GO TO THIS BOOK'S TABLE OF CONTENTS
RETURN TO CD-ROM TABLE OF CONTENTS

OPERATING PRINCIPLES

OF NARKOMED ANESTHESIA SYSTEMS

SECOND EDITION

James H. Cicman
John Gotzon
Craig Himmelwright
Scott Laubach
Vinson F. Skibo
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RETURN TO THIS BOOK'S TABLE OF CONTENTS
RETURN TO CD-ROM TABLE OF CONTENTS

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TABLE OF CONTENTS

RETURN TO THIS BOOK'S TABLE OF CONTENTS
RETURN TO CD-ROM TABLE OF CONTENTS

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James H. Cicman Sr. , BHS, RRT is the Director of Education at North American Dräger. He became a Registered Respiratory Therapist in 1971, and has worked in Anesthesia and Respiratory Care education for over 25 years. Prior to joining the staff at North American Dräger, he was Assistant Professor of Clinical Science at Wheeling Jesuit College, in Wheeling, West Virginia. He has worked at North American Dräger for over 12 years and has had a number of articles published.

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John Gotzon has been in the employ of North American Dräger for over 10 years. As a Technical Service Representative, he provided service to hospitals within the five boroughs of New York City. Later as a Technical Support Specialist, he offered telephone support to field personnel from NAD's Main facility in Telford, Pennsylvania. His experience has prepared him for his current position as a Technical Instructor in the NAD education department. In this position, he is involved in the training of Biomedical Technicians, Anesthesia Technicians and Anesthesia residents. Mr. Gotzon's future plans include completing a Bachelor's Degree in Business.

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Craig Himmelwright is a Technical Instructor in the Education Department of North American Dräger. Throughout his 10 years at NAD, he has worked in the Technical Service and Education departments. He applies his technical experience and knowledge to enhance the content of the various training programs conducted by NAD. He is also an IFSAC and NPQS Certified Fire Service Instructor with over 13 years experience in Emergency Services. At the present time, he serves as the chairman of the NAD Safety Committee. Mr. Himmelwright has an AS in Electronics Technology and is continuing his education towards a bachelors degree.

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RETURN TO THIS BOOK'S TABLE OF CONTENTS
RETURN TO CD-ROM TABLE OF CONTENTS

Introduction

Anesthesia systems have evolved rapidly in the last fifteen years, developing from simple devices with as few as ten controls to complex, computer-based devices that include electronic patient monitoring devices, data management systems, networking capabilities with off-line devices, and enhanced pneumatic circuitry. In this book we offer you a brief introduction to the modern Narkomed anesthesia system, by breaking it down into it's various components and explaining the function of each. After each component is examined and its function described, we will integrate that component into its proper place in the anesthesia system. By examining the anesthesia system in this step-by-step manner, we hope to increase your understanding of the system as a whole. Using these methods, we hope to increase your understanding of the capabilities, and limitations, of the modern Narkomed anesthesia system.

This book has been written as a companion to the anesthesia system seminar program conducted on a continuing basis by the Education Department of North American Dräger. It is not intended as a replacement for these seminars, as a service manual, nor as an operator's manual. This book contains generic information relevant to Narkomed anesthesia systems, but does not pertain specifically to any one model. Specific information on each model is documented in the Operator's Manual included with every anesthesia system shipped by the manufacturer.

Although it is true that clinicians and technicians come into contact with the anesthesia system on a regular basis, it is also true that they rarely have the opportunity to study the functions of the anesthesia systems or become familiar with the principles upon which the modern anesthesia system is based. This book, in conjunction with the anesthesia system seminar program, is designed to enhance your working knowledge of the Narkomed anesthesia system.

The material in this publication has been organized in chronological order. The most recent designs, currently in production, are presented in each chapter concerning each individual segment of the modern anesthesia system.

At the end of some chapters, you will find a supplement. The supplement contains earlier variation(s) of the components featured in that particular chapter. The variation(s) are also arranged in chronological order with the most recent designs first and the earlier designs last. An example of this would be the chapter on pneumatic piping; the current pneumatic components are located in the chapter, the supplement then features the earlier versions of these components.

RETURN TO THIS BOOK'S TABLE OF CONTENTS
RETURN TO CD-ROM TABLE OF CONTENTS

1: The Narkomed Family of Anesthesia Systems

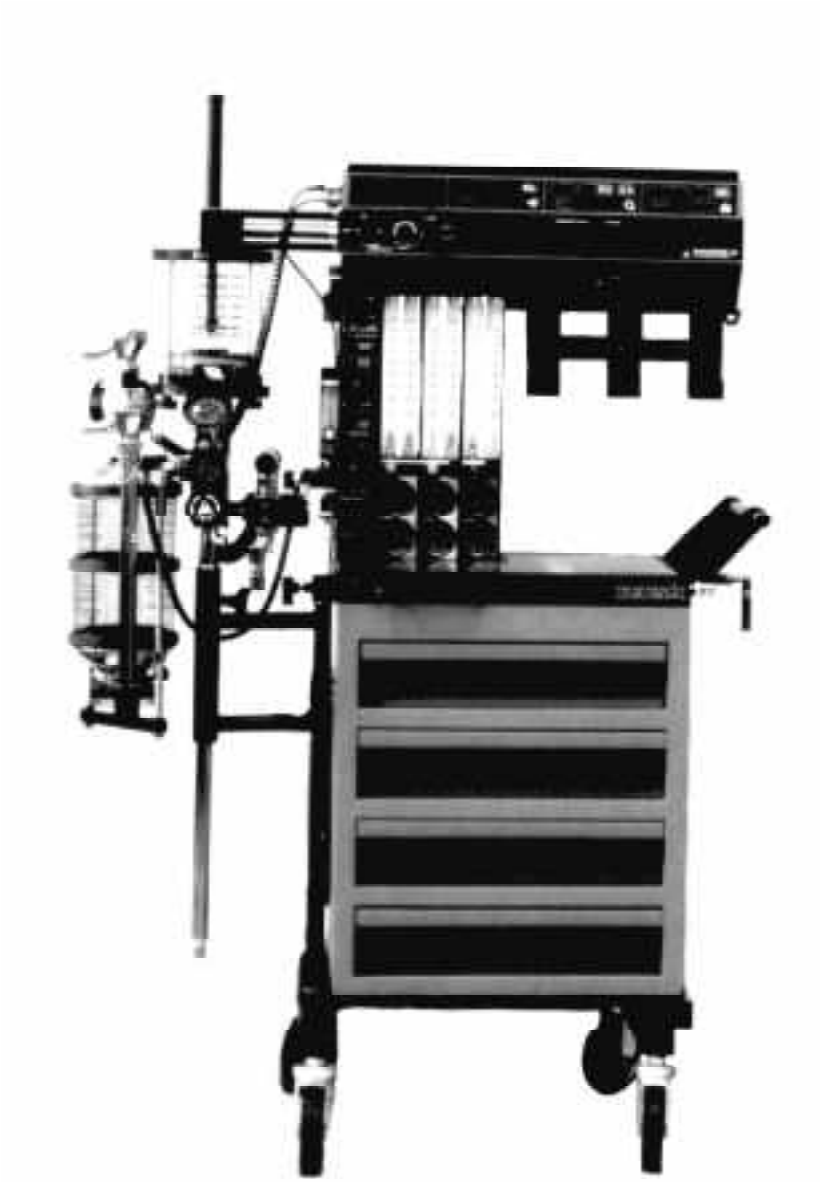
This chapter introduces you to the Narkomed family of anesthesia systems. The equipment pictured represents the most common configurations of this equipment and the anesthesia systems are presented in chronological order. Please note that several of the manufacturing dates overlap.

Narkomed 2A

The Narkomed 2A was the first anesthesia machine that linked individual monitors to a central alarm display via electronic communication.

Manufactured: 1982 - 1988

Available Monitors: Oxygen, Breathing Pressure, and Respiratory Volume.



Narkomed 3

The Narkomed 3 was the first anesthesia system to offer integrated patient monitoring and a structured alarm system. The structured alarm system classified and prioritized all alarms generated by the monitoring system and alerted the operator via an audible and visual interface. This anesthesia system also incorporated the Oxygen Ratio Monitor Controller as standard equipment for the first time.

Manufactured: 1986 - 1992

Standard Monitors: Oxygen and Breathing Pressure
Available Monitors: Respiratory Volume, Pulse Oximetry, Noninvasive Blood Pressure, and Carbon Dioxide and/or Agent Analysis.

Narkomed 2B

The Narkomed 2B was designed as a replacement for the Narkomed 2A. As such, it upgraded certain alarm capabilities and included a structured alarm system that classified and prioritized alarm messages from all three monitors. The main advances in this machine were the increased sophistication of the electronic circuitry and the introduction of a self-diagnostic system that could be accessed by the user through a service screen.

Manufactured: 1987 - present

Standard Monitors: Oxygen, Breathing Pressure, and Respiratory Volume.

Narkomed 4

The Narkomed 4 was the first anesthesia system to offer electroluminescent touch panel displays, a remote display panel, redundant main processors and an integrated data management system for automated patient record keeping. The main advances were in increasingly sophisticated electronic circuitry and an extensive self-diagnostic capability coupled with an expanded memory accessible through a service screen.

Manufactured: 1990 - present

Standard Monitors: Oxygen, Breathing Pressure, Respiratory Volume, Pulse Oximetry, Noninvasive Blood Pressure, and Carbon Dioxide/Agent Analysis.

Narkomed 2C

The Narkomed 2C was designed as a replacement for the Narkomed 2B. Similar to the Narkomed 4, it employs advanced electronic circuitry and includes the convenience of a remote screen. This anesthesia system is designed to communicate with external monitors from many different manufacturers and to prioritize all alarm functions. This anesthesia system can also be configured to include data management and networking capabilities.

Manufactured: 1993 - present

Standard Monitors: Oxygen, Breathing Pressure, and Respiratory Volume.

2: The Pneumatic Piping System

Oxygen Gas Circuit

Because oxygen is the primary gas for all Narkomed machines, we will begin our exploration of the pneumatic circuitry by tracing the flow of gas through the oxygen circuit. The internal pneumatic circuit (Figure 2-1) plays an important role in patient safety.

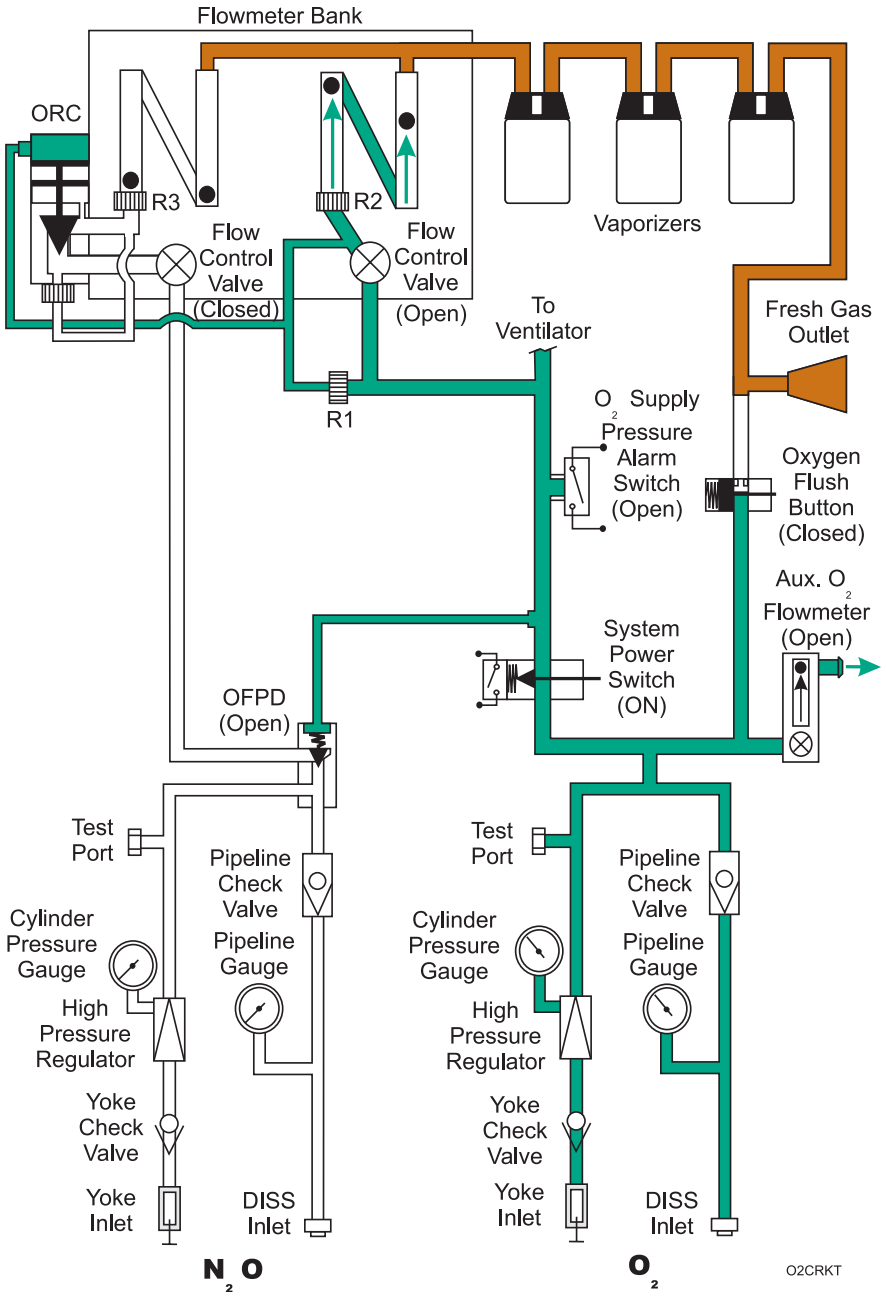


Figure 2-1: The pneumatic circuit for a Narkomed two-gas anesthesia system. The oxygen circuit is shaded in green and fresh gas circuit is shaded in brown, vaporizers are turned "OFF".

Cylinder Gas Supply Enters The Anesthesia System

Oxygen from the E cylinder enters the anesthesia system through the yoke assembly, passing through the yoke check valve (Figure 2-2). The yoke check valve is a one-way valve that allows gas to enter the anesthesia system from the yoke, but does not allow gas to exit the anesthesia system through the yoke. As gas enters the yoke check valve, it forces the ball in the valve away from the seat. The gas flows around the ball and exits the yoke check valve through two holes in the side of the copper tubing connector. If the E cylinder is absent or empty, the gas supplied by the hospital piping system flows in the opposite direction (Figure 2-3). This gas flow forces the ball against the O-ring seat, sealing the entry port of the yoke assembly and retaining the hospital pipeline gas within the anesthesia system.

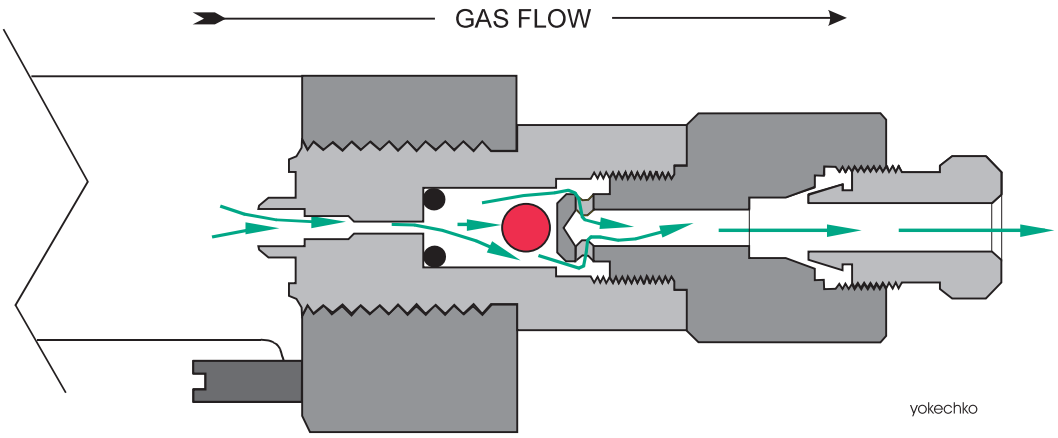


Figure 2-2: Yoke check valve assembly - gas is flowing from the E cylinder through the yoke.

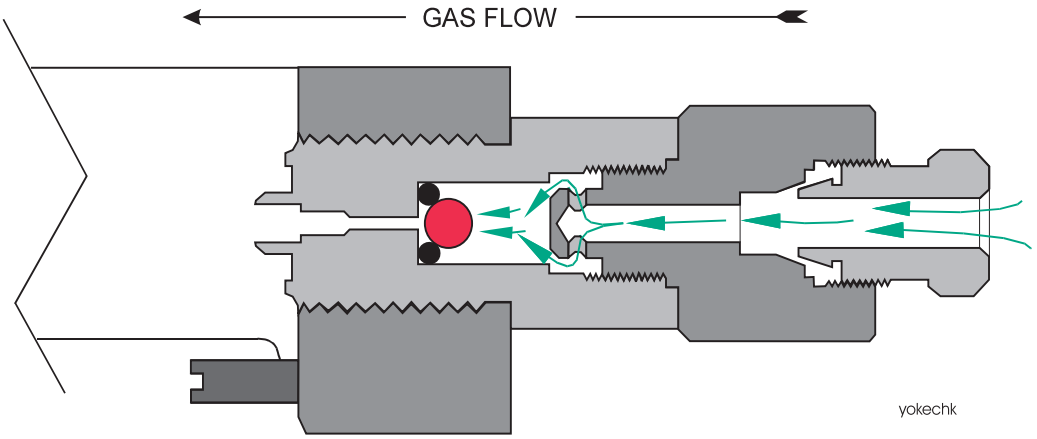


Figure 2-3: Yoke check valve assembly - gas is flowing from the hospital pipeline gas supply toward the yoke.

Pin Index Safety System

The yoke incorporates the Pin Index Safety System (Figure 2-4). This safety system is used with small gas cylinders (size E and smaller) and is designed to prevent a gas cylinder from being connected to the incorrect gas circuit. This is accomplished by two metal pins mounted in the yoke body that correspond to two holes in the cylinder head.

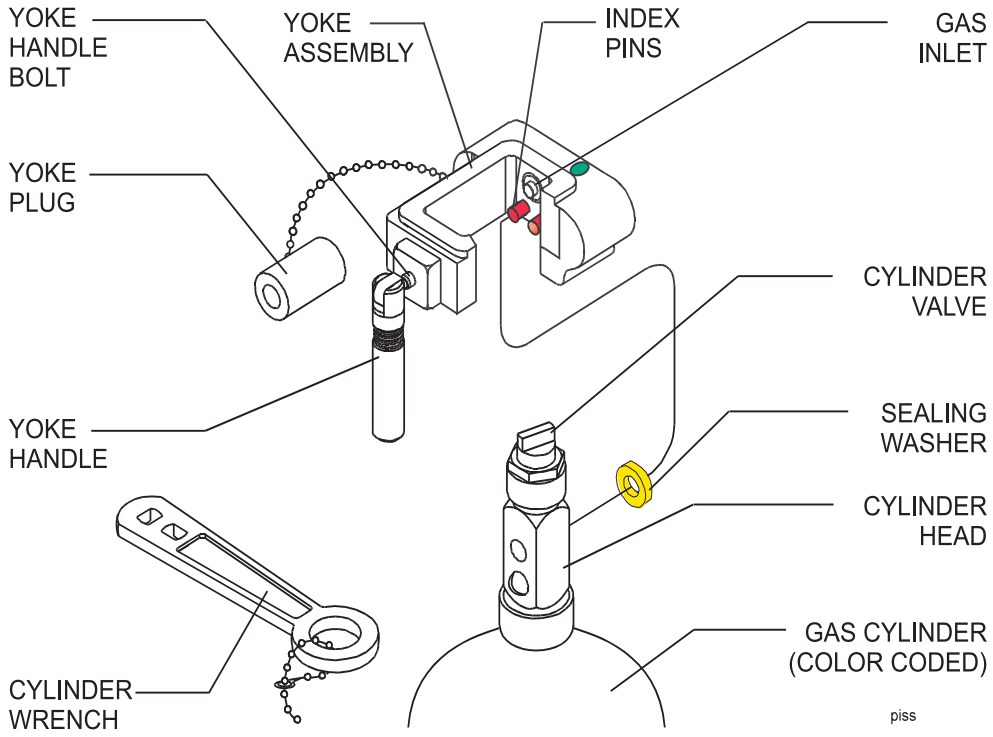


Figure 2-4: Pin Index Safety System.

Pin Positions

There are 6 pin positions in the Pin Index Safety System (Figure 2-5). Note that some gas mixtures have two different pin sets, depending on the proportion of the gas mixture.

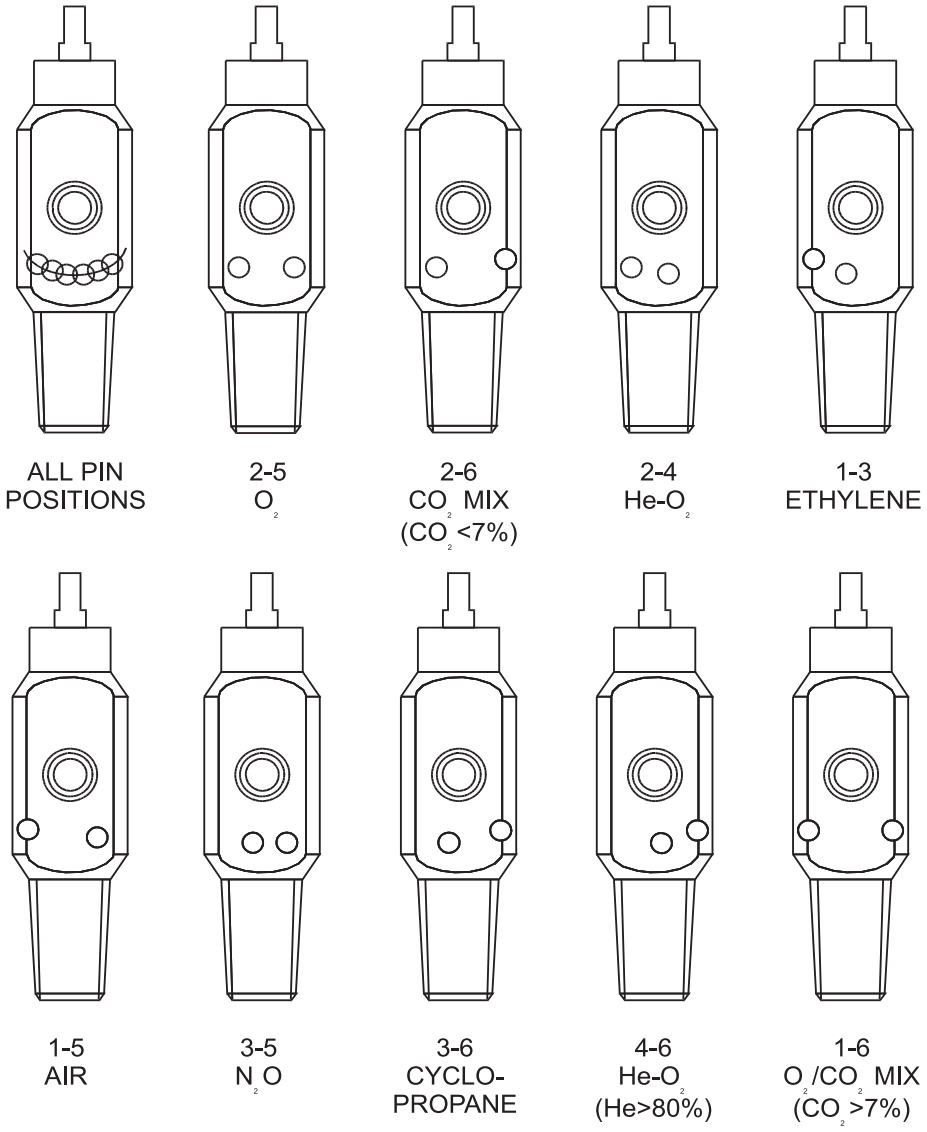


Figure 2-5: Pin positions on the cylinder head and the gases they identify.

Pressure Reducing Regulator

Gas enters the anesthesia system from an E cylinder, through the yoke at a high pressure (typically ranging from 750 psi to 2200 psi). This pressure must be reduced for the gas circuits of the anesthesia system. The pressure reducing regulator accomplishes this task in two phases. Figure 2-6 identifies the components of the regulator.

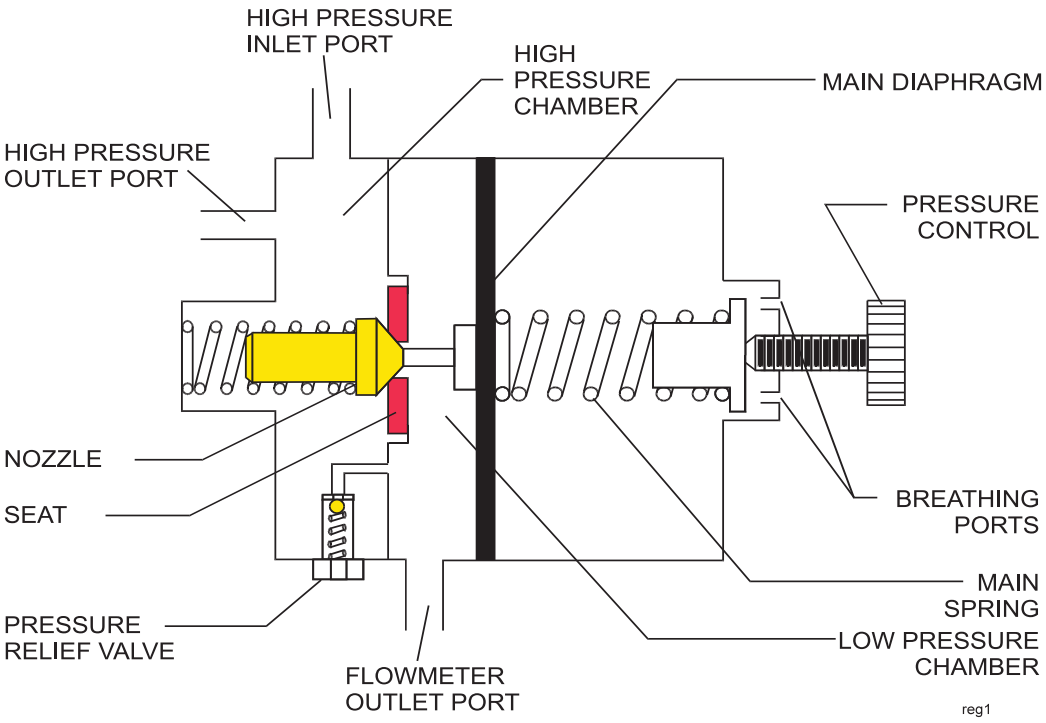


Figure 2-6: Pressure reducing regulator.

