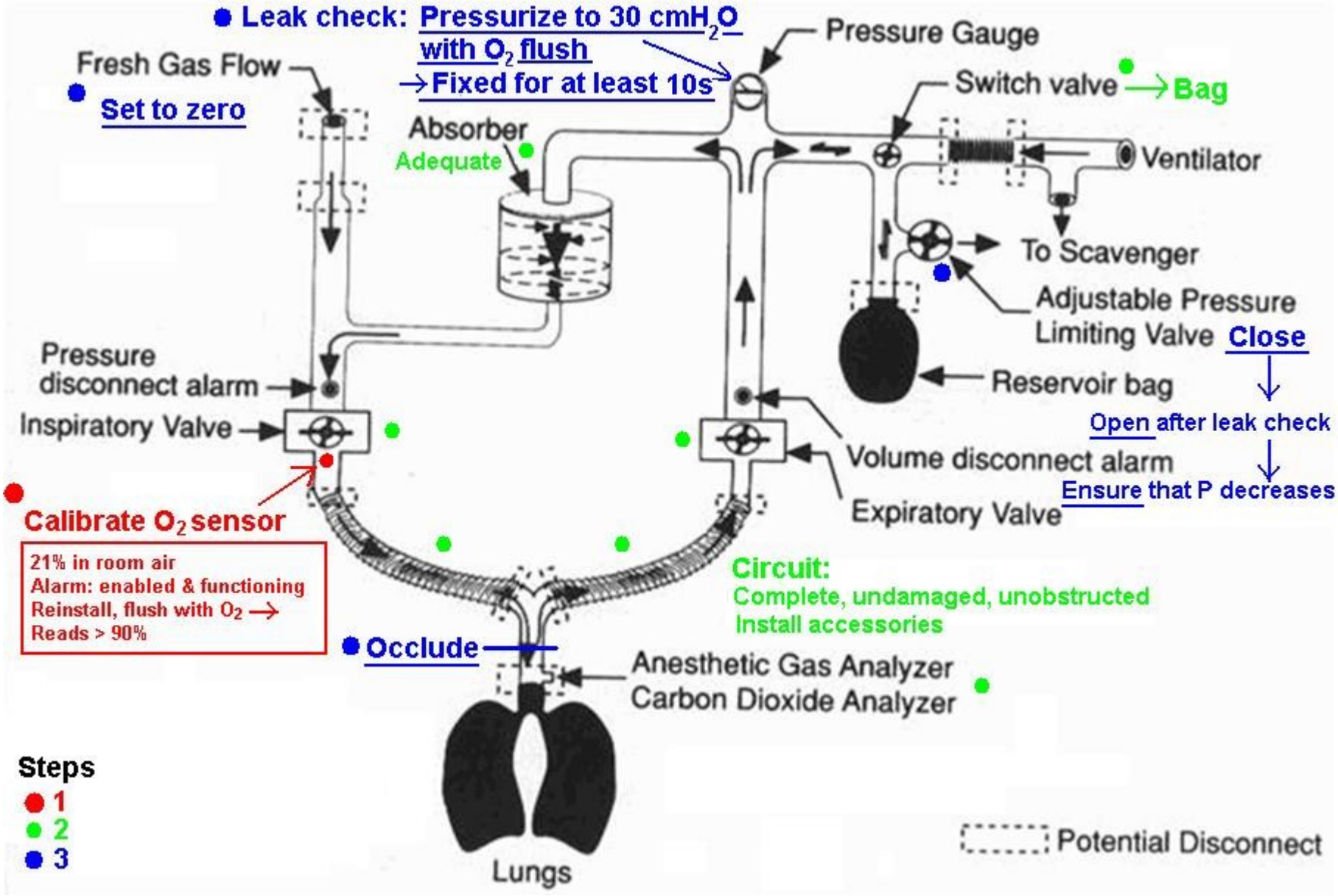
Step 13. Check, calibrate and/or set alarm limits of all monitors.

Capnometer
Pulse oximeter
Oxygen analyzer
Respiratory volume monitor (spirometer)
Pressure monitor with high and low airway alarms.

Final position

Step 14. Check final status of machine.

a. Vaporizers off.
b. APL valve open.
c. Selector switch to "Bag."
d. All flowmeters to zero.
e. Patient suction level adequate.
f. Breathing system ready to use.