Phase 1

High pressure gas flows from the yoke check valve to the inlet port of the regulator and enters the high pressure chamber (Figure 2-7). High pressure gas then flows from the high pressure outlet port to the cylinder pressure gauge. High pressure gas will remain trapped in the high pressure chamber until some adjustment is made to the main spring.

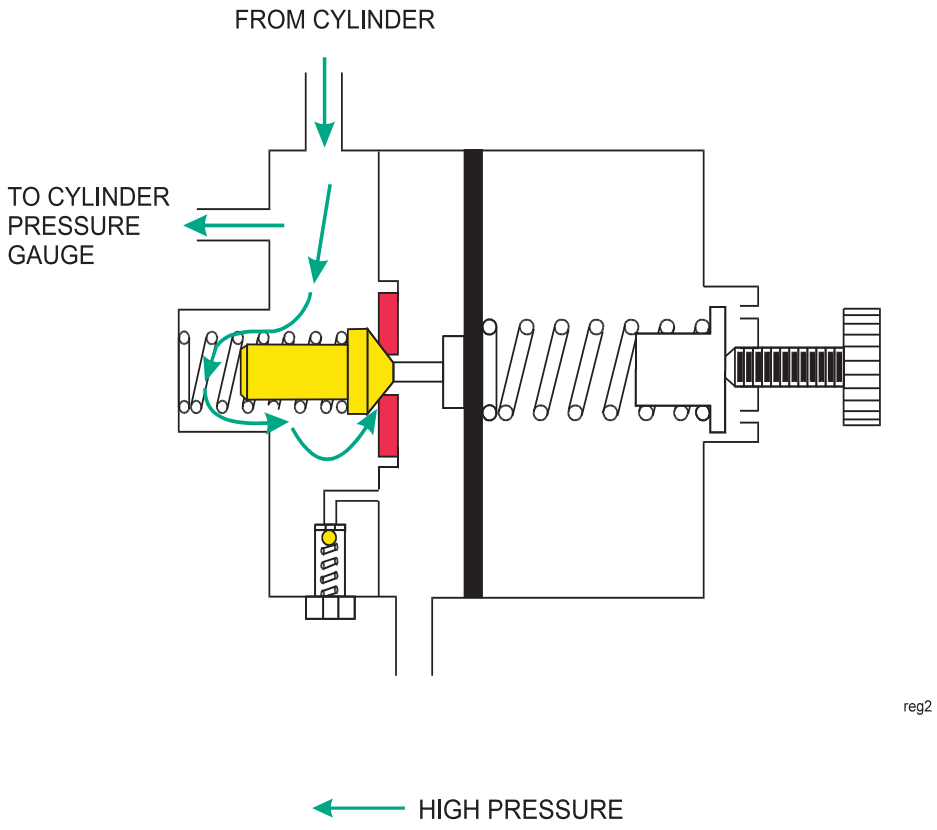


Figure 2-7: High pressure gas enters the regulator.

Once the pressure control is set (Figure 2-8), it compresses the main spring that in turn moves the diaphragm. The diaphragm forces the nozzle away from the seat, allowing high pressure gas to flow into the low pressure chamber.

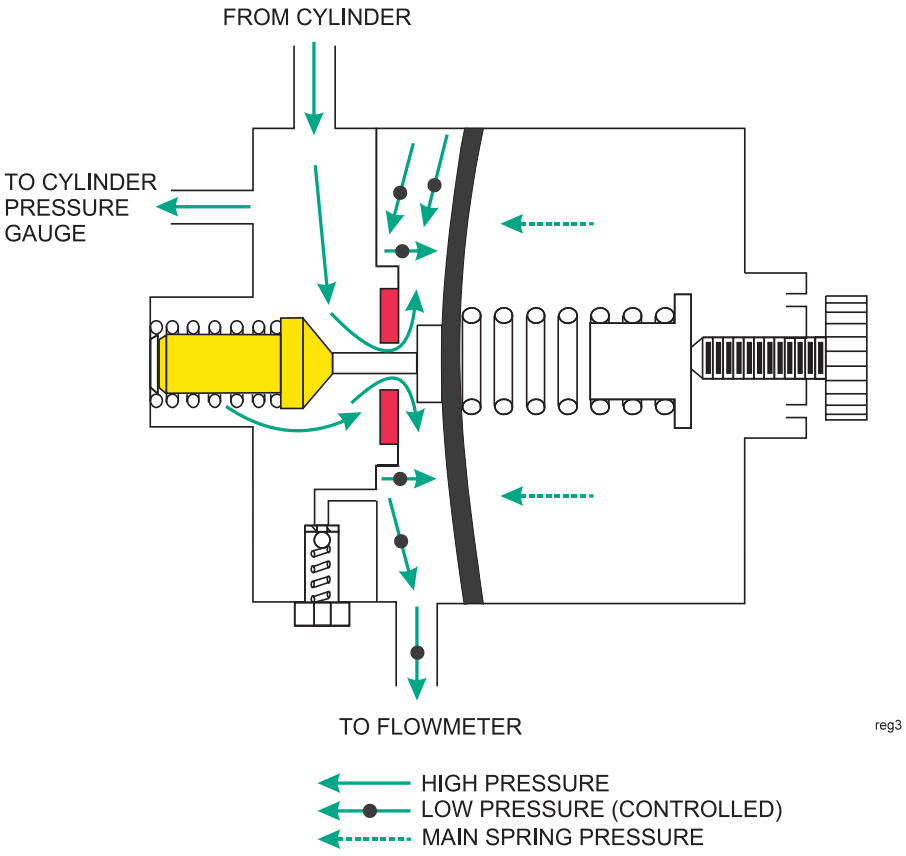


Figure 2-8: High pressure gas flows to the low pressure chamber.

Phase 2

As the high pressure gas flows into the low pressure chamber, the diaphragm is forced backwards and the main spring is compressed (Figure 2-9). This allows the small spring behind the nozzle to move it toward the seat. When the gas pressure in the low pressure chamber equals the tension of the main spring, the nozzle closes against the seat, cutting off the flow of high pressure gas into the low pressure chamber. The gas in the low pressure chamber then flows through the low pressure port and into the pneumatic circuit of the anesthesia system. As the gas leaves the low pressure chamber and the pressure lessens, the main spring forces the diaphragm and the nozzle away from the seat, starting the whole cycle again.

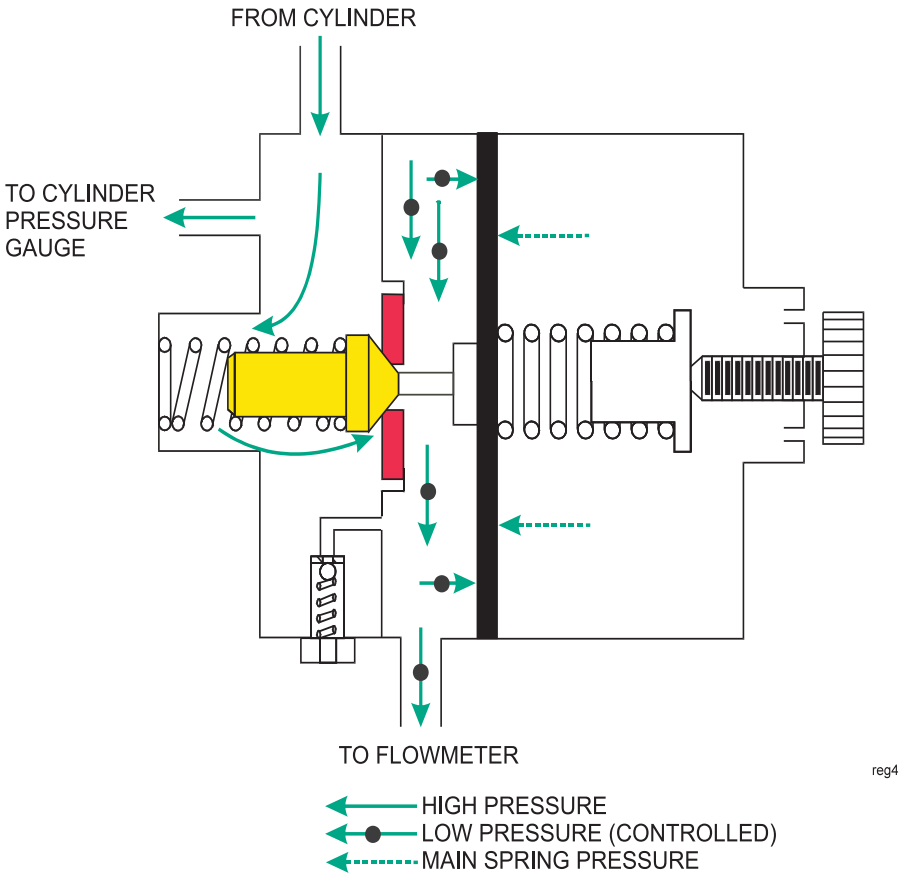


Figure 2-9: Gas pressure and spring pressure equalize.

Cylinder Contents Pressure Gauge

The high pressure gas that flows from the high pressure outlet port of the regulator is piped to a Bourdon pressure gauge (Figure 2-10). The pressure reading obtained from the gauge reflects the amount of gas remaining in the E cylinder. These gauges are used to measure gas pressure in large units, such as psi. This type of gauge is also used to measure pipeline gas pressure.

The gauge consists of a hollow, curved tube connected to a gear rack that meshes with a pinion gear. A needle is mounted on the pinion gear shaft. When the gas pressure increases inside the tube, the tube begins to straighten. This causes the gear train to move, which in turn rotates the needle around the face of the gauge.

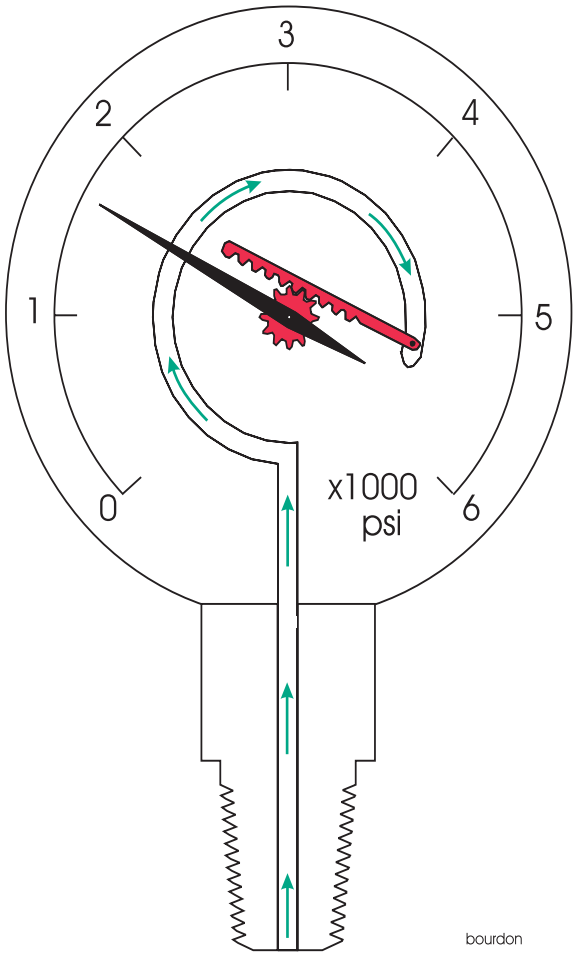


Figure 2-10: A Bourdon pressure gauge.

Pipeline Gas Supply Enters the Anesthesia System

Gas supplied by the hospital piping system enters through a hose connected to the anesthesia system by a Diameter Index Safety System (DISS) fitting (Figure 2-11). The nut and stem assembly on the end of the hose mates to a matching DISS inlet on the anesthesia system. The stem and the body mate via the two shoulders on the stem that match two bores in the inlet. Thus, mismatches between the shoulders and the bores will not allow the wrong gas to be connected to a given gas inlet. The DISS connectors are designed for the delivery of gases at less than 200 psi of pressure.

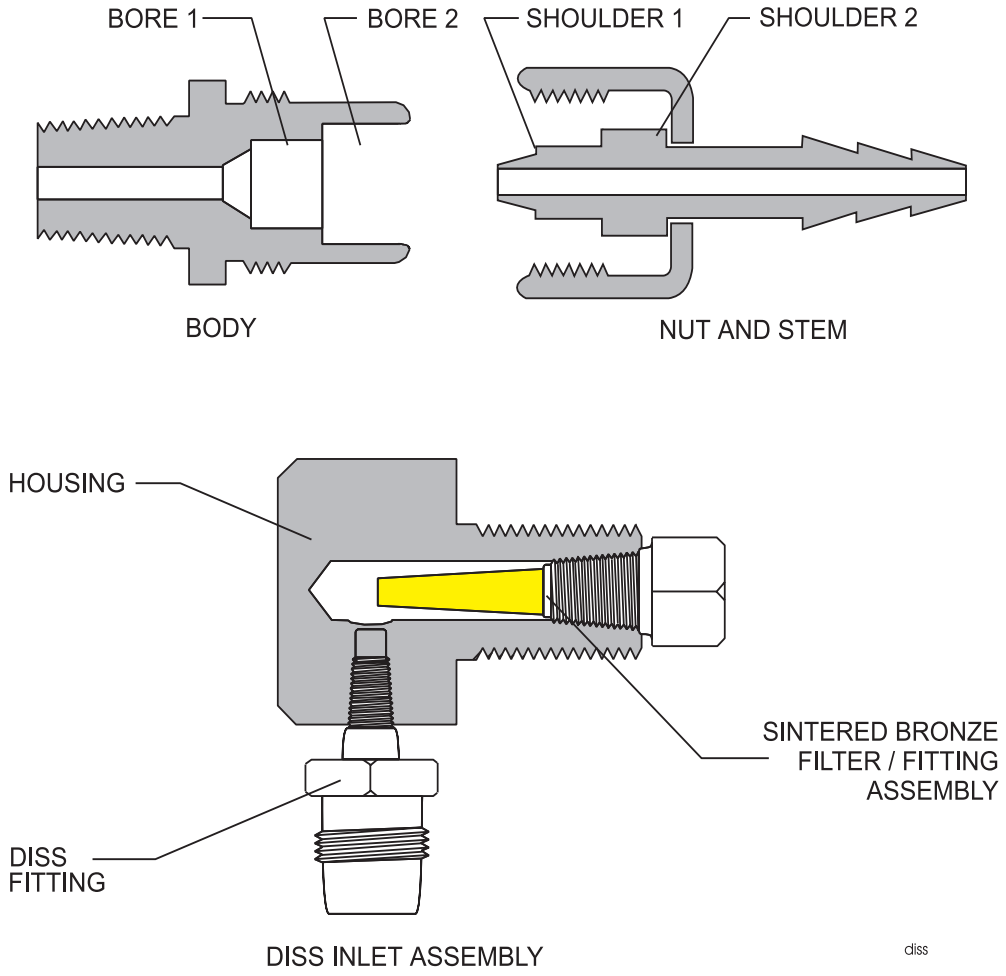


Figure 2-11: Diameter Index Safety System connections.

Pipeline Check Valve

Gas that enters through the DISS inlet flows to the pipeline check valve. The pipeline check valve performs the same function as the yoke check valve. It allows gas from the hospital piping system to enter, but not exit, the anesthesia system. The pipeline check valve is mounted vertically with the pipeline gas entering from the bottom. As the gas flows upward, it lifts the piston and seal off the seat, and exits the pipeline check valve at the top (Figure 2-12). If the hospital pipeline gas supply fails, the piston and seal assembly drops onto the seat and prevents any gas supplied by the E cylinder from escaping through the DISS inlet (Figure 2-13).

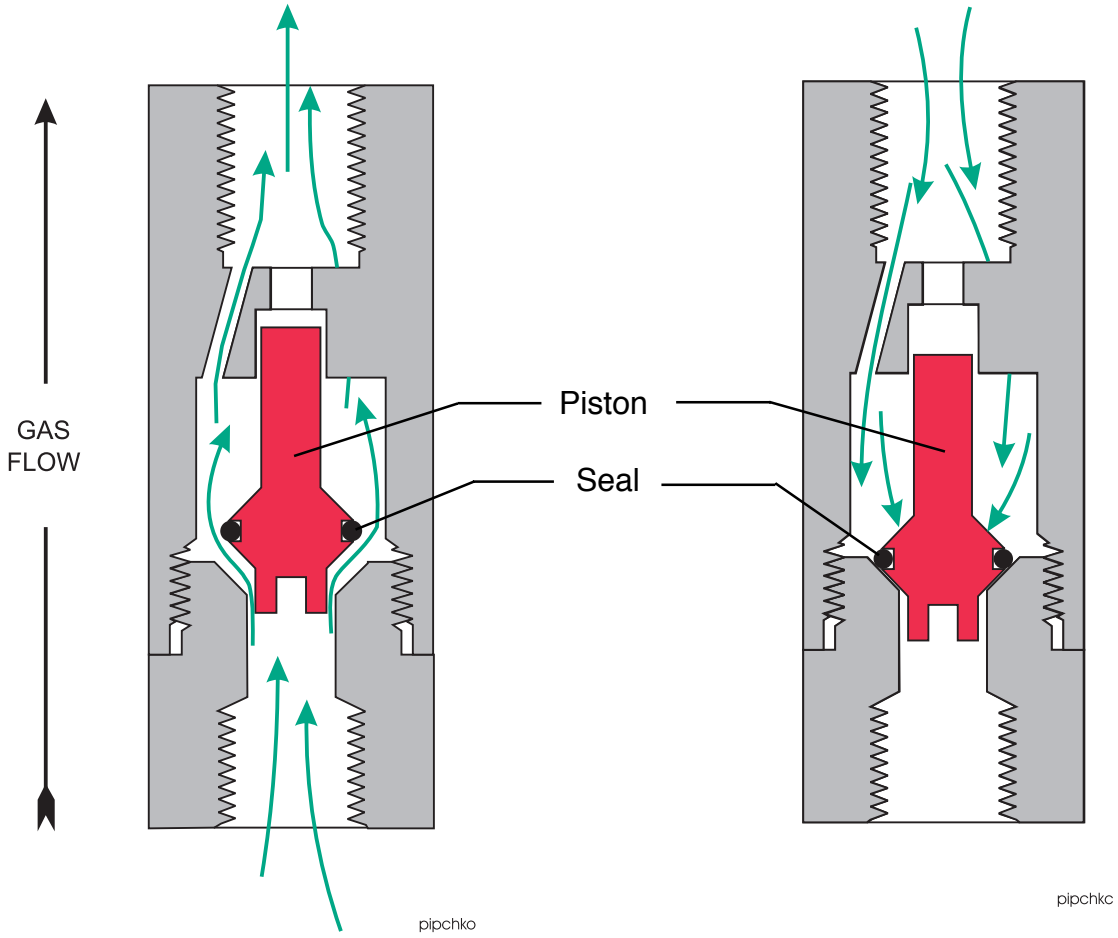


Figure 2-12: Pipeline check valve forward flow.

Figure 2-13: Pipeline check valve reverse flow.

Auxiliary Oxygen Flowmeter

A tee fitting in the oxygen circuit supplies gas from either the pipeline or cylinder supply to the auxiliary oxygen flowmeter (Figure 2-14). This device can be activated whether the main switch is in the ON or STANDBY position. It allows the operator to deliver up to 10 lpm of 100% oxygen to a patient, usually through a nasal cannula. This device is a convenience feature and is seldom used in the administration of general inhalation anesthesia.

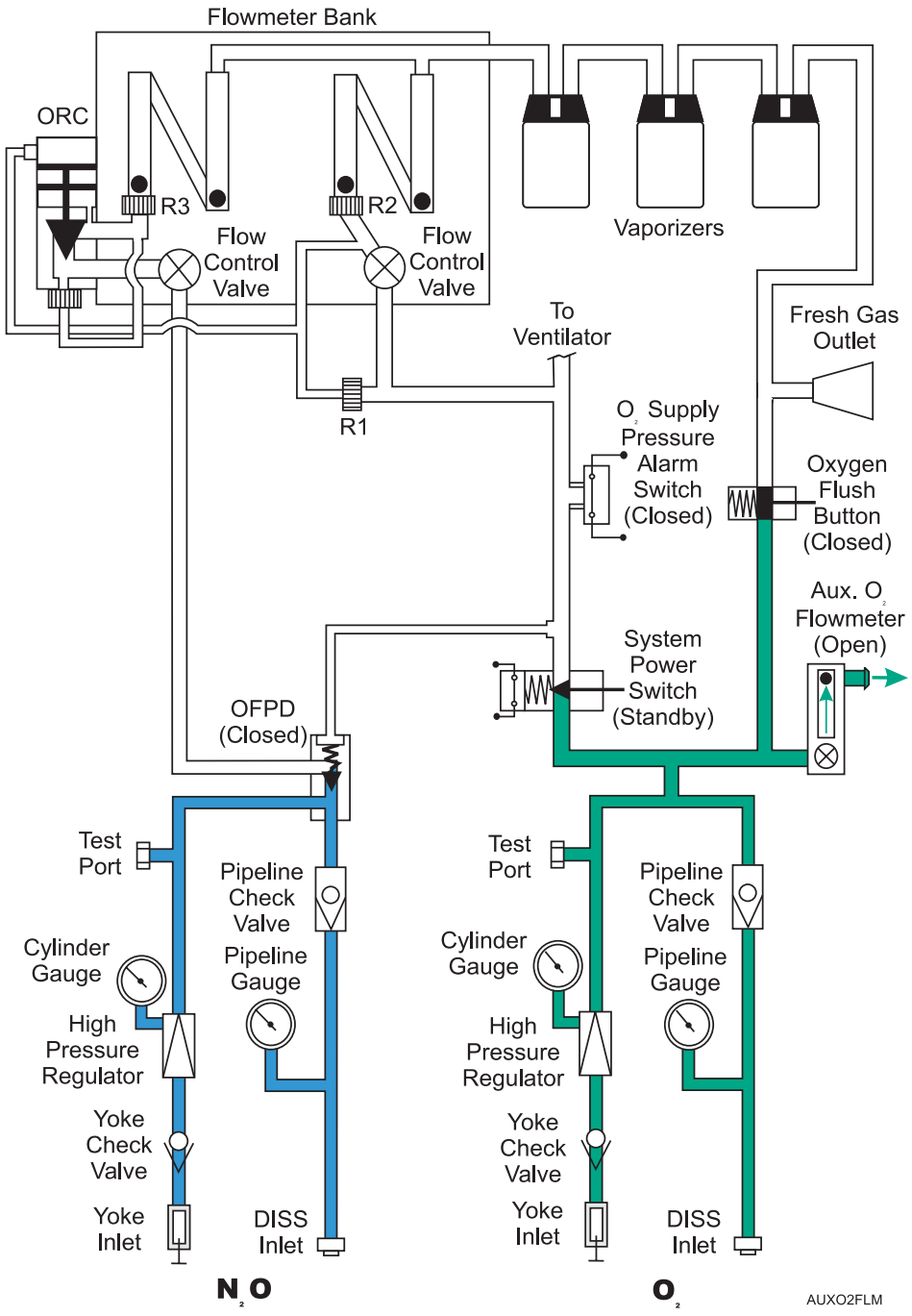


Figure 2-14: Flow of oxygen to the auxiliary oxygen flowmeter.

Oxygen Flush Button

Regardless of whether the gas in the oxygen circuit was supplied by the hospital piping system or an E cylinder, a tee fitting allows oxygen to flow to the oxygen flush button at all times (Figure 2-15). The flush button consists of a valve and a restrictor. The flow restrictor is located in the outlet port of the valve.