Manual pre-use checkout of the BS (Steps 9, 10 and 11)

ASA 2008

Recommended Essential Steps in a Preanesthesia Checkout Procedure

TO BE COMPLETED DAILY, OR AFTER A MACHINE IS MOVED OR VAPORIZERS CHANGED

Item to Be Completed		Responsible Party
Item 1	Verify auxiliary oxygen cylinder and manual ventilation device (Ambu Bag) are available and functioning	Provider and technician
Item 2	Verify patient suction is adequate to clear the airway	Provider and technician
Item 3	Turn on anesthesia delivery system and confirm that AC power is available.	Provider or technician
Item 4	Verify availability of required monitors, including alarms	Provider or technician
Item 5	Verify that pressure is adequate on the spare oxygen cylinder mounted on the anesthesia machine	Provider and technician
Item 6	Verify that the piped gas pressures are ≥ 50 psig	Provider and technician
Item 7	Verify that vaporizers are adequately filled and, if applicable, that the filler ports are tightly closed	Provider or technician
Item 8	Verify that there are no leaks in the gas supply lines between the flow meters and the common gas outlet	Provider or technician
Item 9	Test scavenging system function	Provider or technician
Item 10	Calibrate, or verify calibration of, the oxygen monitor and check the low-oxygen alarm	Provider or technician
Item 11	Verify carbon dioxide absorbent is fresh and not exhausted	Provider or technician
Item 12	Perform breathing system pressure and leak testing	Provider and technician
Item 13	Verify that gas flows properly through the breathing circuit during both inspiration and exhalation	Provider and technician
Item 14	Document completion of checkout procedures	Provider and technician
Item 15	Confirm ventilator settings and evaluate readiness to deliver anesthesia care (Anesthesia Time Out)	Provider

ASA
2008

Recommended Essential Steps in a Preanesthesia Checkout Procedure

TO BE COMPLETED PRIOR TO EACH PROCEDURE		
Subset of Items in the Daily Checklist to Be Completed between Cases		Responsible Party
Item 2	Verify patient suction is adequate to clear the airway	Provider and technician
Item 4	Verify availability of required monitors, including alarms	Provider or technician
Item 7	Verify that vaporizers are adequately filled and if applicable that the filler ports are tightly closed	Provider
Item 11	Verify carbon dioxide absorbent is not exhausted	Provider or technician
Item 12	Breathing system pressure and leak testing	Provider and technician
Item 13	Verify that gas flows properly through the breathing circuit during both inspiration and exhalation	Provider and technician
Item 14	Document completion of checkout procedures	Provider and technician
Item 15	Confirm ventilator settings and evaluate readiness to deliver anesthesia care (Anesthesia Time Out)	Provider

Although the new electronic AWSs provide an automated checkout, some steps in the preuse checkout must be performed by the user because they cannot be automated.

It is essential that the user understand what these procedures are and perform them correctly. For example, the oxygen tank must be opened and then closed for the tank pressure to be measured.

- Although an automated preuse checkout can pressurize the BS, check for leaks, and measure C, it cannot check for correct assembly of the BS and possible misconnections of the hoses.
- Thus, in the 2008 preuse checkout guidelines, item 13 (‘‘Verify that gas flows properly through the breathing circuit during both I & E’’) is an essential step. A 3-L bag should be connected at the Y-piece of the breathing circuit to simulate a model lung. Squeezing and releasing the reservoir bag in manual (bag) mode and operation of the ventilator (in automatic mode) should result in inflation and deflation of the model lung and verify presence and correct operation of the I & E unidirectional valves.

New Workstation Designs: New Problems

- Some AWSs use FGD to ensure that changes in FGF do not affect the desired (set) V_T delivered to the patient's airway.
- With FGD, during the I phase of IPPV, only gas from the piston chamber (Drager) or hanging bellows (Anestar) is delivered to the I limb of the circle system because the decoupling valve closes to divert FG into the reservoir bag.
- The FGD circuits differ from the traditional circle system in function and therefore may be associated with different problems, including detection of an air entraining leak in the BS and failure of the FGD valve resulting in failure to ventilate.

- The new AWSs incorporate many more electronic systems than their predecessors. These systems sometimes fail and render the AWS nonfunctional. The user must understand how to proceed in the event of a power loss.
- In addition, the electrical systems are sometimes the cause of a fire or smoke condition

Thank you