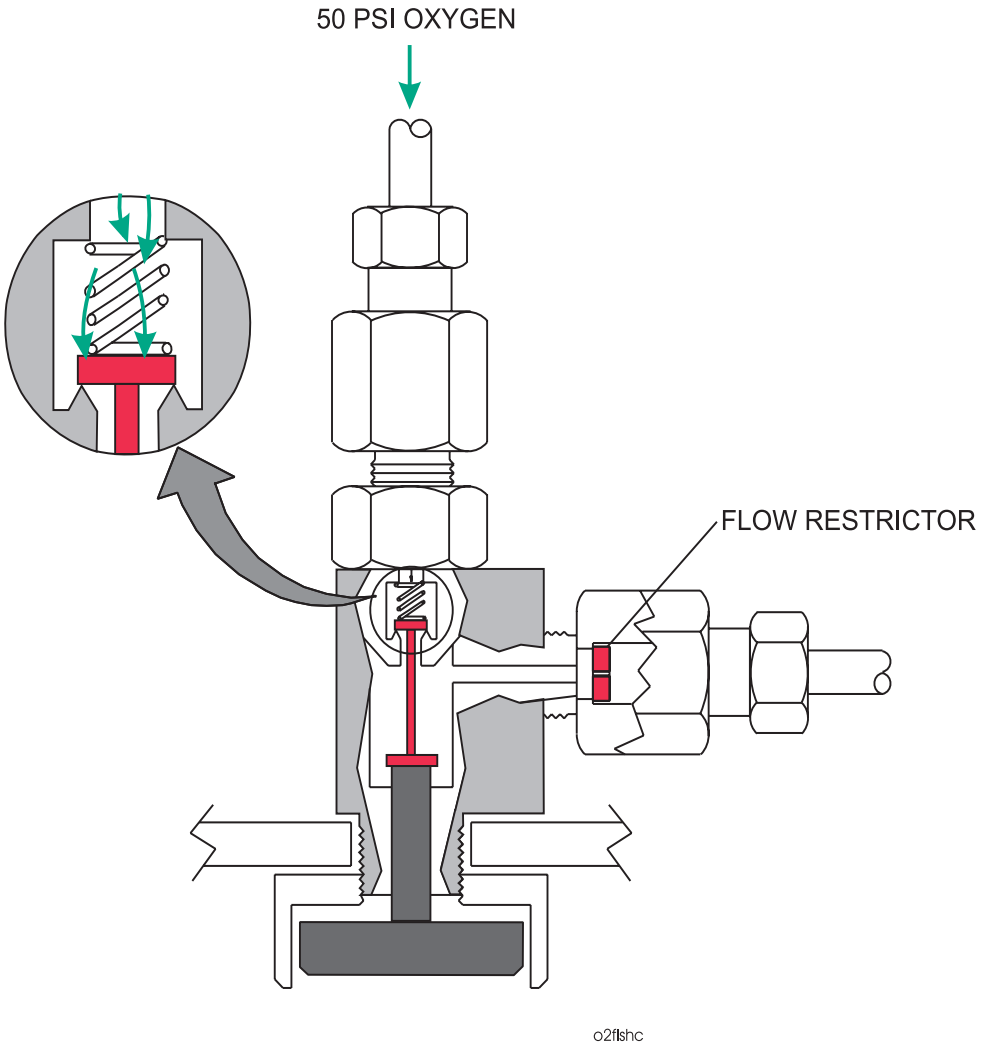


Figure 2-15: Oxygen flush button - inactive.

When the oxygen flush button is activated (Figure 2-16), it supplies the patient breathing circuit with 100% oxygen. The flush button can be activated whether the main switch is in the ON or STANDBY position. When activated, the valve opens, permitting 50 psi of oxygen to be applied to the flow restrictor resulting in an output flow of approximately 55 l/min. This flow of oxygen is delivered to the patient breathing circuit through the fresh gas outlet.

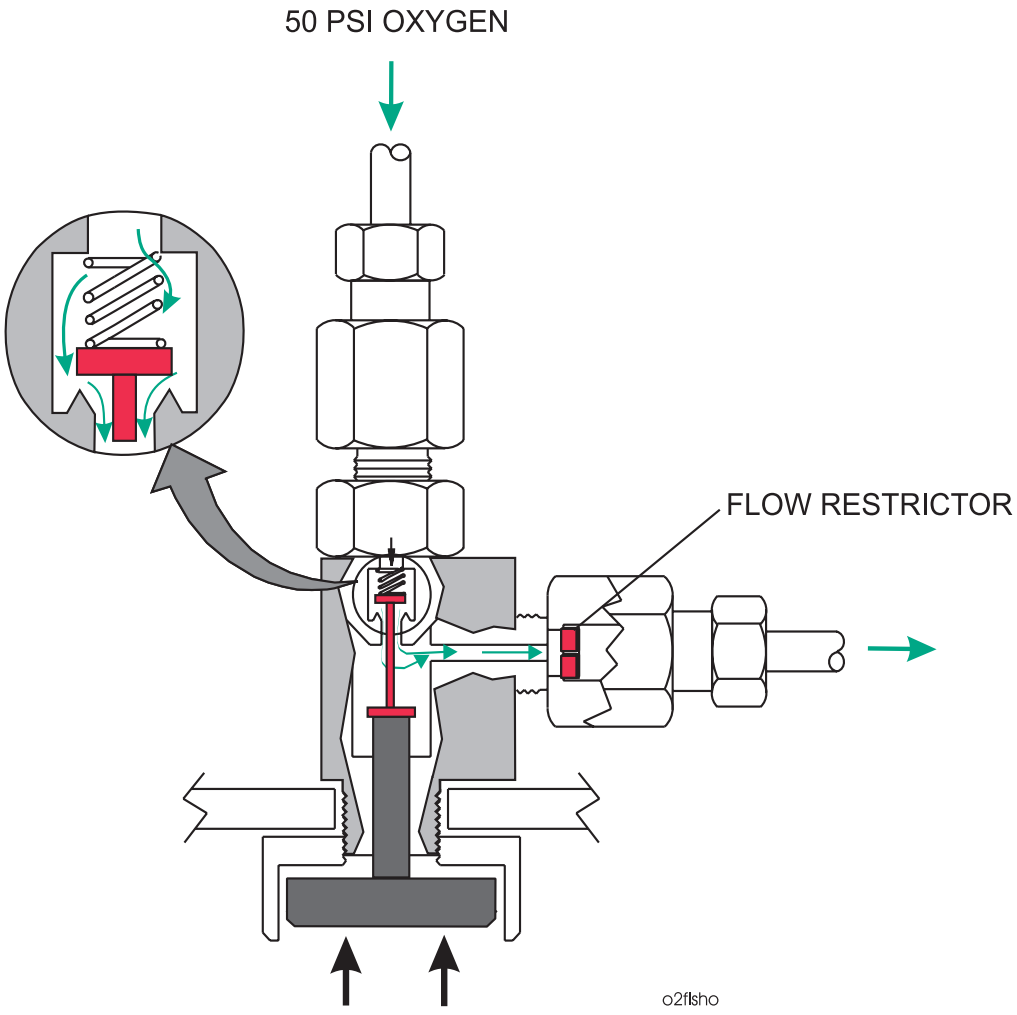


Figure 2-16: Oxygen flush button - activated.

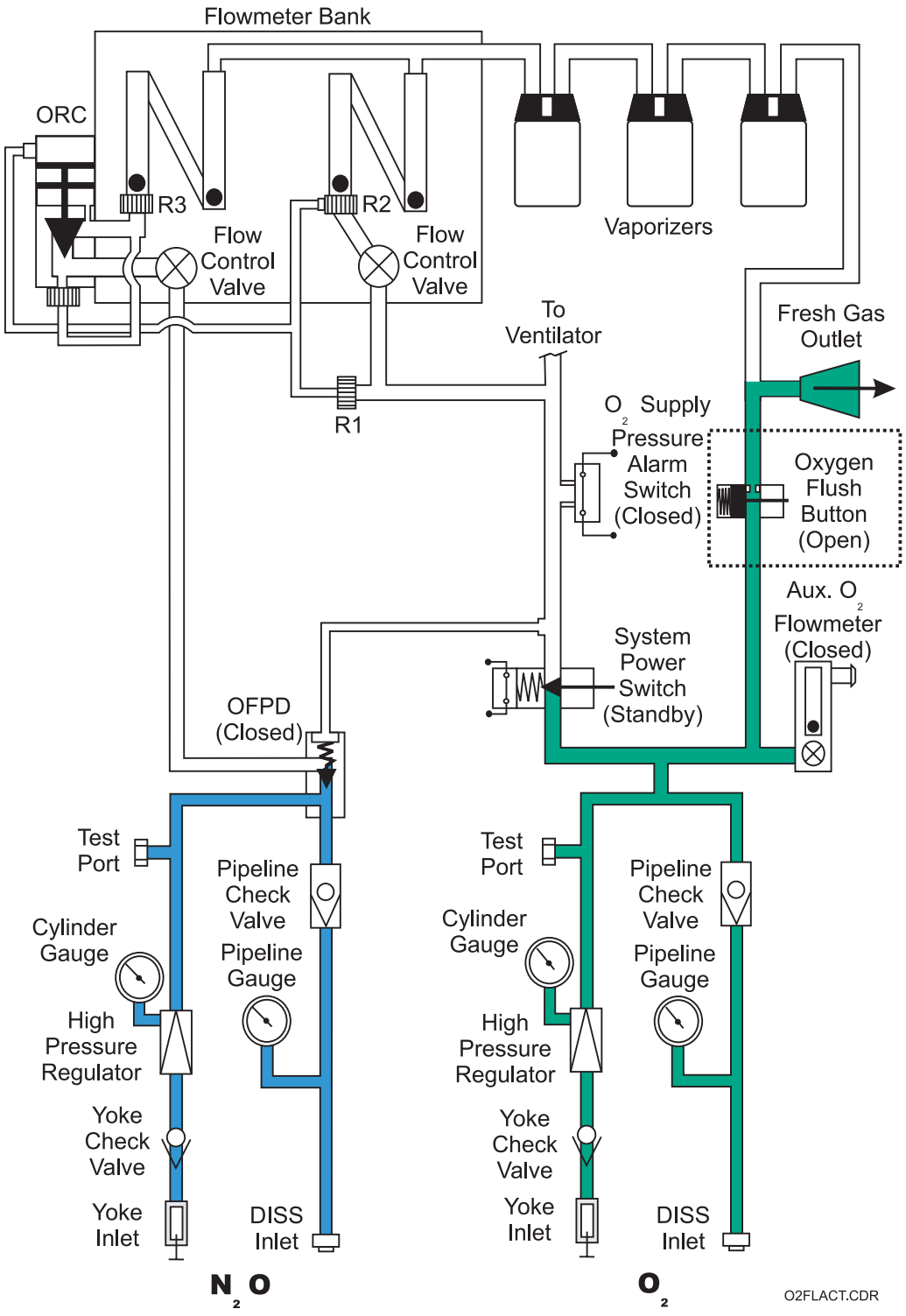


Figure 2-17: Location of the oxygen flush button in the pneumatic circuit

Locking Fresh Gas Outlet

All gases flow from the coarse flowtube and enter the fresh gas circuit. The fresh gas then flows through the vaporizer bank where anesthetic agent from a single vaporizer is added to the fresh gas mixture. The fresh gas mixture then flows to the patient breathing circuit through the Locking Fresh Gas Outlet (Figure 2-18). The fresh gas outlet has a spring-loaded locking cap designed to prevent an accidental disconnect between the fresh gas outlet and the fresh gas hose of the patient breathing circuit. The fresh gas outlet mates with the fresh gas hose through a standard 15 mm tapered fitting.

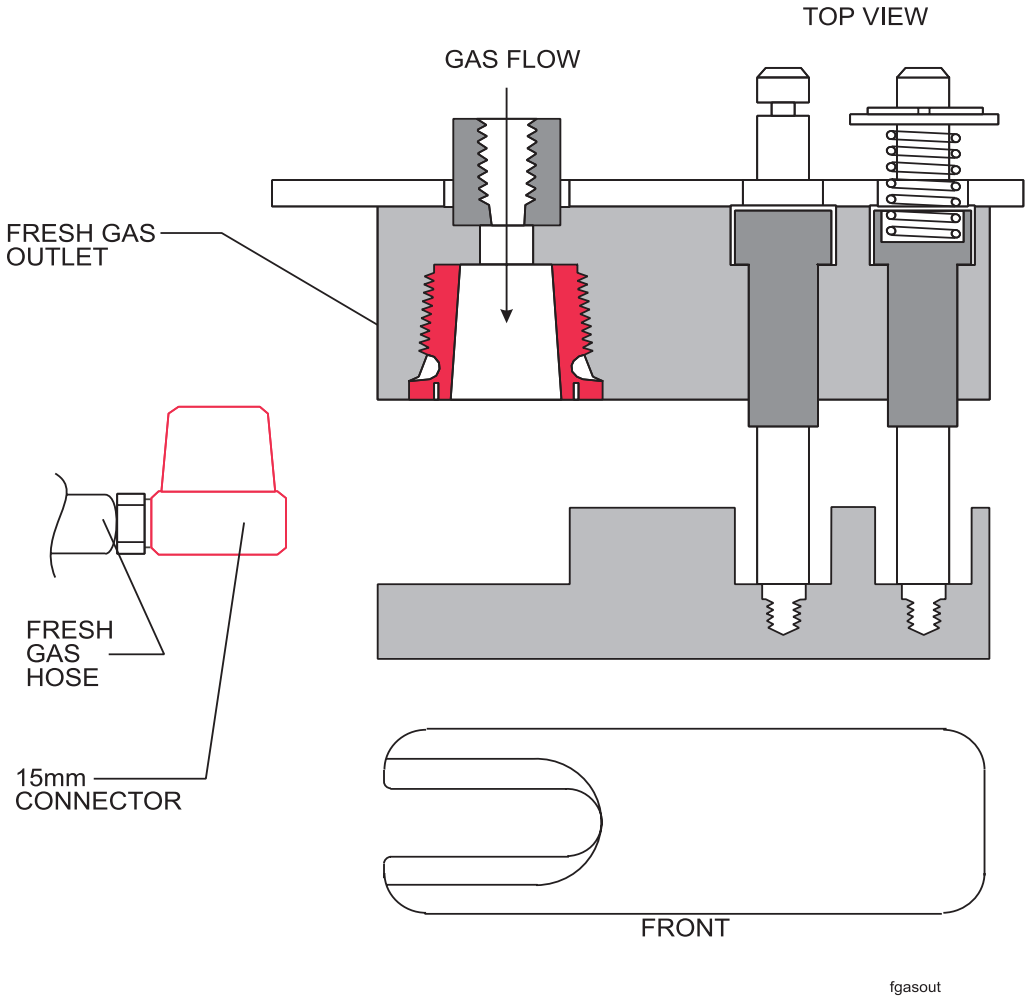


Figure 2-18: Locking fresh gas outlet.

System Power Switch

A tee fitting allows both sources of oxygen to flow to the system power switch (Figure 2-19). With the system power switch in the STANDBY position, the valve remains closed eliminating pneumatic power. The leaf also switch remains closed eliminating electrical power.

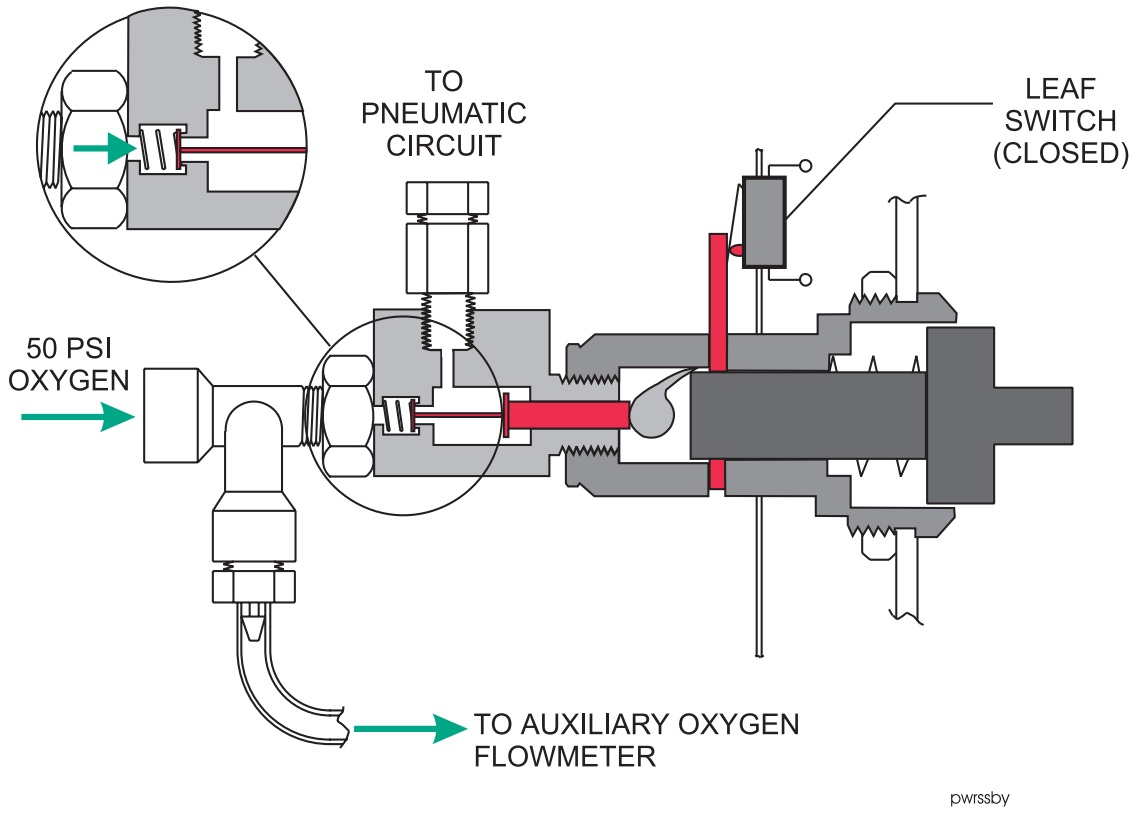


Figure 2-19: System power switch in the STANDBY position.

As the system power switch is rotated to the ON position (Figure 2-20), the switch moves into the assembly. It depresses the valve plunger, allowing oxygen to flow to the rest of the oxygen circuit. At the same time, the rotation causes the pin to move away from the leaf switch. The switch opens and activates the electrical circuitry of the anesthesia system. Notice that the leaf switch opens when turned ON, allowing the anesthesia system to remain in use should the leaf switch malfunction.

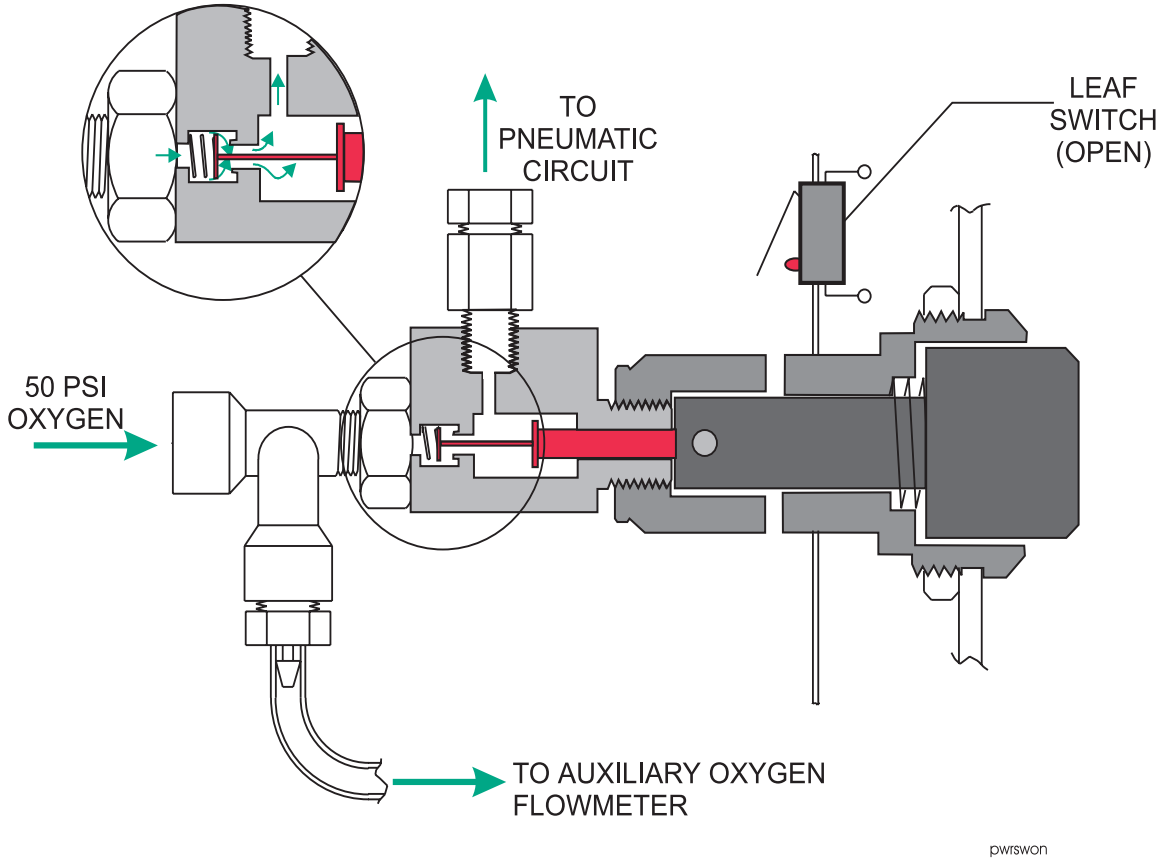


Figure 2-20: System power switch in the ON position.

Oxygen Supply Pressure Alarm Switch

A tee fitting located directly downstream of the system power switch allows oxygen to flow to the oxygen supply pressure alarm switch. This pressure switch warns the operator of diminishing oxygen supplies. In the inactive position, oxygen pressure enters the bellows. The bellows expand in proportion to the gas pressure in the oxygen circuit (Figure 2-21). The bellows in turn compresses a spring and moves the connecting rod toward the electrical switch, opening the contacts. The switch remains open and the alarms are inactive as long as the pressure in the oxygen circuit remains above the set point.

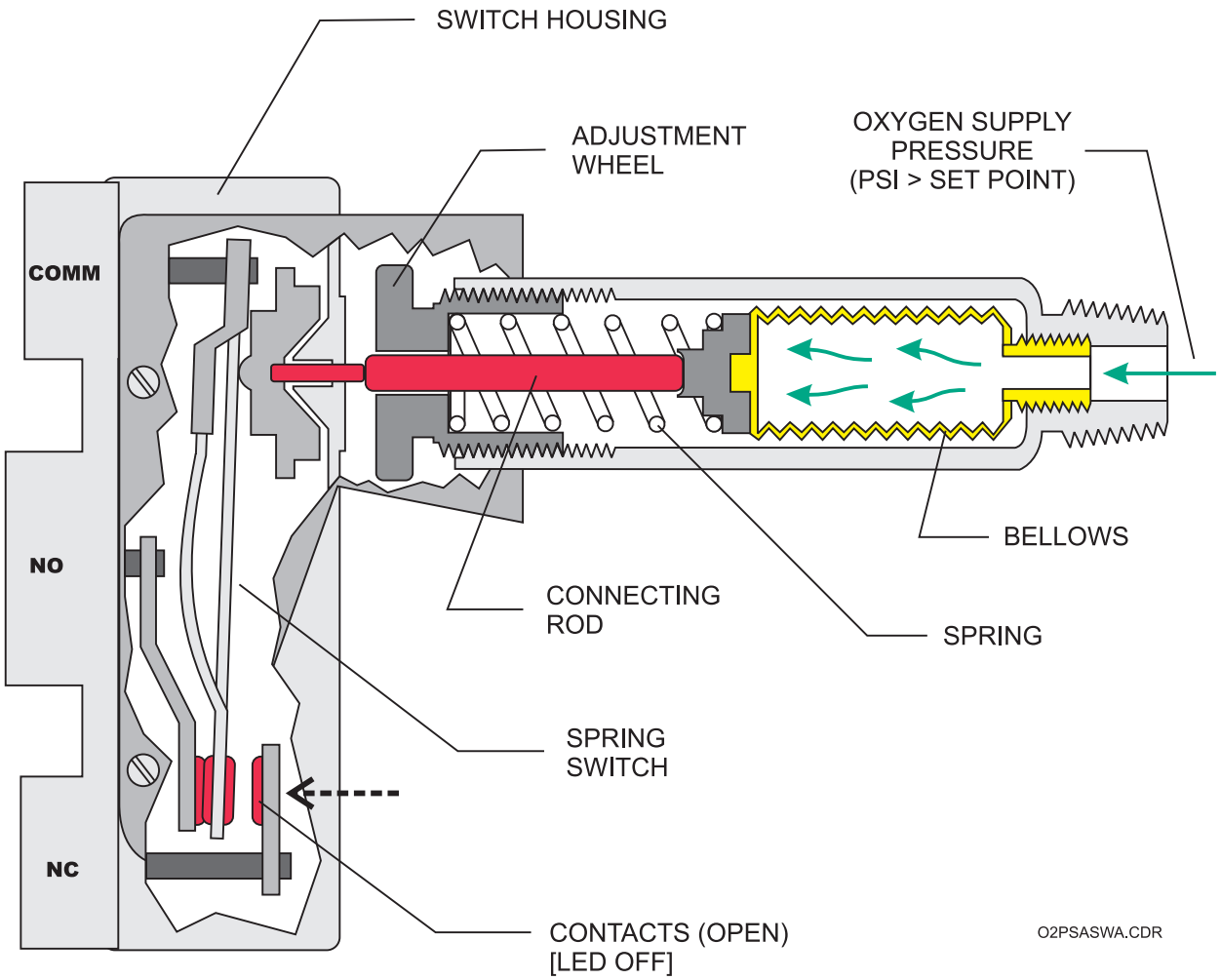


Figure 2-21: The oxygen supply pressure alarm - inactive.

As the gas pressure in the oxygen circuit decreases, the pressure inside the bellows also drops. As the pressure in the bellows drops, the spring causes the bellows to collapse, allowing the connecting rod to move away from the electrical switch (Figure 2-22). When the pressure falls below the set point, the electrical switch closes and the clinician gets both an audible and a visual alarm.

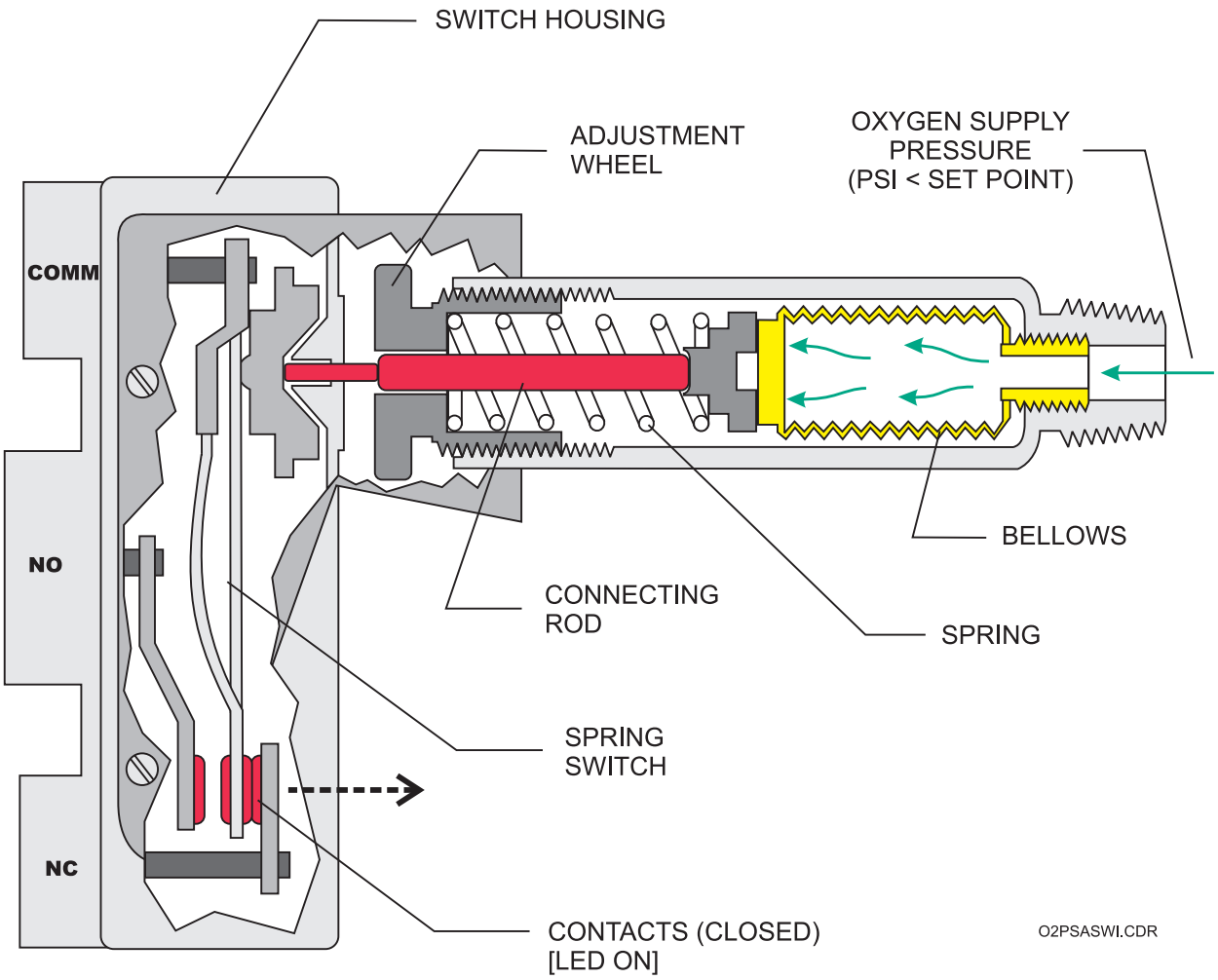


Figure 2-22: The oxygen supply pressure alarm switch - activated.

Oxygen Supply for the Ventilator

A tee fitting in the oxygen circuit allows the 50 psi oxygen supply to flow to the ventilator (Figure 2-23). The flow of oxygen and its role in the drive gas circuit of the ventilator are described in Chapter 7.

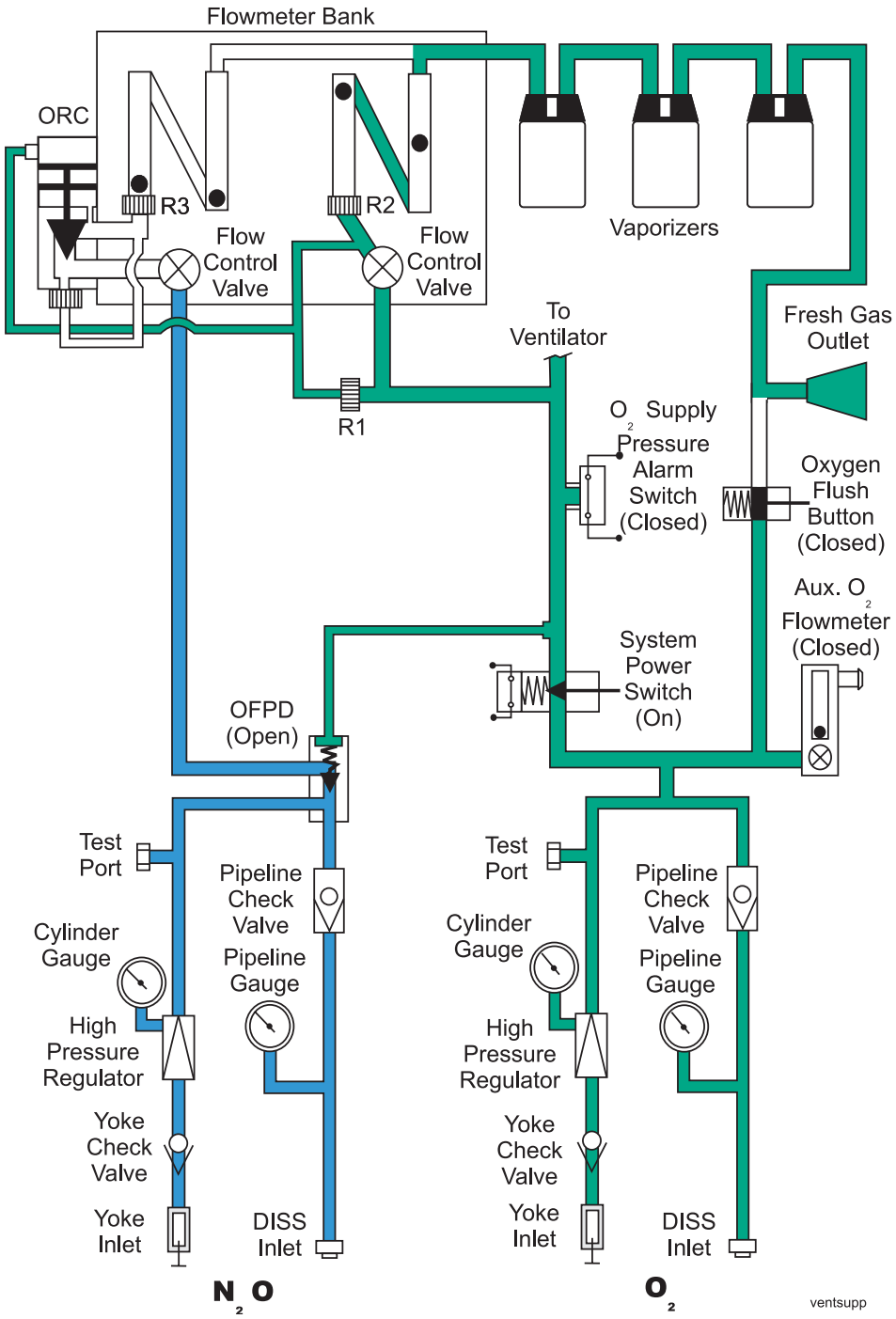


Figure 2-23: Oxygen supply for the ventilator drive gas circuit.

Minimum Oxygen Flow

Another tee in the oxygen circuit allows oxygen to flow to the minimum flow resistor (A in Figure 2-24). When an oxygen source of 50 psi is applied to the series resistance created by resistors A and B, the result is an output flow of approximately 150 ml/min. This gas flows to the oxygen circuit bypassing the flow control valve. This minimum flow of oxygen then flows to the patient breathing circuit through the fresh gas outlet. This flow cannot be eliminated on current anesthesia systems, but ceases to flow on earlier three and four gas anesthesia systems when the gas selector switch is in the ALL GASES position. Anesthesia systems produced before 1986 had a minimum oxygen flow of 250 ml/min.

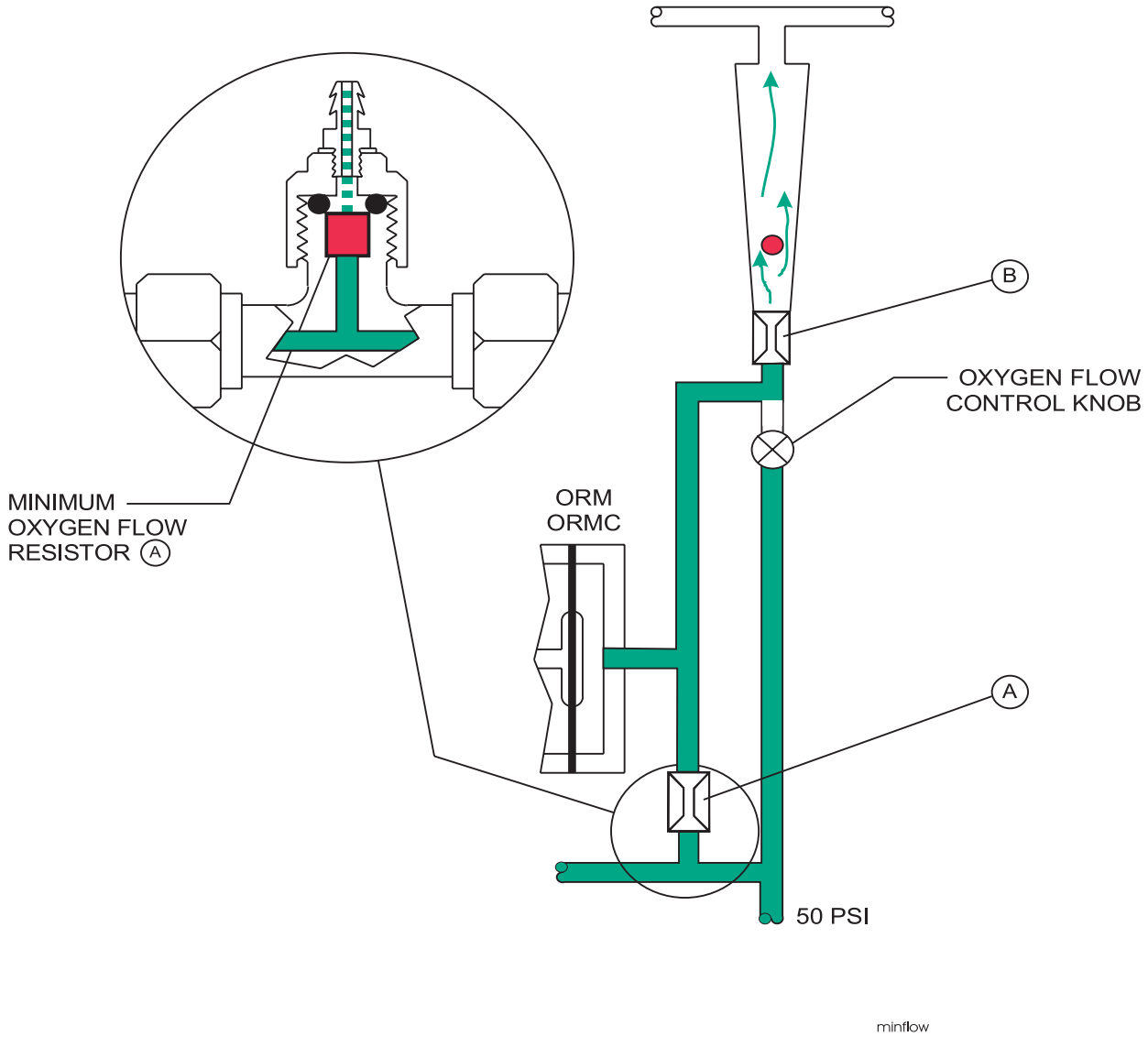


Figure 2-24: Minimum oxygen flow.

Flow Control Valve

The oxygen circuit on a Narkomed anesthesia system terminates at the flow control valve. This valve regulates the flow of oxygen supplied to the patient breathing circuit through the fresh gas outlet. The valve consists of a threaded shaft with a tapered end that mates with a tapered seat. When the flow control valve is closed (Figure 2-25), the tapered end seals against the tapered seat and does not allow any gas to flow through the valve.

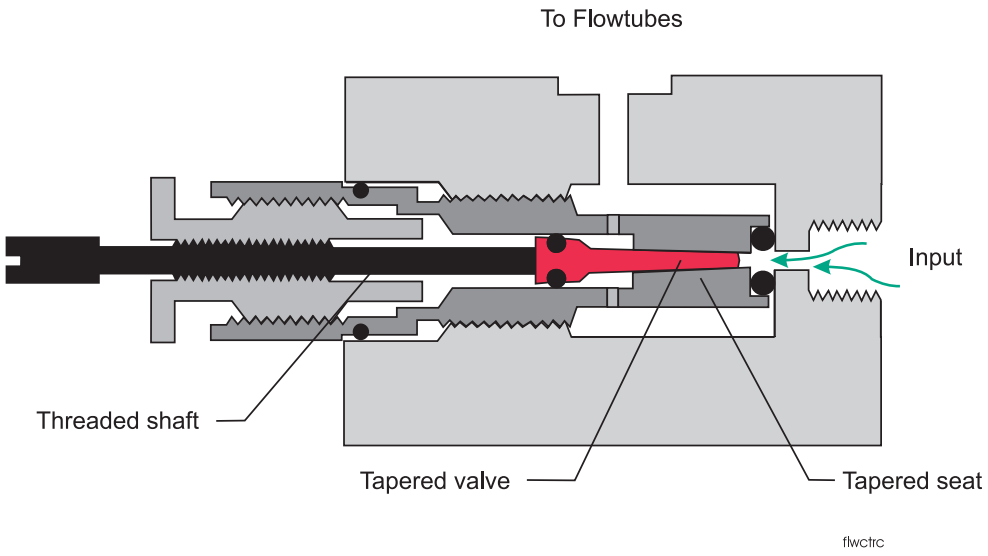


Figure 2-25: Flow control valve - closed position.

As the flow control valve is opened (Figure 2-26), the tapered end of the threaded shaft moves away from the seat, allowing the oxygen to flow through the valve. The greater the space between the tapered end and the tapered seat, the higher the gas flow.

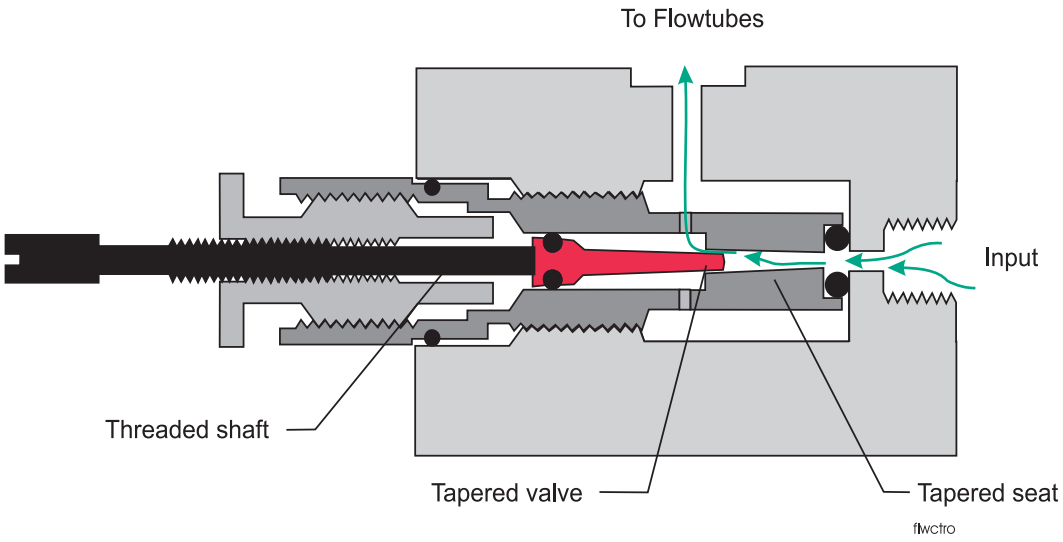


Figure 2-26: Flow control valve - open position.

Flowtubes

After establishing gas flow through the flow control valve, the gas flow must be measured. All Narkomed anesthesia systems use two flowtubes, a fine flow tube that measures gas in ml/minute and a coarse flowtube that measures gas in l/minute. The fine and coarse flowtubes are connected in tandem to measure the flow of a given gas (Figure 2-27). Using tandem flowtubes allows for more accurate delivery of gas throughout the entire flow range. All flowtubes used in Narkomed anesthesia systems are permanently calibrated.

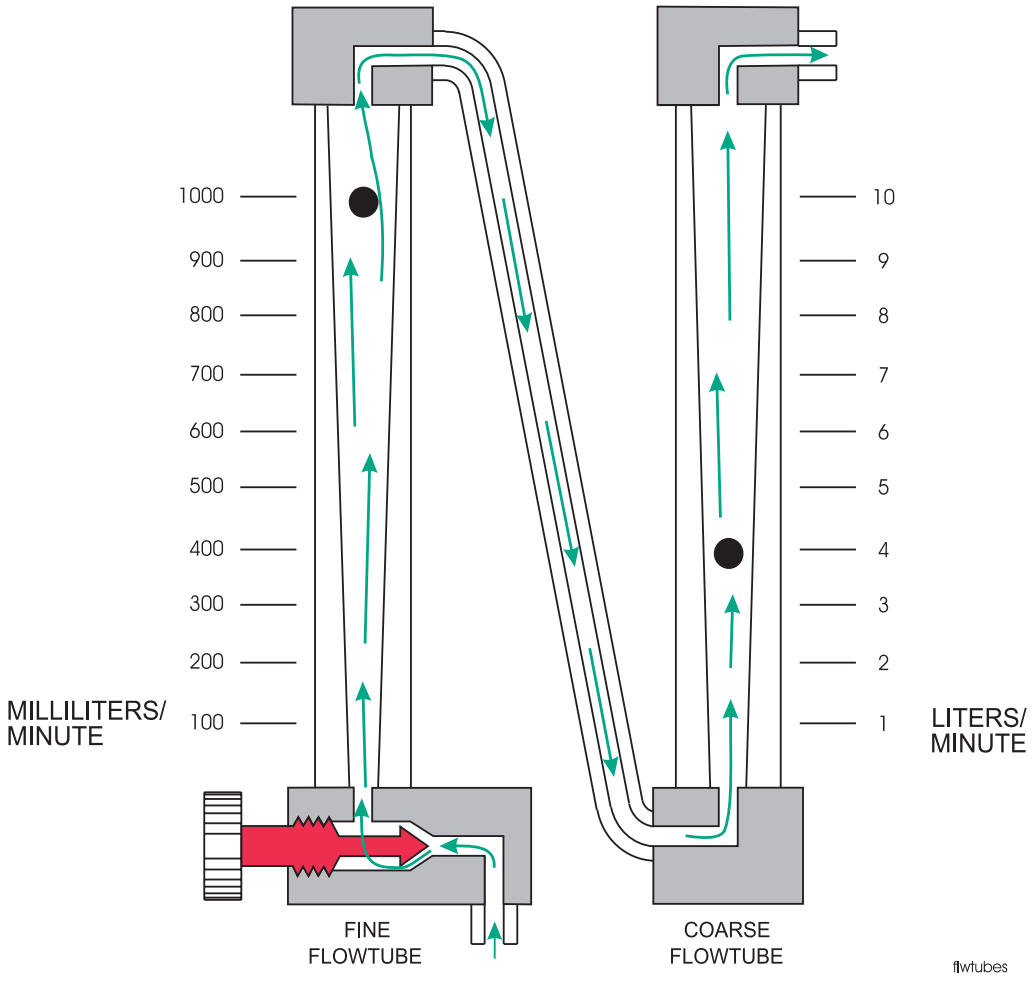


Figure 2-27: A fine flowtube and a coarse flowtube connected in tandem.

Single Taper Flowtubes

The inside diameter of the flowtube is tapered, with a smaller inside diameter at the bottom, tapering up to a larger inside diameter at the top (Figure 2-28). As the gas from the flow control valve flows up through the flowtube, it must flow around the float, causing a pressure differential above and below the float. The pressure above the float (P2) is less than the pressure below the float (P1), causing the float to rise inside the tube. As the float raises inside the tube, the inside diameter increases (because of the taper) and the gas has more room to flow around the float. As the space between the inside diameter of the flowtube and the float widens, the pressure differential above and below the float becomes less pronounced. Eventually the float raises to a point where there is enough space between the inside diameter and the float for the gas to flow around the float without generating an unbalanced pressure differential, and equilibrium is achieved. When the float stops raising in the tube, it indicates the gas flow as marked on the outside of the flowtube.

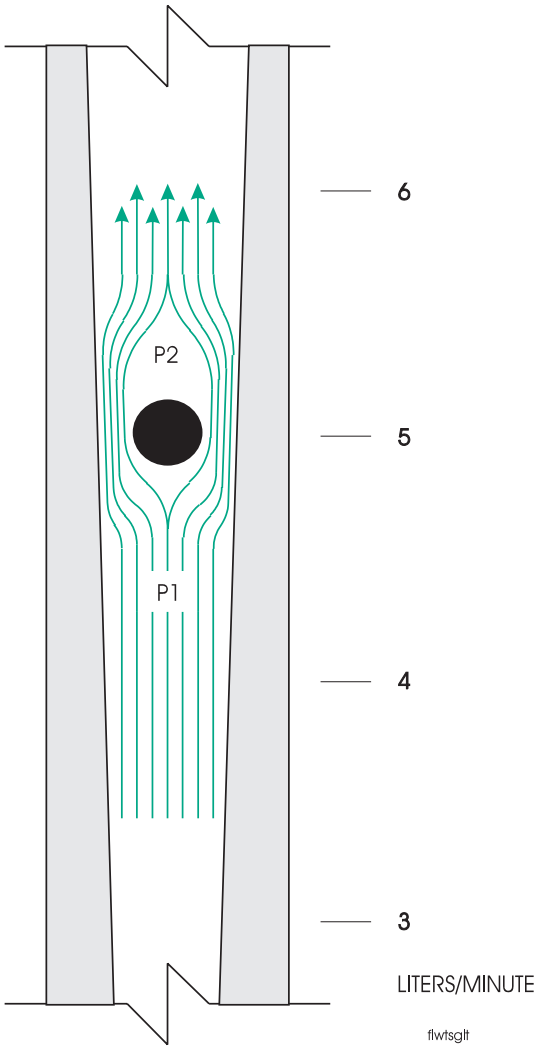


Figure 2-28: Gas flow through a single taper flowtube.

Dual-Taper Flowtubes

On any Narkomed anesthesia system equipped with four gases, delivery of the third and fourth gases is metered by dual-taper flowtubes (Figure 2-29). These flowtubes work on the same principle as the single-taper flowtube, but make it possible to combine both the fine and coarse flow scales on one tube. This is accomplished by making the inside diameter of the flowtube taper at two different angles. The steeper angle corresponds to the fine flow scale and the shallower angle corresponds to the coarse flow scale. By employing dual-taper flowtubes, it is possible to overcome the space limitations of the flowmeter housing.

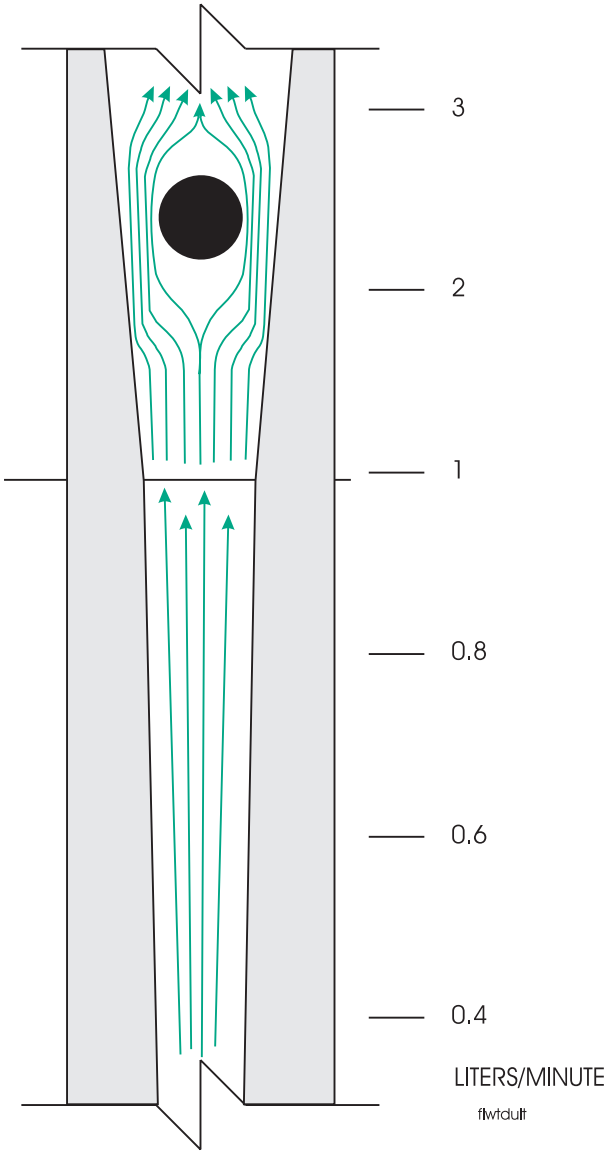


Figure 2-29: A dual-taper flowtube.

Nitrous Oxide Gas Circuit

The nitrous oxide gas circuit shares many of the same components as the oxygen circuit. Nitrous oxide supplied by an E cylinder enters the anesthesia system through a yoke indexed for nitrous oxide. The nitrous oxide flows through a yoke check valve into the high pressure regulator. From the regulator, the nitrous oxide flows to the cylinder pressure gauge and the oxygen failure protection device (Figure 2-30). Nitrous oxide supplied by the hospital piping system enters the anesthesia system through a DISS inlet and flows to the pipeline pressure gauge and the pipeline check valve. Nitrous oxide flows through the pipeline check valve to the oxygen failure protection device. As the nitrous oxide flows out of the oxygen failure protection device it enters a gas proportioning device in the anesthesia system.

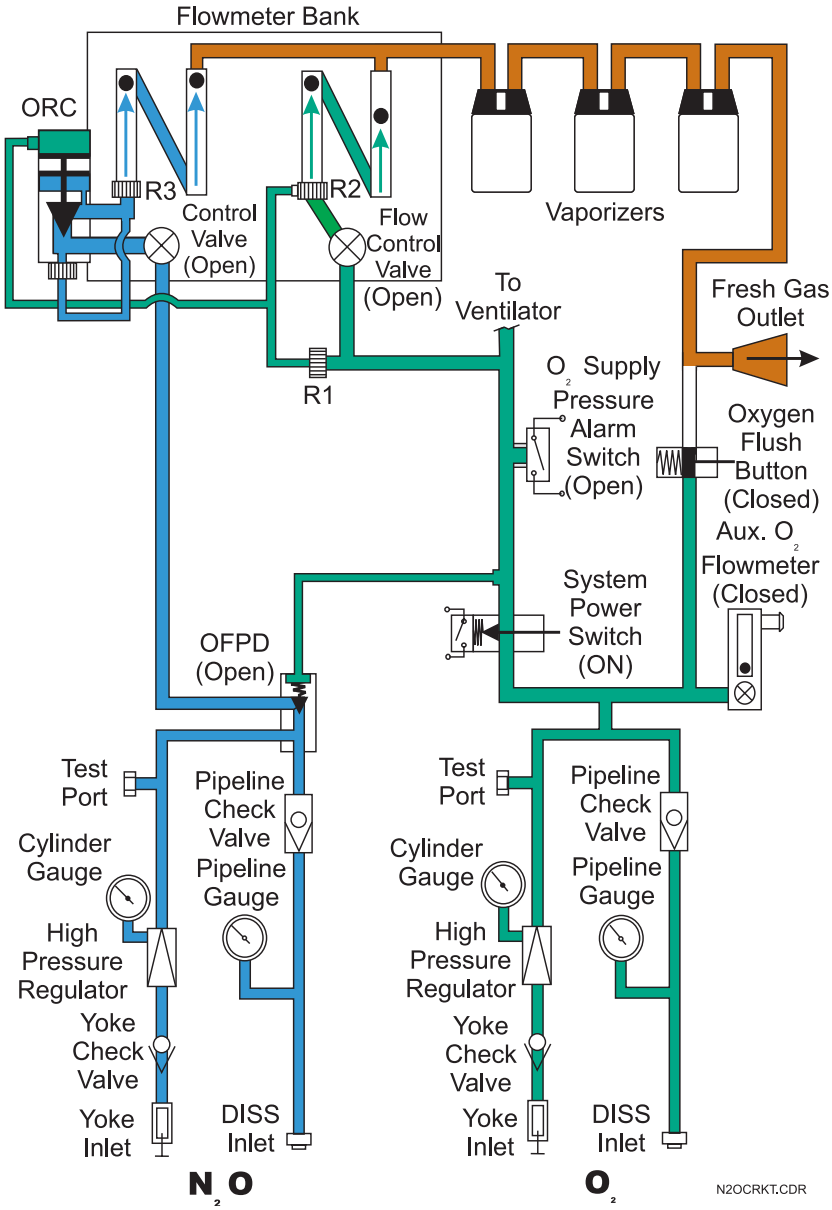


Figure 2-30: The nitrous oxide gas circuit.

Oxygen Failure Protection Device

In the event of a total failure of the oxygen supply system, it is necessary to protect the patient against the delivery of a hypoxic gas mixture. To prevent hypoxic gas mixtures, an Oxygen Failure Protection Device (OFPD) is incorporated into all gas circuits, except oxygen, in the anesthesia system.

In the example shown, both supply sources of nitrous oxide flow into the bottom of the OFPD. Under normal circumstances, the OFPD is activated (Figure 2-31) by the oxygen supply pressure. The oxygen enters the OFPD under pressure and forces the piston downward. As the piston moves down, it compresses the spring and opens the valve. When the valve opens, the nitrous oxide flows through the OFPD, toward the nitrous oxide flowmeters.

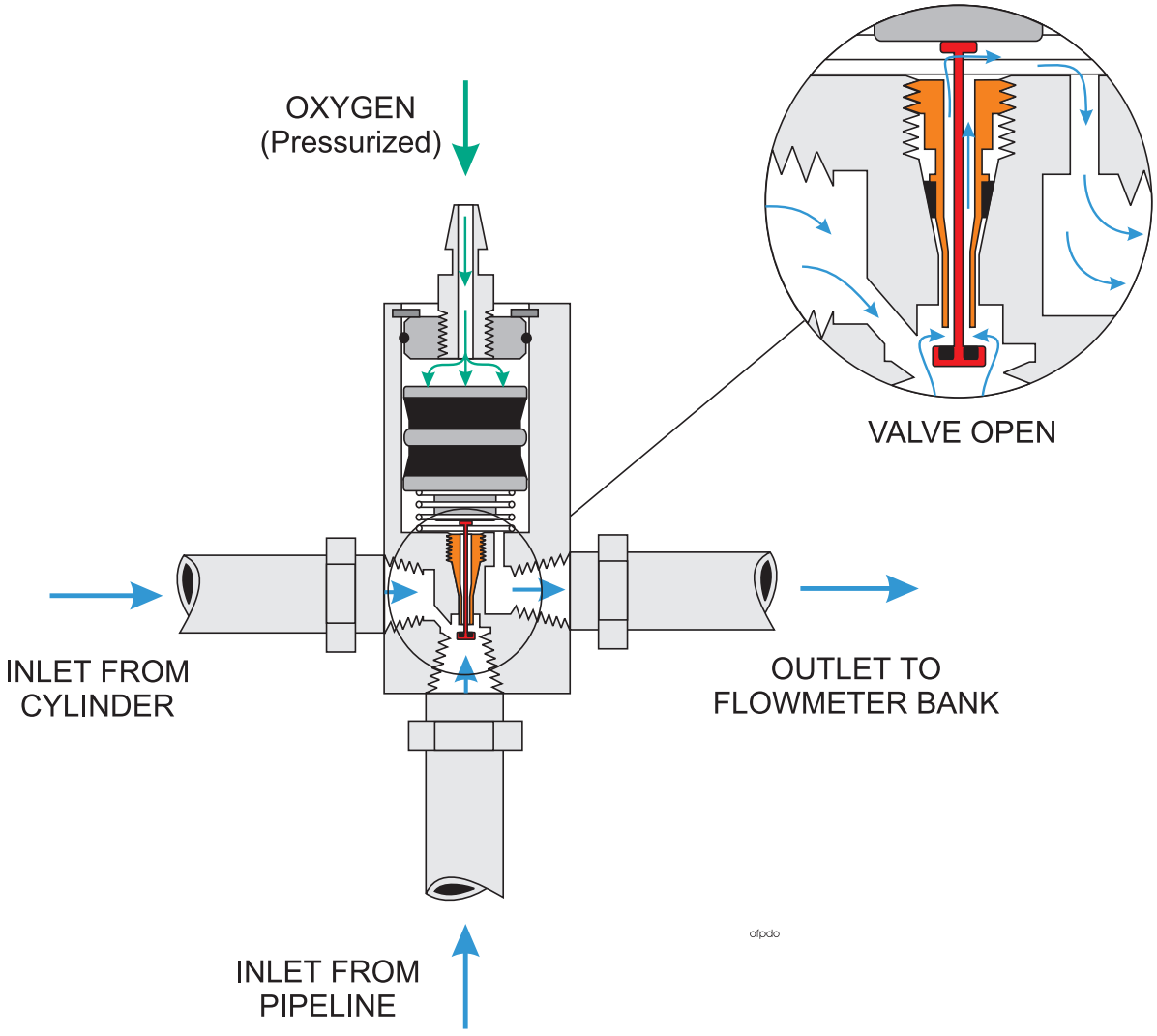


Figure 2-31: The oxygen failure protection device - activated.

If the oxygen supply to the anesthesia system fails, the OFPDs stop the flow of all other gases to the patient. As the supply pressure of the oxygen decreases, the spring forces the piston and seal assembly up, narrowing the valve opening and decreasing the flow of nitrous oxide in proportion to the oxygen flow. If the oxygen pressure fails completely, the valve closes (Figure 2-32) and the nitrous oxide flow stops at the OFPD.

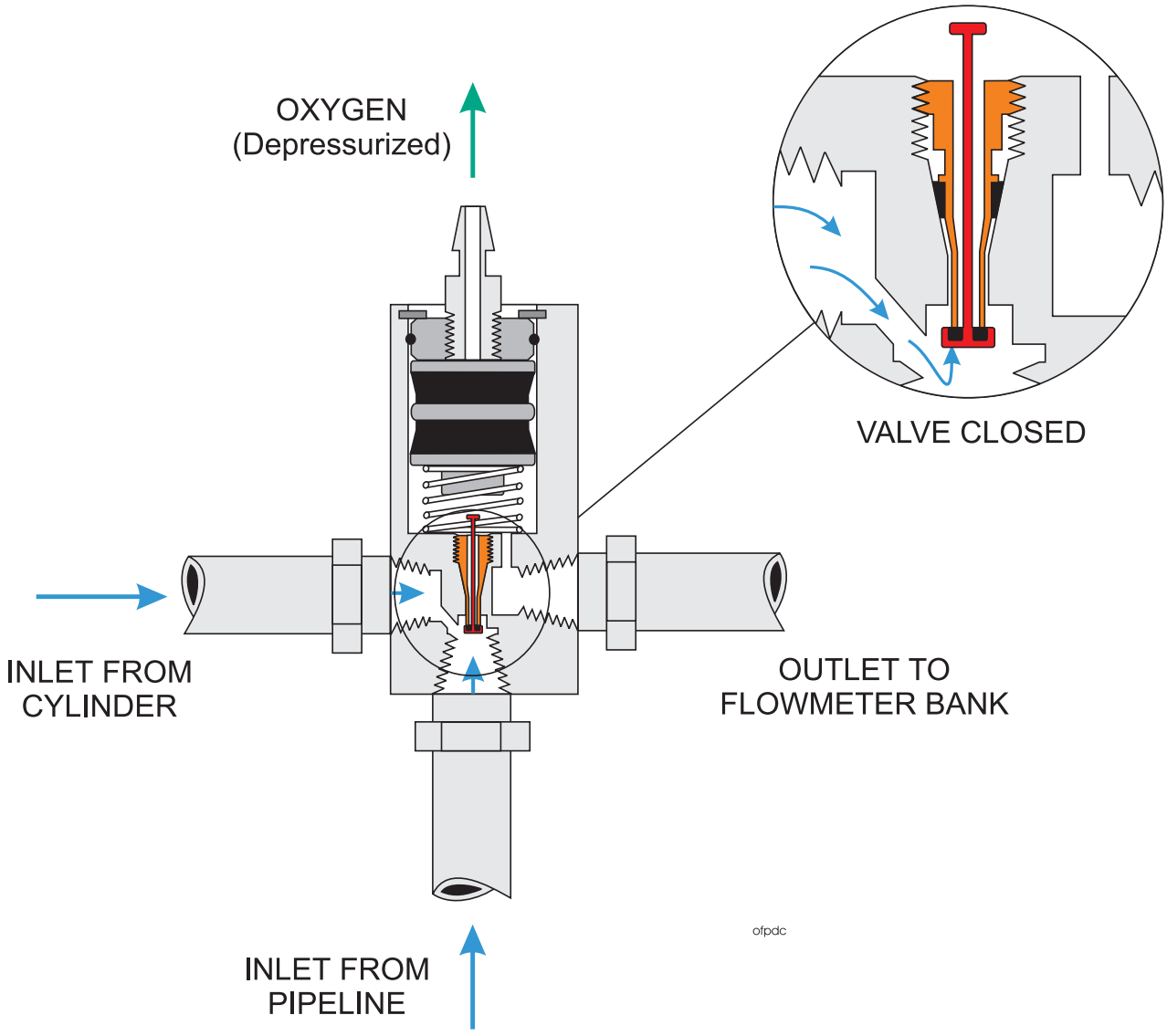


Figure 2-32: The oxygen failure protection device - deactivated.

Oxygen Ratio Controller

Much like the OFPD, the Oxygen Ratio Controller (ORC) is designed to prevent the delivery of a hypoxic gas mixture to the patient breathing circuit. On a Narkomed anesthesia system, this is achieved by controlling the ratio of nitrous oxide to oxygen.

The ORC (Figure 2-33) is essentially a proportioning device that responds to pressure differentials produced by resistors placed between the flow control valves and the fine flow tubes in both the oxygen and nitrous oxide gas circuits.

The ORC consists primarily of two rolling diaphragms connected by a moveable piston, which in turn controls a proportioning valve. As gas flows through the flow control valves and through the resistors, each resistor generates a back pressure proportionate to the amount of gas flowing through each respective flow control valve. The back pressure of oxygen flows to the upper chamber of the ORC. The back pressure of nitrous oxide flows to the lower chamber. Each gas exerts a pressure on its respective rolling diaphragm. The piston that connects these two diaphragms moves up or down in response to any changes in back pressure from either gas, opening or closing the proportioning valve located below the lower chamber.

The ORC is designed to prevent the delivery of less than 22 - 28% oxygen to the patient breathing circuit. The following illustrations show the changing positions of the various components of the ORC in response to changes in the flow rate of oxygen or nitrous oxide.

1. O_2 Back-pressure inlet
2. Locknut
3. Adjustment screw
4. Spring
5. O_2 Diaphragm
6. Piston
7. N_2O Diaphragm
8. Breather hole
9. Guide sleeve
10. Set screw
11. Spring
12. N_2O Outlet
13. N_2O Inlet
14. Filter
15. Flow Resistor
16. Resonance restrictor
17. Pin
18. Nut valve
19. Ball
20. Ball seat
21. Spring

Oxygen ratio controller (ORC) - Legend

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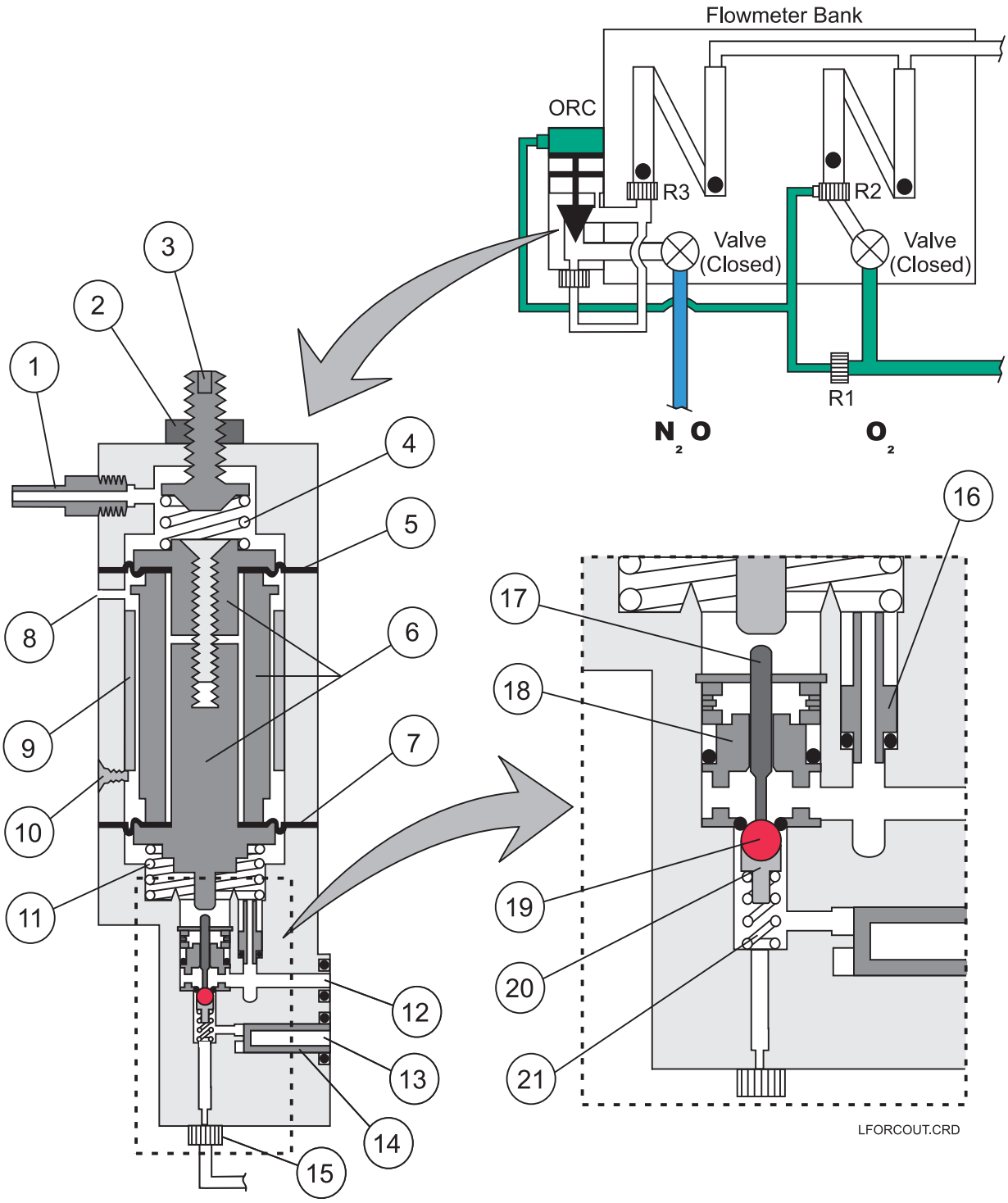

Figure 2-33: Oxygen Ratio Controller (ORC) - callouts

In this illustration (Figure 2-34), both flow control valves are delivering 10 lpm of gas to the patient breathing circuit. This represents a 50/50 proportion of oxygen and nitrous oxide. At this point, nitrous oxide is not being controlled by oxygen, because more than 22 - 28% of oxygen is delivered to the patient breathing circuit. The back-pressure of oxygen is proportionately greater than the back-pressure of nitrous oxide because the resistors are not of equal value.

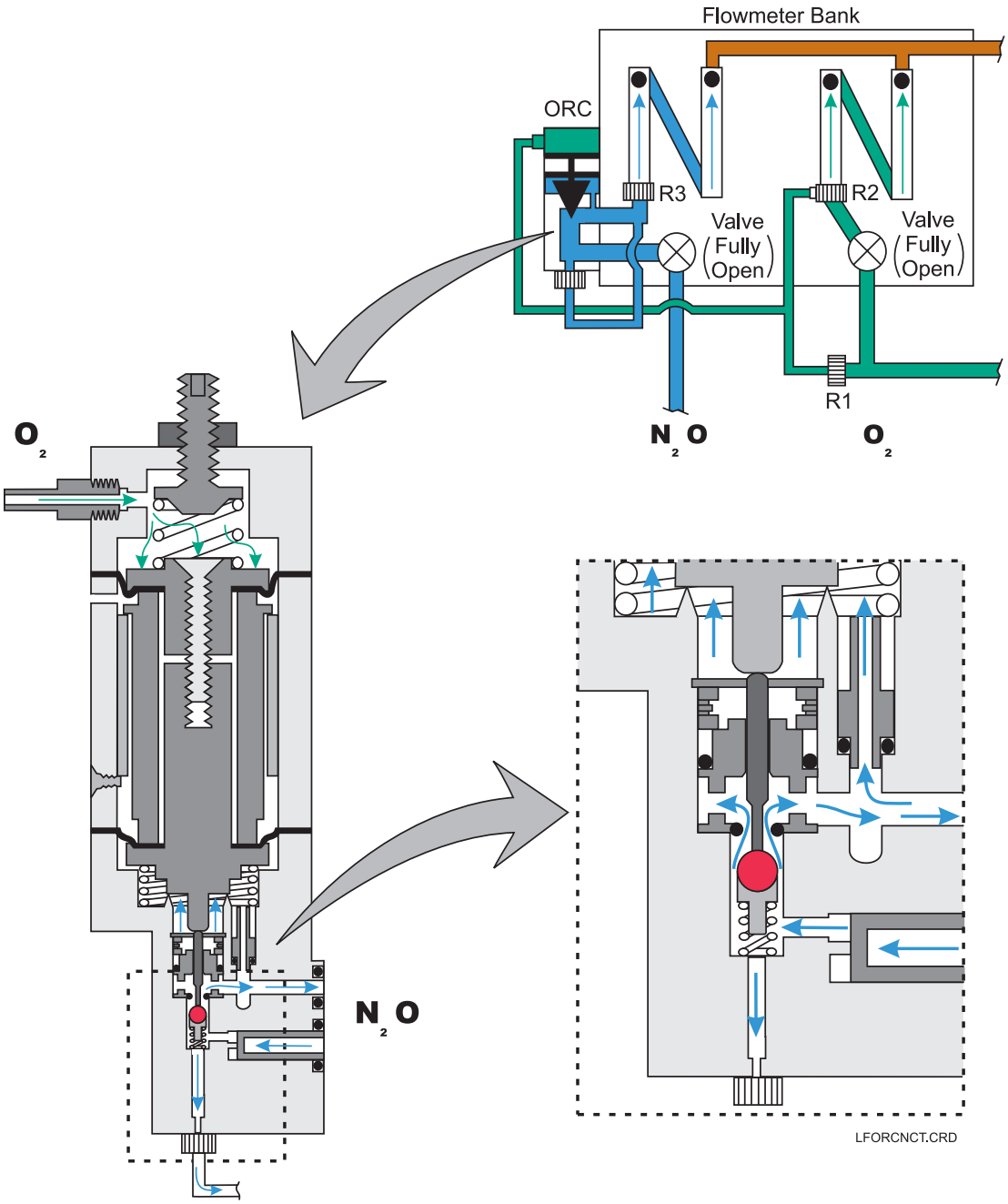

Figure 2-34: The ORC in a noncontrolling condition.

As the flow control valve for oxygen is rotated to reduce the flow of oxygen to the patient breathing circuit, the threshold where the ORC begins to control the flow of nitrous oxide is reached. When this proportion of gases is reached (Figure 2-35), the back-pressure of nitrous oxide is greater than the back-pressure of oxygen and the piston begins to move up. As the piston moves up, the small spring under the proportioning valve moves the ball closer to the seat, reducing the amount of nitrous oxide flowing through the valve. As the flow of nitrous oxide to the flowmeter is reduced, the back-pressure generated by the nitrous oxide resistor is reduced until a state of equilibrium is established again between the oxygen and the nitrous oxide.

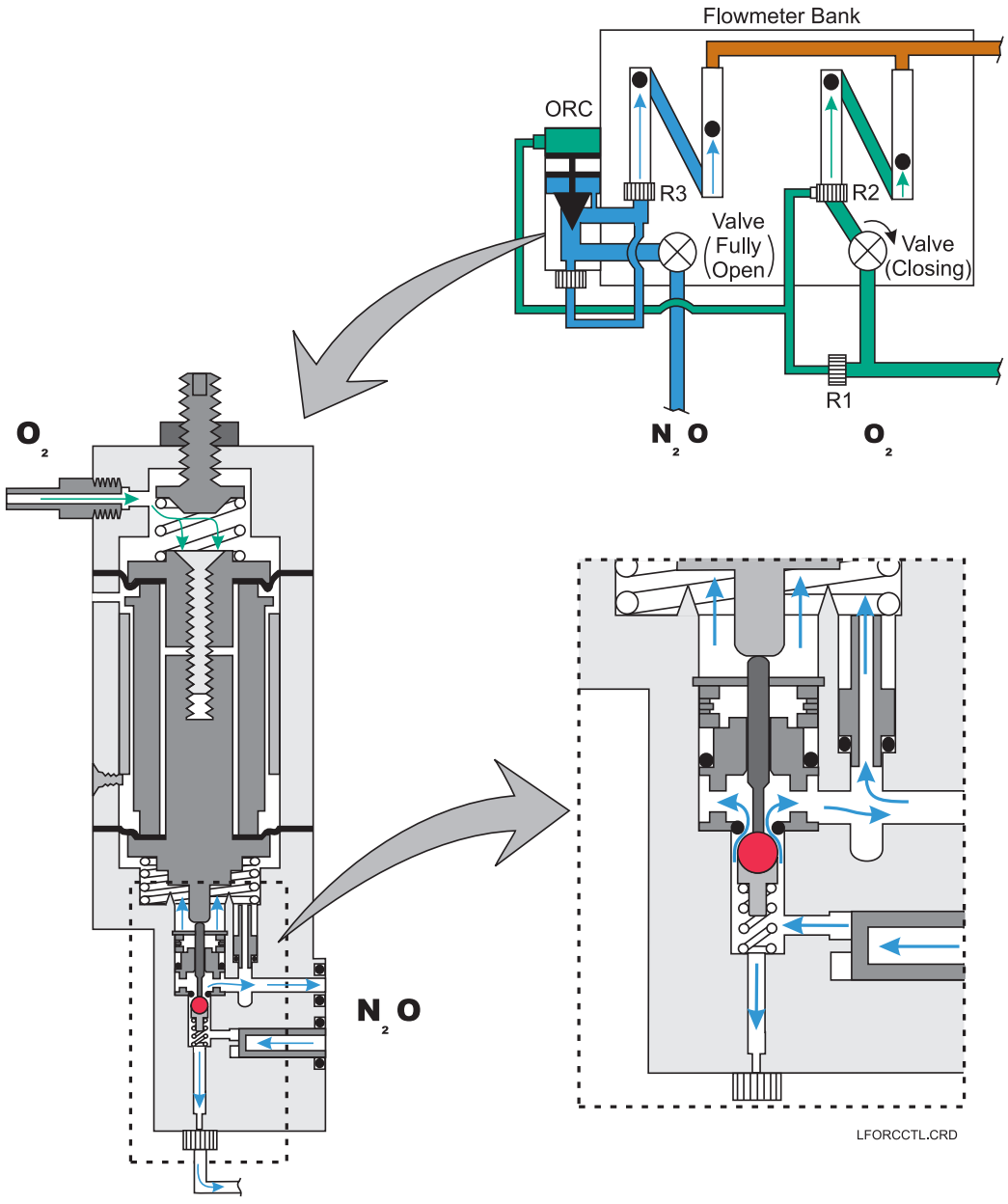

Figure 2-35: The ORC in a controlling condition.

If the flow of oxygen continues to be reduced, the flow of nitrous oxide to the patient breathing circuit is limited proportionally (Figure 2-36). As the flow of oxygen decreases, the back-pressure in the upper chamber of the ORC continues to decrease and the piston continues to move up. When the back-pressure of oxygen in the upper chamber becomes too low, the spring will force the piston up still further and the small spring below the proportioning valve will push the ball against the seat and stop the flow of nitrous oxide to the patient breathing circuit completely. In this manner, the percentage of oxygen being delivered to the patient breathing circuit always remains at least 22 - 28%. When the ORC is shut off and the nitrous oxide flow control valve is still open, there will be a minimum flow of nitrous oxide. This gas flows through the bypass circuit, consisting of a resistor and tubing, mounted to the bottom of the ORC.

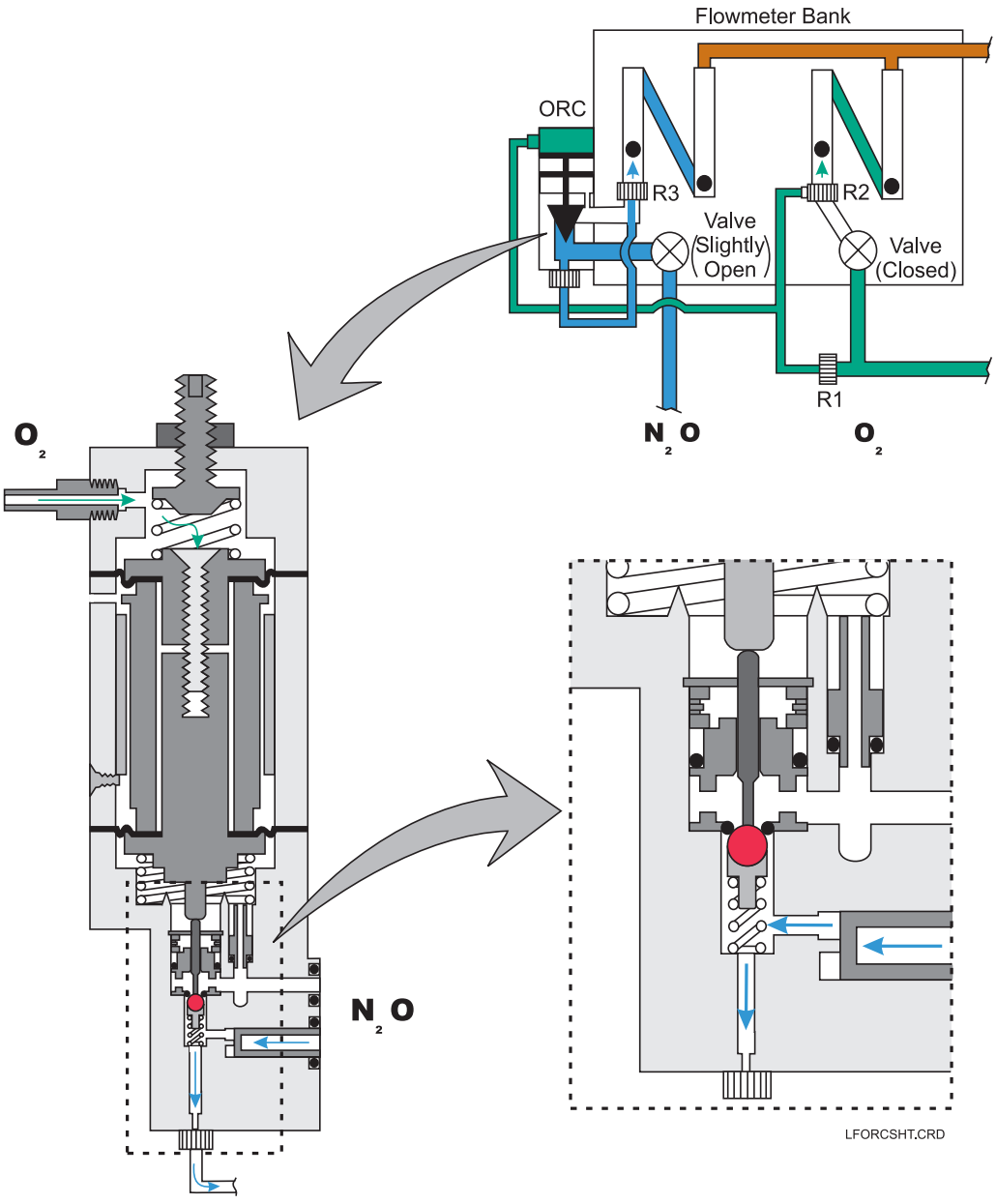

Figure 2-36: The ORC in a shut-off position.

Three Gas Circuits

A Narkomed anesthesia system can be equipped with a third gas circuit. The third gas circuit is very similar to the nitrous oxide circuit up to the OFPD. The OFPD is controlled by oxygen pressure and as long as sufficient oxygen is available to the anesthesia system, the third gas circuit will remain enabled.

The third gas is not controlled by any shut off valves or proportioning devices and it is possible to deliver only the third gas to the patient. As long as the third gas circuit is configured for Air, it is not possible to give an hypoxic gas mixture to the patient even if the flow of oxygen has been reduced to minimum flow.

If the third gas circuit is configured for Heliox mixtures, the yoke is configured to allow only mixtures of less than 80% Helium. The pin index safety system allows for this distinction (Figure 2-5). In the event that only minimum oxygen flow is being given in conjunction with the Heliox mixture containing at least 21% oxygen, the patient still does not receive an hypoxic gas mixture.

With this piping configuration, it is possible to deliver all three gases at the same time. Even though the third gas circuit is independent of the other gas circuits (with the exception of the OFPD), the flow of nitrous oxide is still controlled by the flow of oxygen via the Oxygen Ratio Controller.

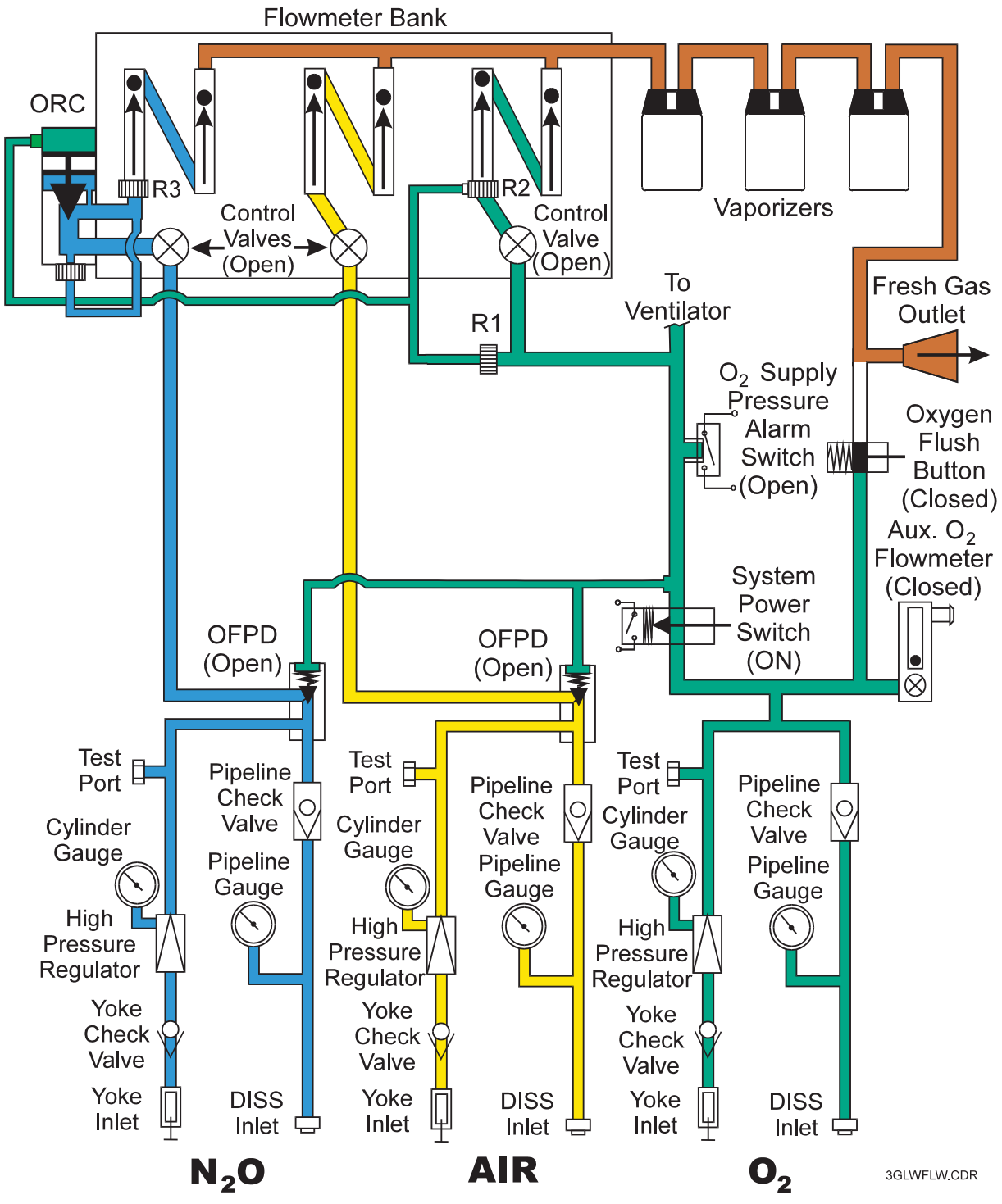

Figure 2-37: Low flow three gas circuit

Supplement to Chapter 2

Oxygen Ratio Monitor Controller

The Oxygen Ratio Monitor Controller (ORMC) is designed to prevent the delivery of a hypoxic gas mixture to the patient breathing circuit. On a Narkomed anesthesia system, the ORMC achieves this by controlling the ratio of nitrous oxide to oxygen.

The ORMC consists primarily of two diaphragms connected by a movable horizontal shaft that activates a proportioning valve and a leaf switch. The nitrous oxide and oxygen circuits each have a resistor located between the flow control valve and the fine flowtube. As gas flows through these resistors, they generate a back-pressure that varies proportionally to the gas flow. The back-pressure of nitrous oxide and oxygen flow to their respective chambers where they exert pressure on their respective diaphragms. In this manner, the back-pressure of nitrous oxide and oxygen directly oppose each other through the diaphragms and the connecting shaft. When the flow control valve for oxygen is opened and nitrous oxide is not flowing, the back-pressure in the oxygen chamber forces the shaft toward the nitrous oxide chamber, opening the proportioning valve. When the nitrous oxide flow control valve is opened, back-pressure inside the nitrous oxide chamber pushes the shaft back toward the oxygen chamber until equilibrium is reached between the two gases relative to the amount of flow allowed by their respective flow control valves.

As long as the flow of nitrous oxide and oxygen maintains a ratio of at least 75%:25%, the ORMC does not control the flow of nitrous oxide (Figure 2-38). If the flow of oxygen is decreased, back-pressure on the oxygen diaphragm is decreased and the shaft will move toward the oxygen chamber. The proportioning valve begins to close and restrict the amount of nitrous oxide that can flow to the flow control valve. The leaf switch also closes, activating the audible/visual alarms. The proportioning valve continues to close until the flow of nitrous oxide is again proportional to the flow of oxygen (Figure 2-39). The result is, that the mixture of fresh gas delivered to the patient breathing circuit always contains approximately 25% oxygen. The alarm functions of the ORMC were eliminated from all Narkomed anesthesia systems in 1992.

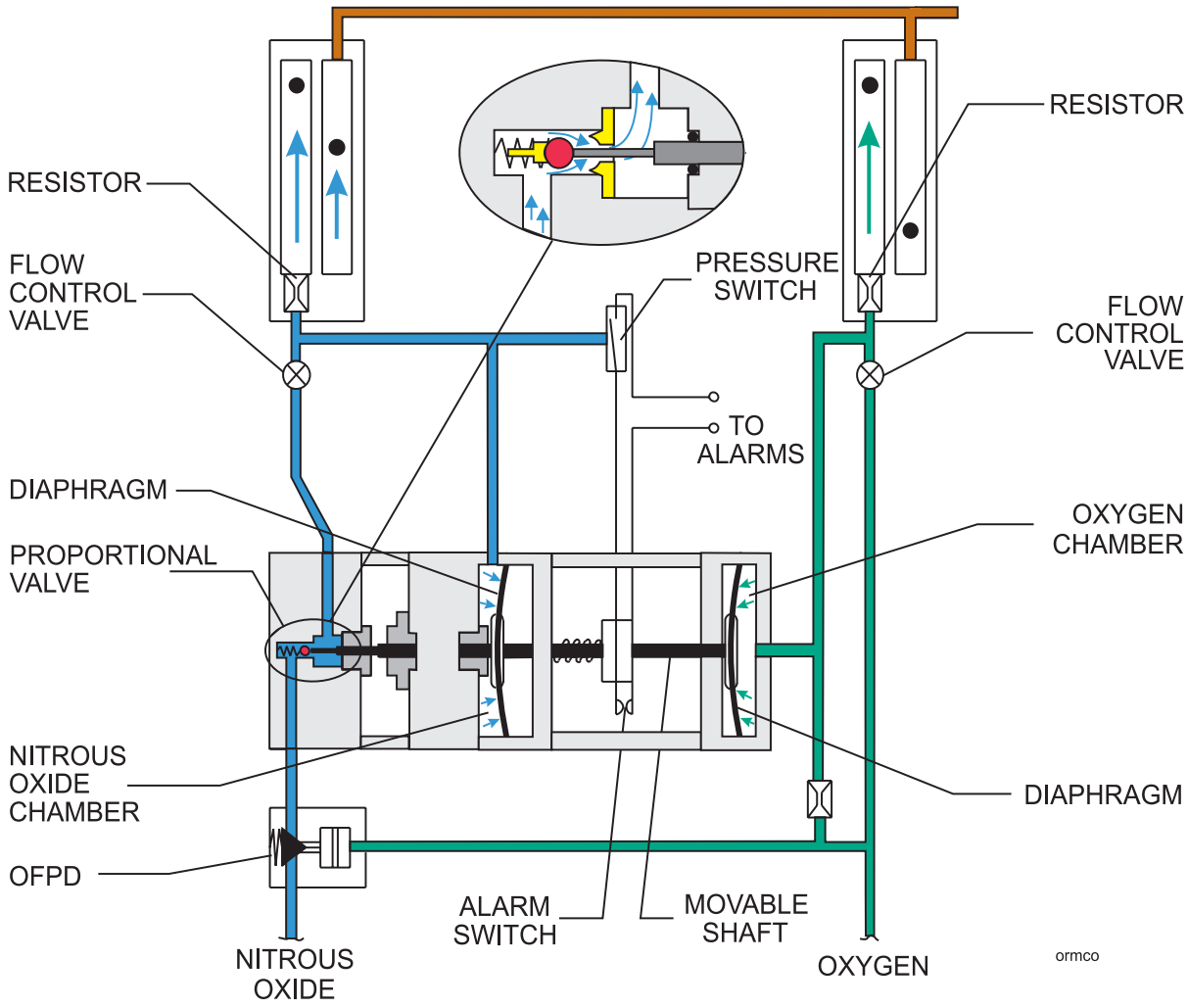

Figure 2-38: Adequate oxygen pressure (relative to nitrous oxide pressure) allows nitrous oxide to flow to the nitrous oxide flow control valve.

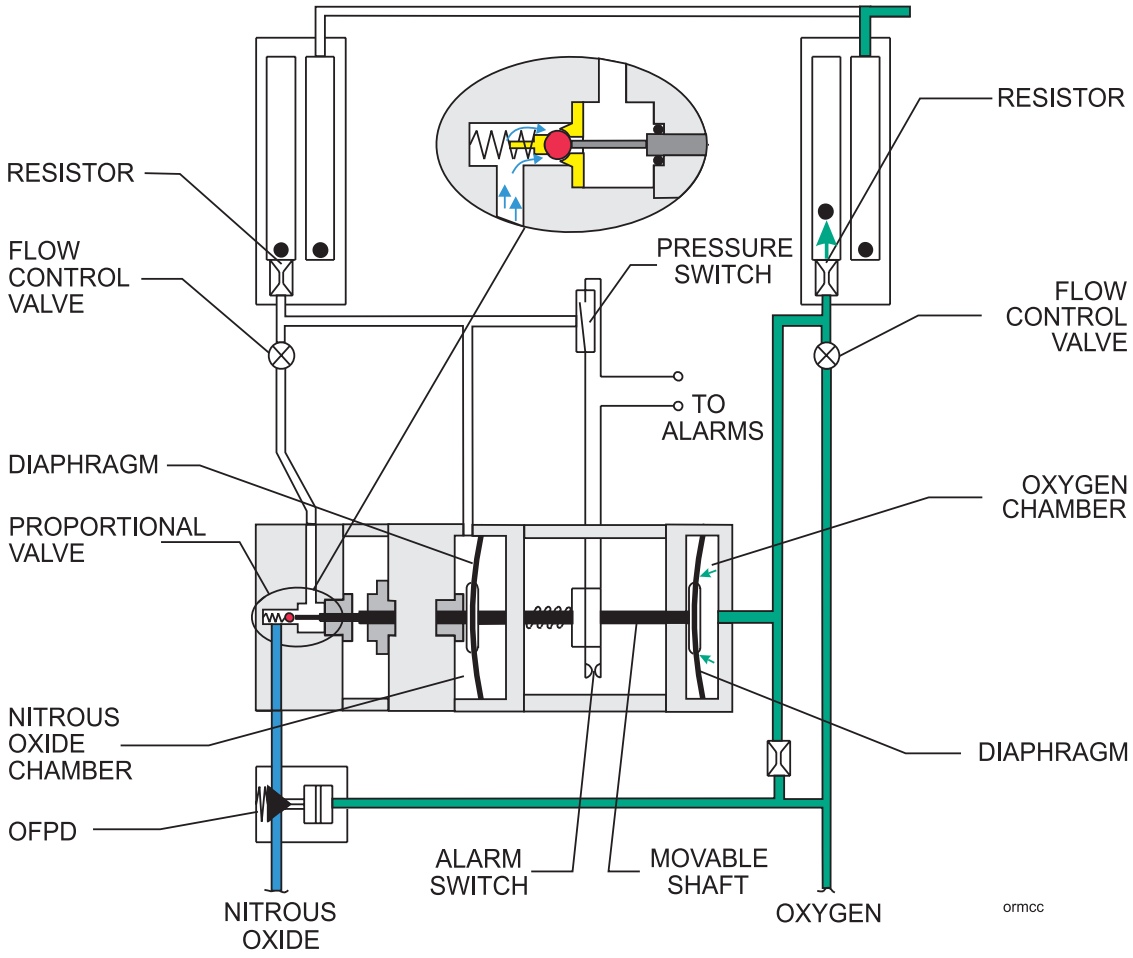

Figure 2-39: Inadequate oxygen pressure causes the proportioning valve to close, eliminating the flow of nitrous oxide to the nitrous oxide flow control valve.

Three-Gas Circuit

In addition to oxygen and nitrous oxide, Narkomed anesthesia systems can be equipped with two more gas circuits, including circuits for air, oxygen-helium (heliox), and/or carbon dioxide. When an anesthesia system has three or more gas circuits, the pneumatic circuitry has two modes of operation. The operating mode is controlled by the gas selector switch. When the gas selector switch is in the $O_2 + N_2O$ position (Figure 2-40), the anesthesia system can deliver oxygen and nitrous oxide, the minimum oxygen flow is enabled, and the third gas circuit is disabled by the OFPD in its circuit.

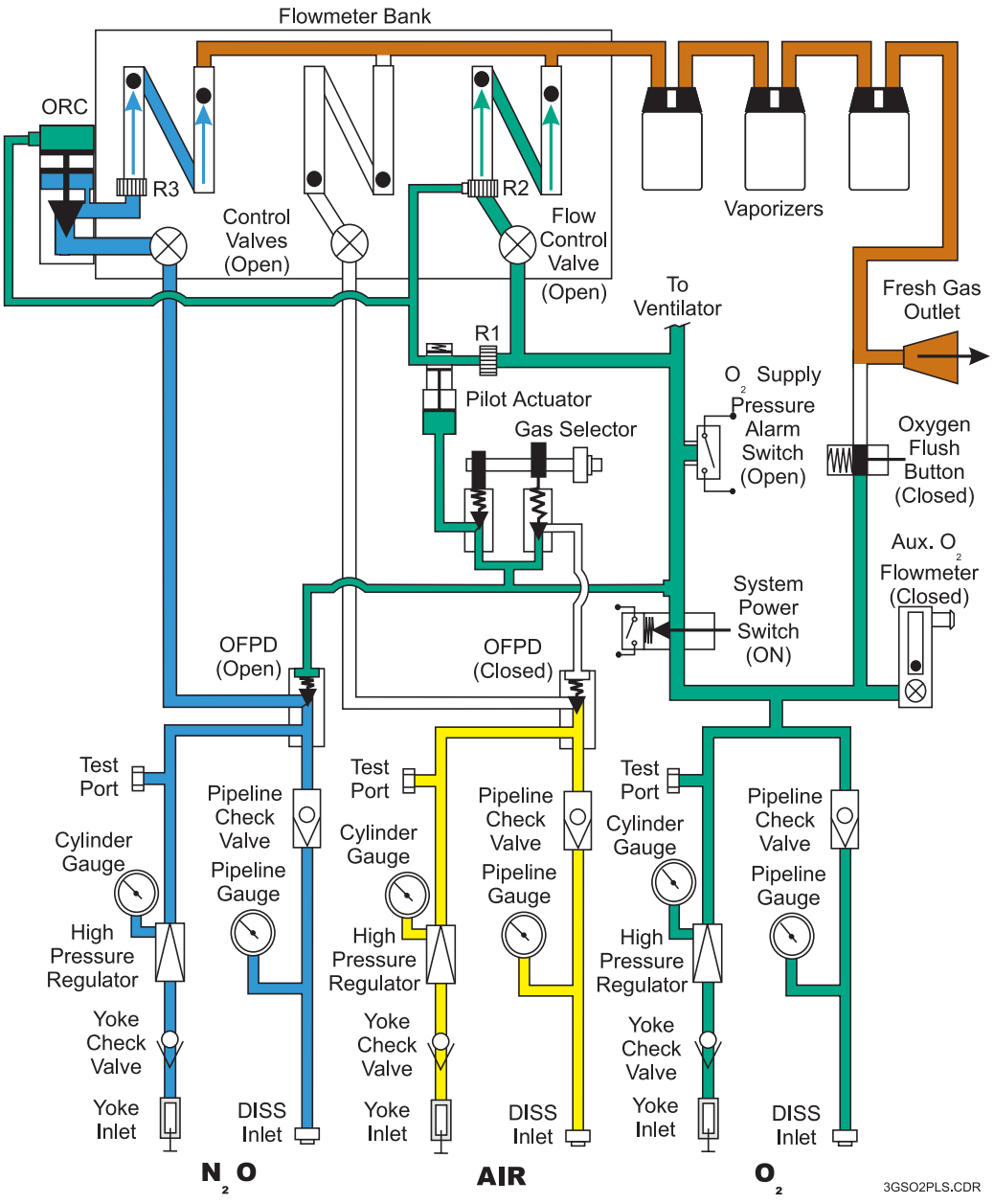

Figure 2-40: A three gas anesthesia system with the gas selector switch in the O_2 + N_2O position.

When the gas selector switch on a three-gas anesthesia system is turned to ALL GASES (Figure 2-41), the anesthesia system can deliver oxygen, nitrous oxide, and the third gas. Minimum oxygen flow is eliminated when the gas selector switch is set to ALL GASES. The function of the ORC remains the same regardless of which mode the gas selector switch is in.

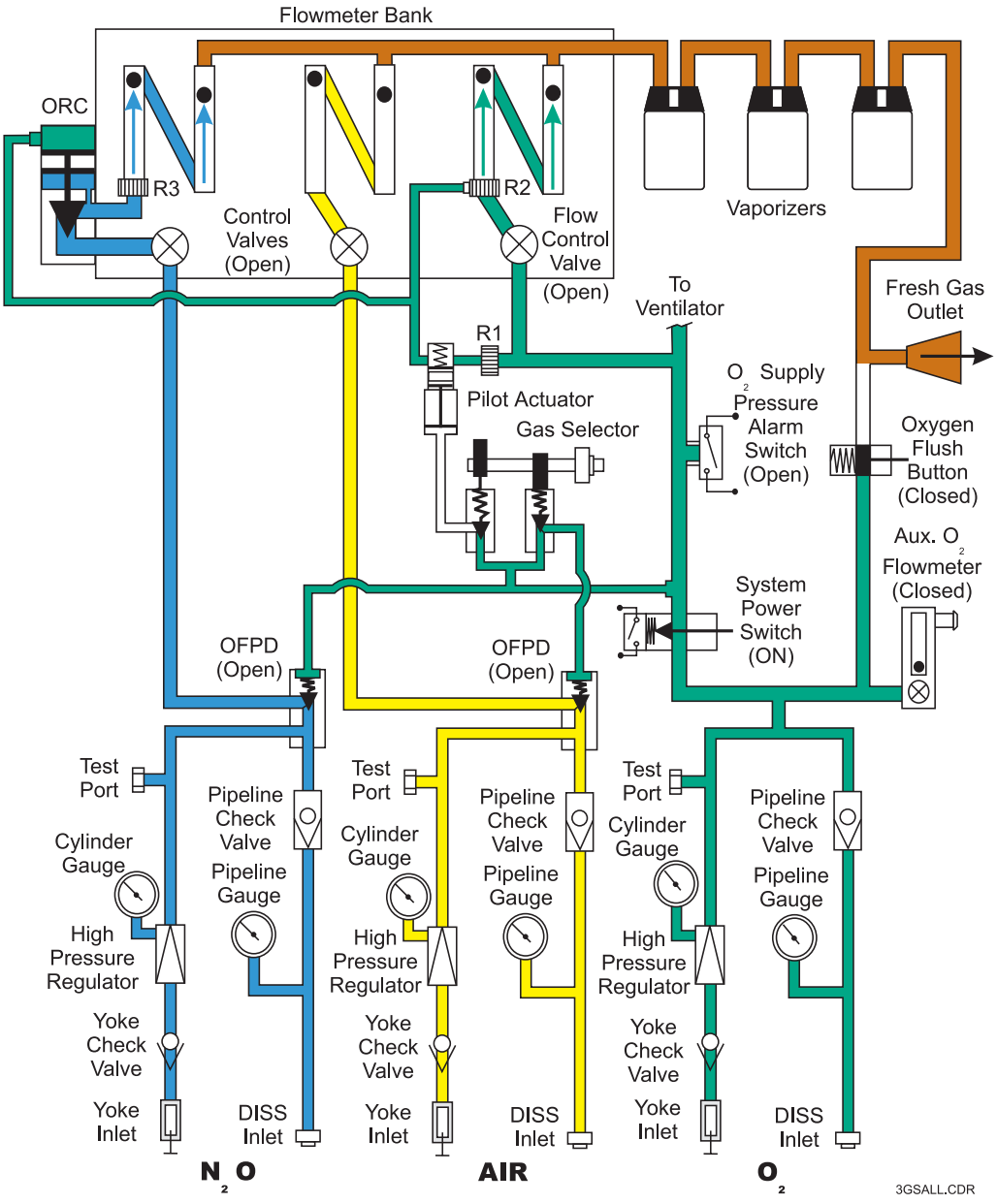

Figure 2-41: A three-gas anesthesia system with the gas selector switch set to ALL GASES.

Gas Selector Switch

When a Narkomed anesthesia system is equipped with a gas selector switch, an additional oxygen circuit is added to power the selector switch and the tee fitting that houses the minimum oxygen flow resistor is changed to a four-way fitting. The fourth arm allows gas to flow to the three-way poppet valves associated with the gas selector switch assembly. When the gas selector switch is set to $O_2 + N_2O$ position (Figure 2-42), the cam depresses the plunger on one three-way poppet valve. This allows gas to flow to the pilot actuator that controls the minimum oxygen flow circuit.

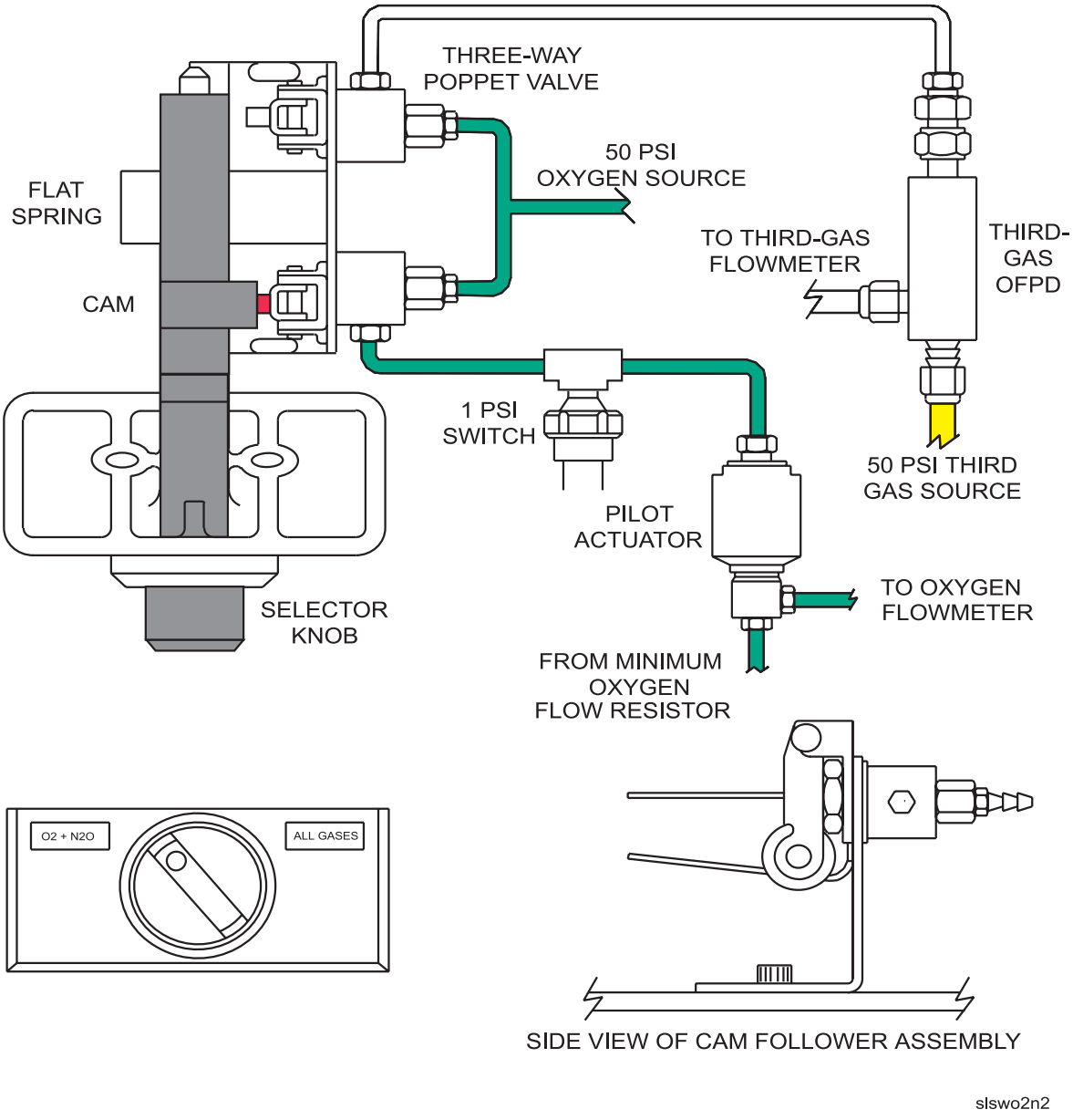

Figure 2-42: Gas selector switch set to $O_2 + N_2O$.

When the gas selector switch is rotated to ALL GASES, the cam activates the other three-way poppet valve (Figure 2-43). When this valve is opened, it allows gas pressure to flow to the OFPD in the third gas circuit. When the OFPD is pressurized, gas is allowed to flow to the flow control valve in the third gas circuit. When the gas selector switch is rotated to ALL GASES, the other three-way poppet valve depressurizes, eliminating gas flow to the pilot actuator. The pilot actuator deactivates and minimum oxygen flow is eliminated.

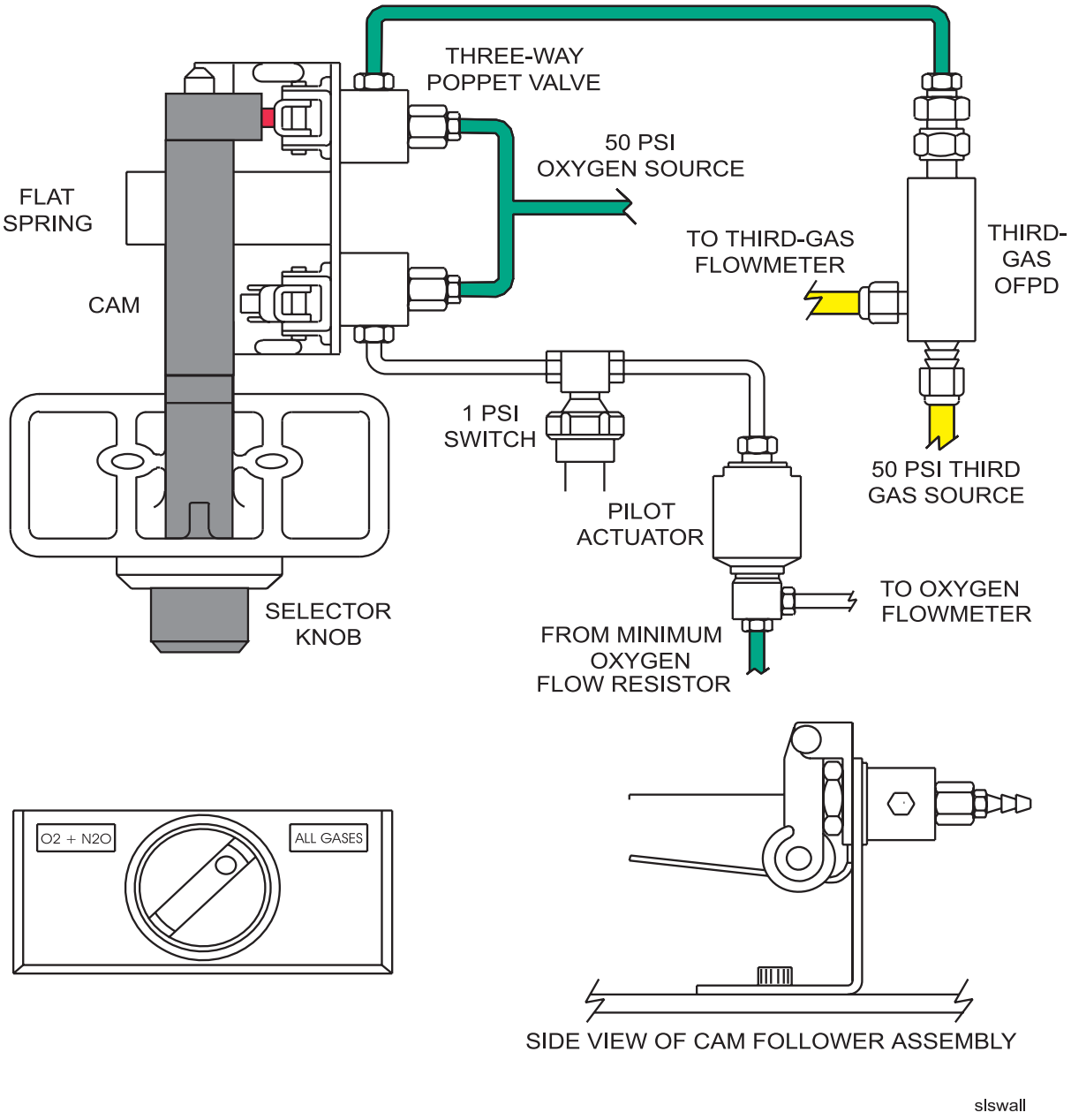

Figure 2-43: Gas selector switch set to ALL GASES.

Pilot Actuator Assembly

When the gas selector switch set to $O_2 + N_2O$, the oxygen flows through one of the three-way poppet valves to the Pilot Actuator assembly (Figure 2-44). The gas pressure forces the piston down, compressing a spring and depressing the plunger of a two-way poppet valve. When the plunger of the two-way poppet valve is depressed, the valve opens and the minimum oxygen supply can now flow to the flowmeter. If the gas selector switch is rotated to ALL GASES , the gas flow to the pilot actuator ceases. The spring forces the piston up, the two-way poppet valve closes, and minimum oxygen flow is eliminated.

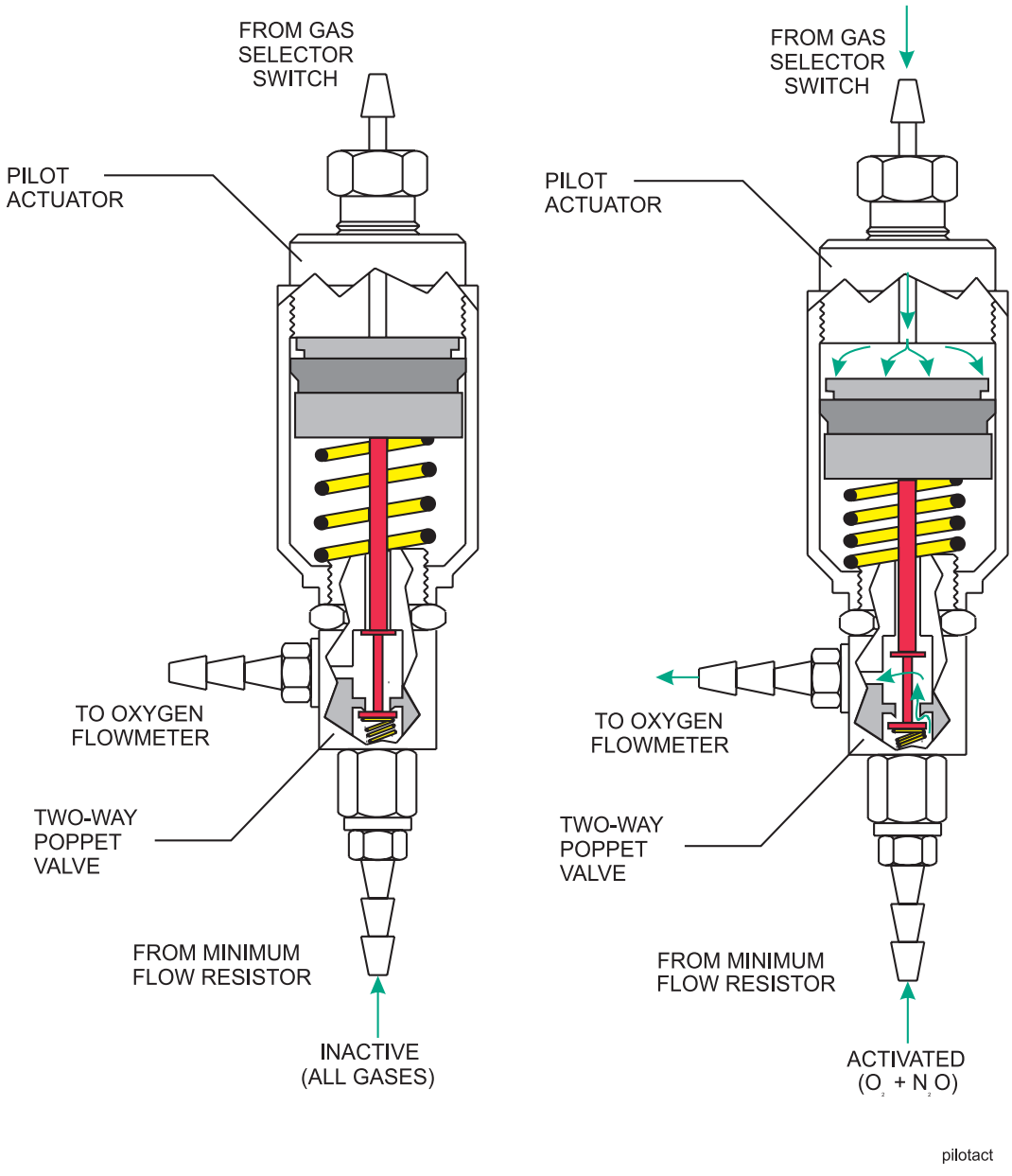

Figure 2-44: Minimum flow is activated only when the gas selector switch is set to $O_2 + N_2O$.

Oxygen Ratio Controller (early version)

The Oxygen Ratio Controller was originally configured without the minimum nitrous oxide flow resistor, mounted on the bottom of the current model. In all other respects, the early version of this device is identical to the current model, and serves the same function within the Narkomed anesthesia system.

1. O_2 Back-pressure inlet
2. Locknut
3. Adjustment screw
4. Spring
5. O_2 Diaphragm
6. Piston
7. N_2O Diaphragm
8. Breather hole
9. Guide sleeve
10. Set screw
11. Spring
12. N_2O Outlet
13. N_2O Inlet
14. Filter
15. Resonance restrictor
16. Pin
17. Nut valve
18. Ball
19. Ball seat
20. Spring

Oxygen ratio controller (ORC) - Legend

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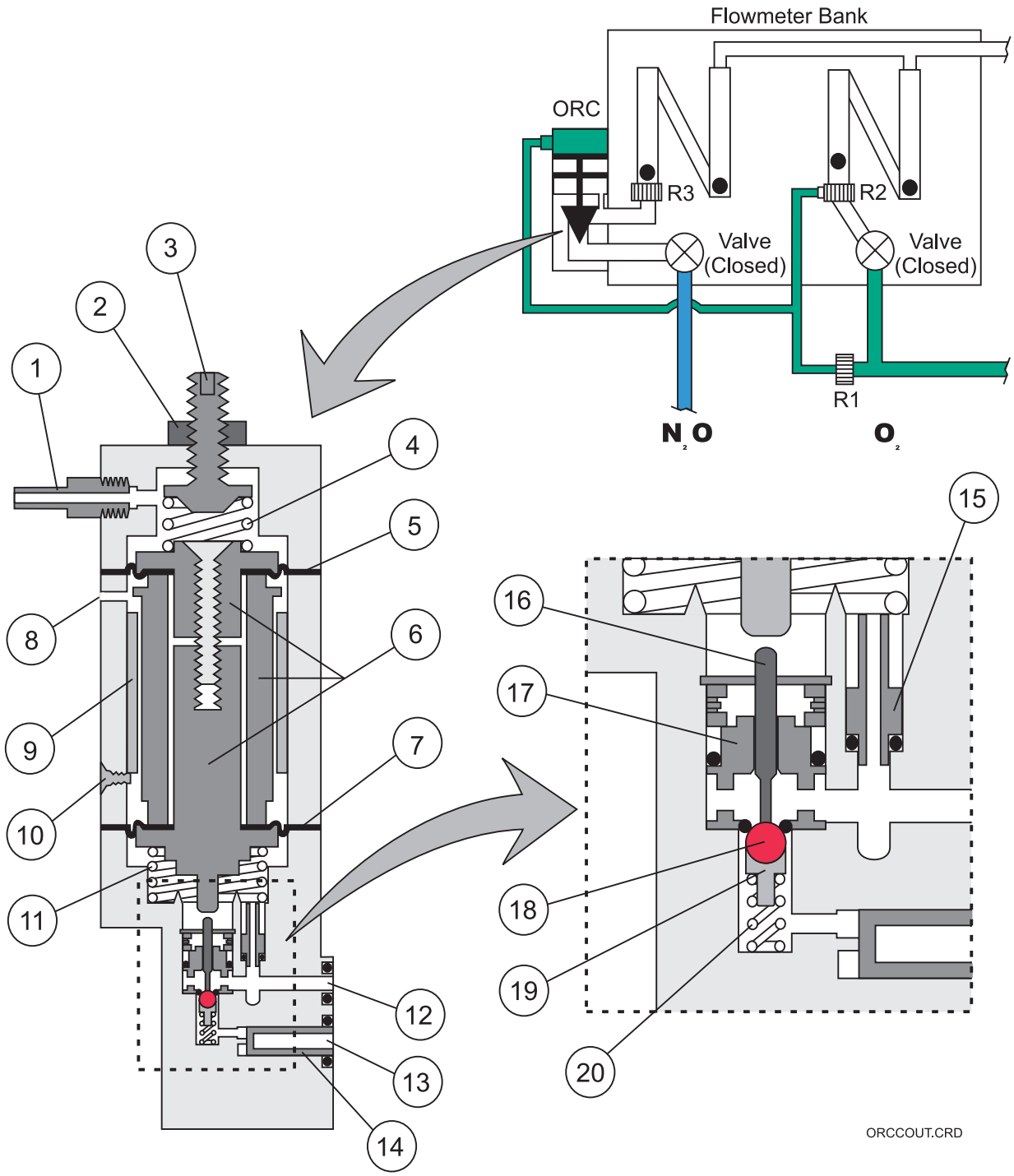


Figure 2-45: The oxygen ratio controller (early version)

RETURN TO THIS BOOK'S TABLE OF CONTENTS
RETURN TO CD-ROM TABLE OF CONTENTS

3: The 19.n Vaporizer

The heart of any anesthesia system is the vaporizer. The vaporizer used on Narkomed anesthesia systems is the 19.1 Vaporizer (Figure 3-1). The primary function of the vaporizer is to control the rate of evaporation of a given liquid anesthetic and introduce a precise volume percentage of that anesthetic vapor into the fresh gas stream of the anesthesia system. The vaporizer must be able to control or counteract all physical changes that affect the percent volume output of anesthetic vapor in the fresh gas stream. Tracing the flow of fresh gas on its journey through the vaporizer will demonstrate how this is accomplished.

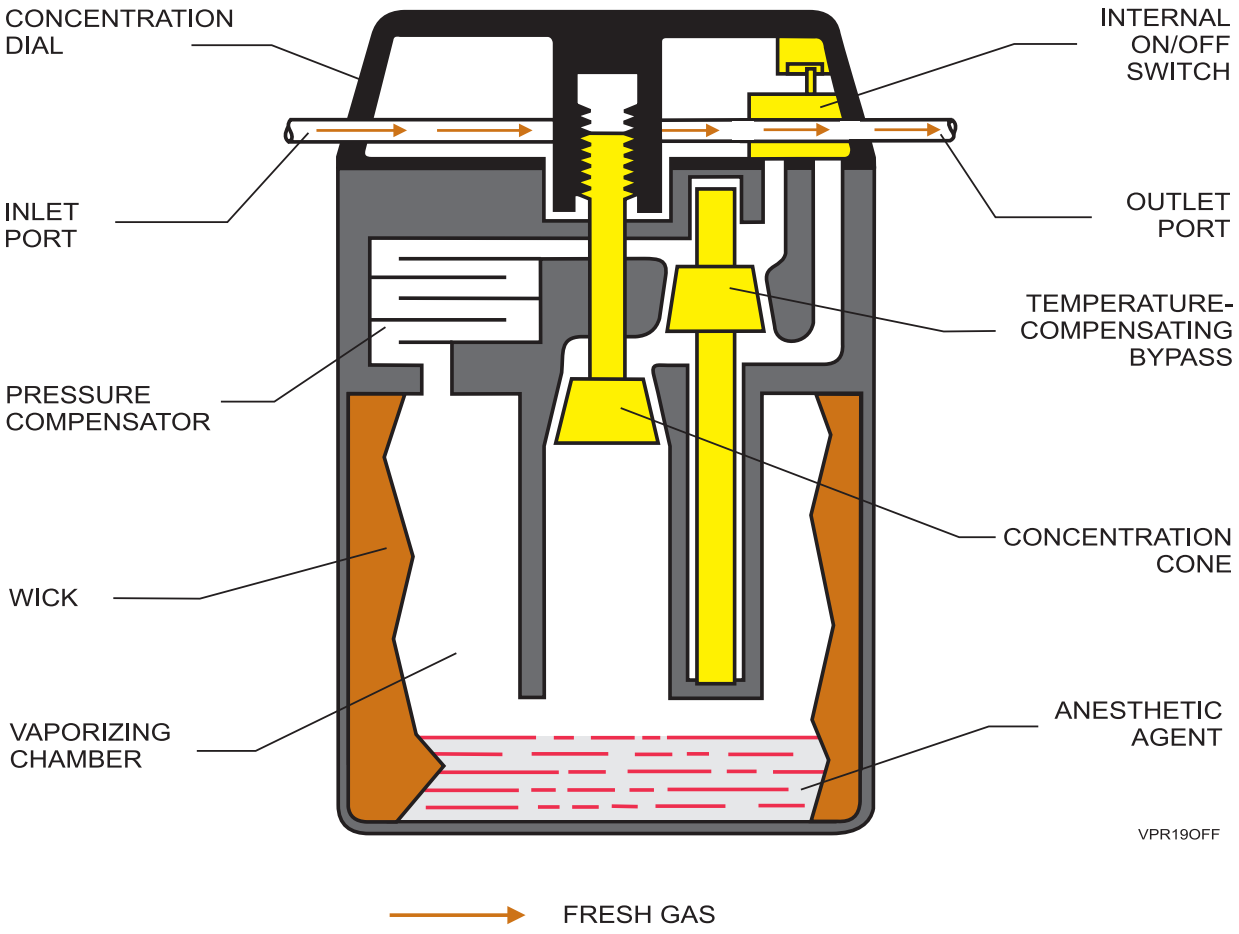


Figure 3-1: The 19.n vaporizer in the "0" position.

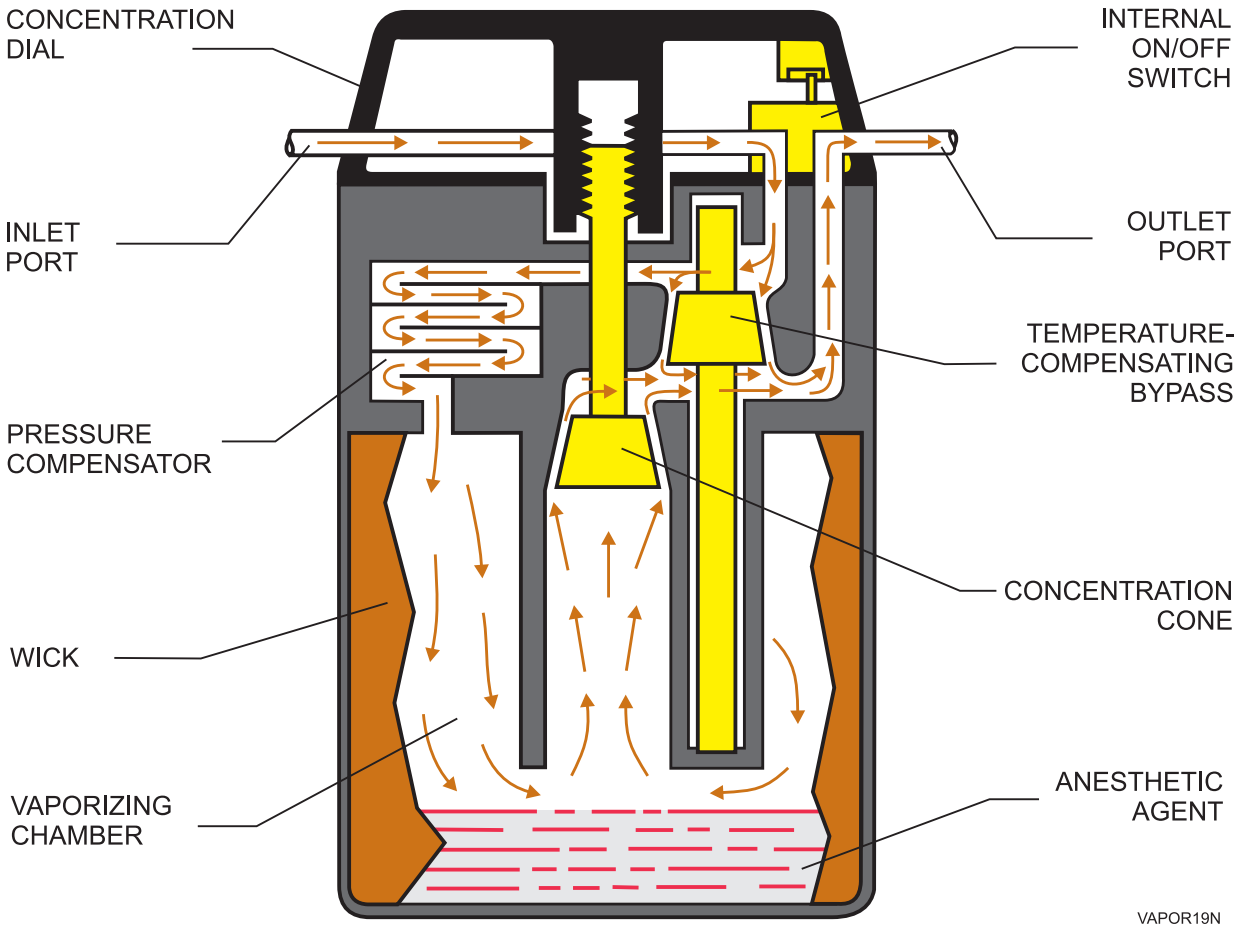


Figure 3-2: Fresh gas flow through the 19.n vaporizer.

Gas Flow Through the Vaporizer

When the concentration dial of the vaporizer is in the "0" position, the internal on/off switch is in the "off" position. In this position, the fresh gas enters the vaporizer through the inlet port, flows through the on/off switch, and is directed to the outlet port without entering the interior of the vaporizer (Figure 3-1).

When the concentration dial is rotated to any concentration above 0.2% a cam in the handwheel rotates the on/off switch to the "on" position. The fresh gas flows through the on/off switch and is directed into the interior of the vaporizer (Figure 3-2). When the fresh gas flow enters the interior of the vaporizer, it encounters the temperature compensating bypass. The bypass divides the fresh gas flow into two streams. The majority of the fresh gas flows through the bypass and exits the vaporizer without combining with any anesthetic vapor. The remaining stream of fresh gas does not flow through the bypass, but proceeds directly to the pressure compensator. The pressure compensator eliminates pressure fluctuations within the vaporizing chamber. Without a pressure compensator, any pressure fluctuations upstream or downstream of the vaporizing chamber could affect the percent volume concentration output of the vaporizer.

The fresh gas stream flows through the pressure compensator and into the vaporizing chamber, where it becomes partially saturated with anesthetic agent as it flows over the wick. The fresh gas/agent mixture then flows out of the vaporizing chamber through the concentration control cone, which is actuated by the concentration dial. As the concentration is increased or decreased, the space between the concentration control cone and the cone housing increases or decreases, allowing more or less fresh gas/agent mixture to flow out of the vaporizing chamber. After the fresh gas/agent stream flows through the concentration cone, it rejoins the fresh gas stream that passed through the temperature compensating bypass. The reunification of the two streams of fresh gas, one stream containing anesthetic agent and the other unchanged, results in the final percent volume concentration of anesthetic agent that goes to the patient breathing circuit.

Temperature changes inside the vaporizing chamber (caused primarily by changes in the rate of evaporation) are the major influence on the concentration output of the vaporizer. The temperature compensating bypass corrects for temperature variations by altering the ratio of gas between the two streams of fresh gas flow. If the temperature decreases in the vaporizing chamber (due to an increase in the rate of evaporation), the bypass cools, the brass shell contracts, and the bypass moves upward. This action further restricts the fresh gas stream that flows through the bypass, forcing a greater proportion of the fresh gas flow into the stream that flows to the vaporizing chamber. The extra fresh gas offsets the lower vapor pressure (caused by the decrease in temperature) in the evaporation process, the concentration rises, and thermostability is reestablished in the temperature compensating bypass. The opposite occurs if the temperature increases in the vaporizing chamber.

Effect of Gas Flow Rate on Agent Concentration

The flow rate of the fresh gas can have some effect on the percent volume output of the vaporizer (Figure 3-3). Extremely high flow rates (greater than 10 lpm), combined with high concentration settings on the vaporizer, produce a slightly reduced concentration of delivered anesthetic agent. At the more common flow rates and anesthetic concentration settings used in general anesthesia for humans, anesthetic delivery to the patient breathing circuit is stable and accurate.

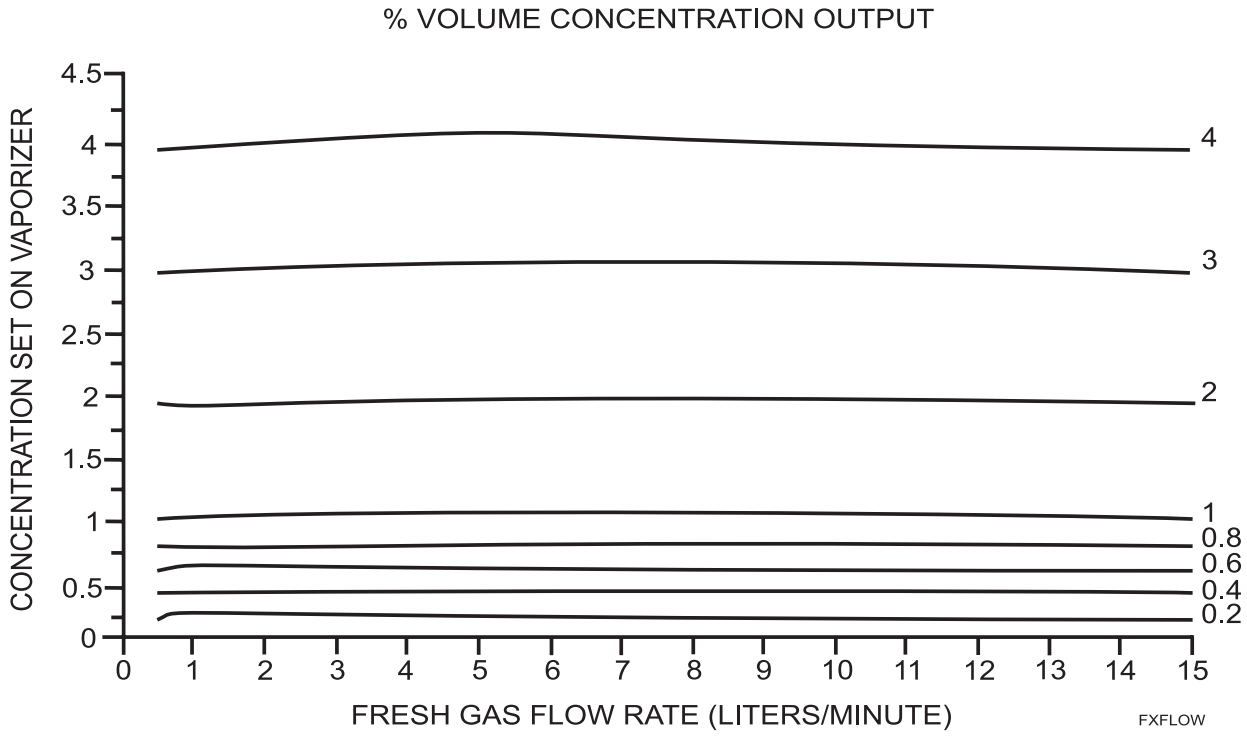


Figure 3-3: Effect of flow rate on delivered anesthetic agent concentration.

Effect of Fresh Gas Composition on Agent Concentration

The composition of the fresh gas mixture affects the output of the vaporizer (Figure 3-4). The change in percent volume output relative to the fresh gas mixture is caused by the differences in agent solubility in different fresh gas mixtures.

The 19.n vaporizer is originally calibrated using 100% air as the fresh gas mixture, because air represents a median between the most commonly used gas mixtures in human anesthesia (30% oxygen/70% nitrous oxide) and veterinary anesthesia (100% oxygen). Using a fresh gas mixture of 100% air, a dial setting of 1% of halothane results in the delivery of exactly 1% volume of halothane in air. Changing the fresh gas mixture to 30% oxygen/70% nitrous oxide, leaving the dial setting at 1%, results in a decreased volume percent output of approximately 0.85%. In this case, the percent volume output decreases (relative to air) because the anesthetic agent is less soluble in the oxygen/nitrous oxide mixture than it is in air. Conversely, when the fresh gas mixture is changed to 100% oxygen, the output of the vaporizer rises because the anesthetic agent is more soluble in oxygen than in air. The time line along the bottom of this chart shows that these changes are not instantaneous, but may require time to stabilize and adjust to the correct percent volume output when a change in carrier gas occurs.

Although other factors can influence the accuracy of the percent volume output of a vaporizer, they are not significant and are not discussed in this book.

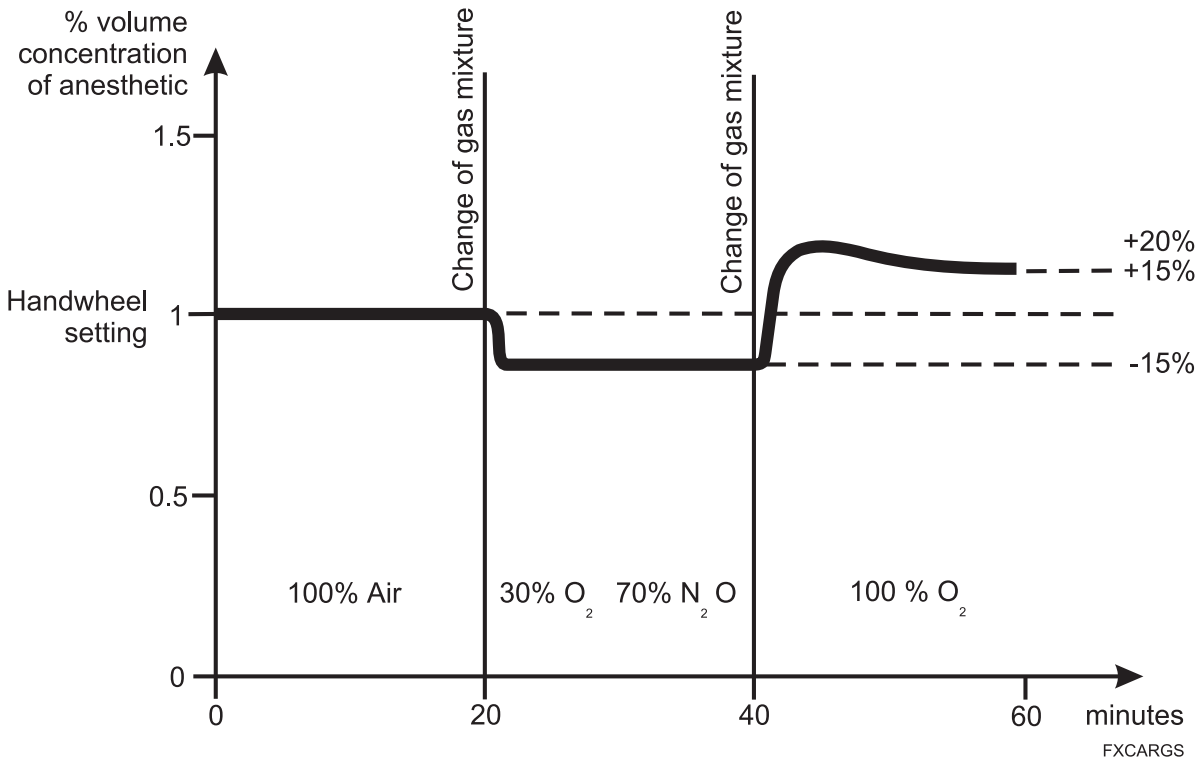


Figure 3-4: Effect of fresh gas mixtures on the delivered concentration of agent.

Vaporizer Exclusion System

The vaporizer exclusion system incorporates cams, pins and levers to allow only one vaporizer to be turned on at a time (Figure 3-5). For example, when the vaporizer on the right is turned on, the top of the handwheel acts as a cam and forces the pin backward. The pin then forces the long lever and one of the short levers backward. The opposite ends of the levers then force the other two pins into the notches on the handwheels of the other two vaporizers, locking them into their "0" (off) positions.

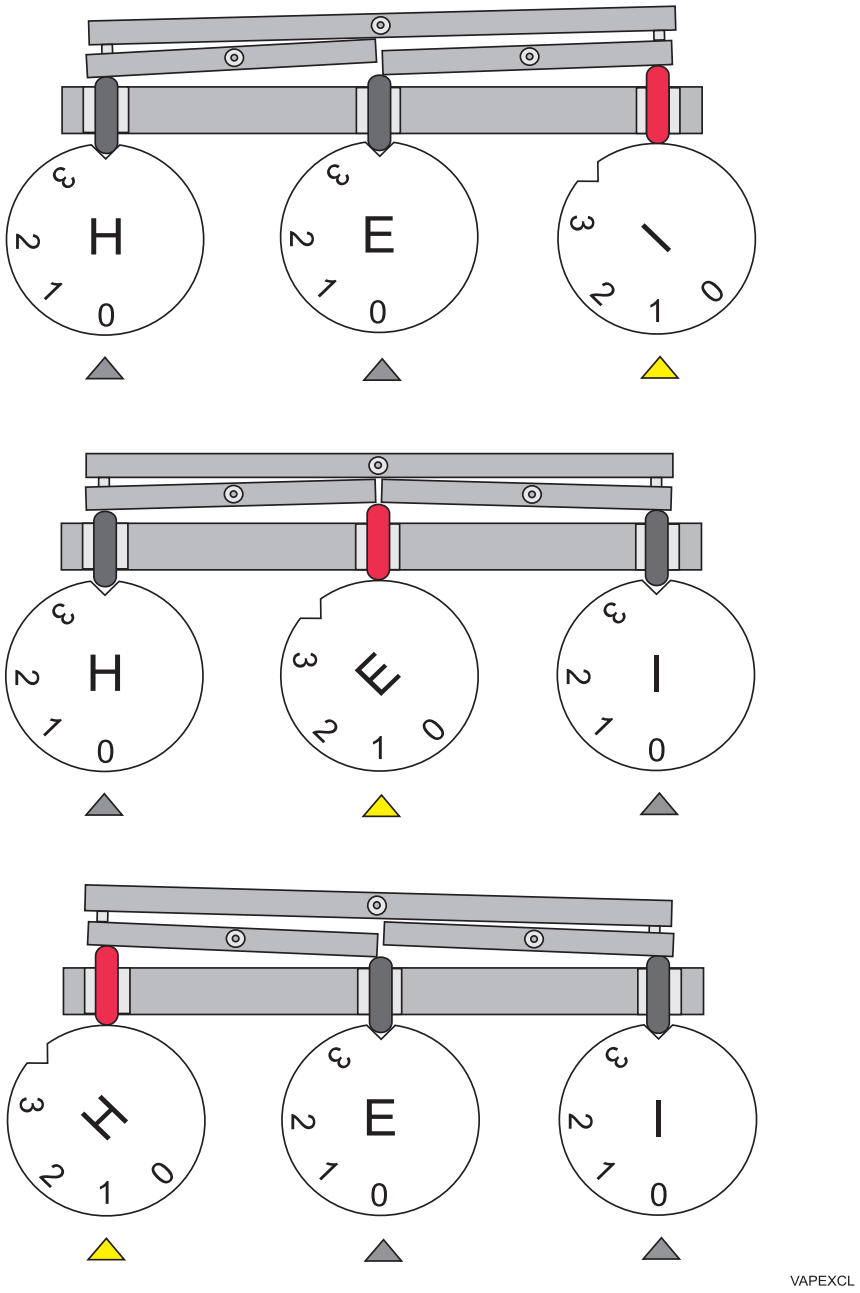


Figure 3-5: Vaporizer exclusion system.

Vaporizer Uncompensated for Pressure

Only a few vaporizers, even today, compensate for the effects of fluctuating pressure. When gas enters the vaporization chamber, it combines with anesthetic agent, but is not totally saturated. The concentration of the agent in the vaporizer output depends on this partial saturation. When pressure fluctuations occur within the vaporization chamber, gas can move in and out of the chamber. This additional movement allows the gas to become more saturated with agent, raising the concentration of the output. This is known as the pumping effect and can cause serious overdoses of anesthetic agent to the patient.

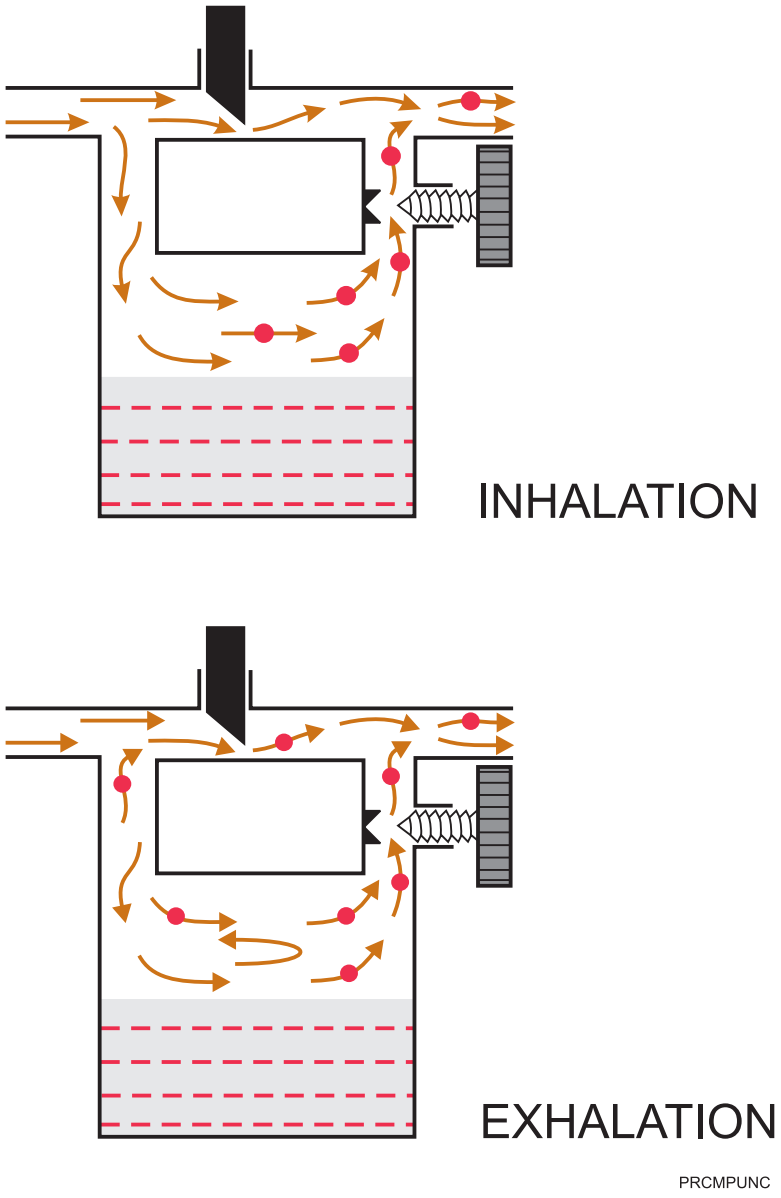


Figure 3-6: A vaporizer design that does not compensate for pressure fluctuations.

Vaporizer Compensated for Pressure

Vaporizers that compensate for pressure fluctuations counteract the pumping effect. Gas flows through a serpentine passage before it reaches the vaporization chamber. In this serpentine passage, the gas loses some of the energy from its pressure fluctuations every time it changes direction. As a result, a smooth, even flow of gas enters the vaporization chamber without pressure fluctuations.

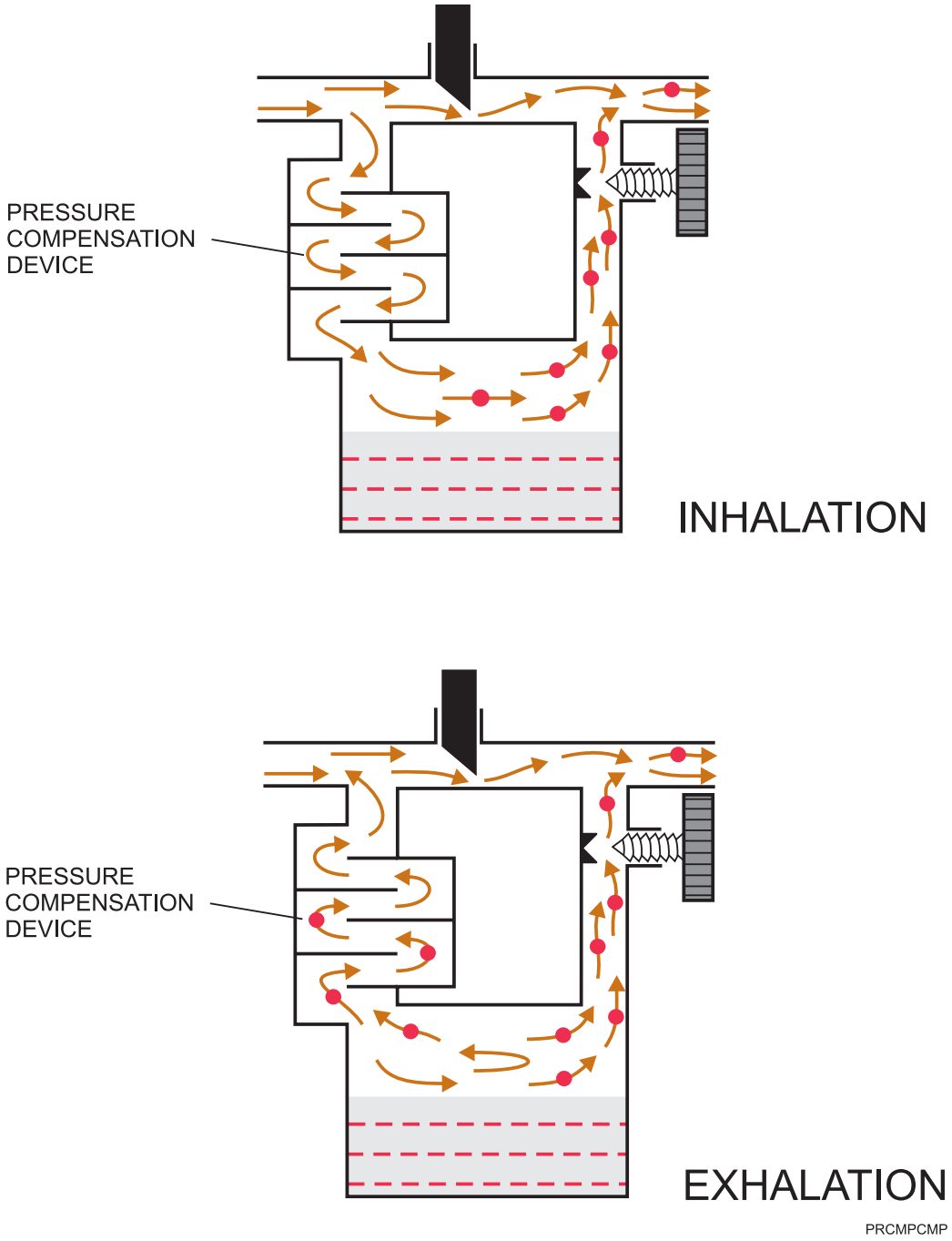


Figure 3-7: A vaporizer design that incorporates a pressure compensation device.

Supplement to Chapter 3

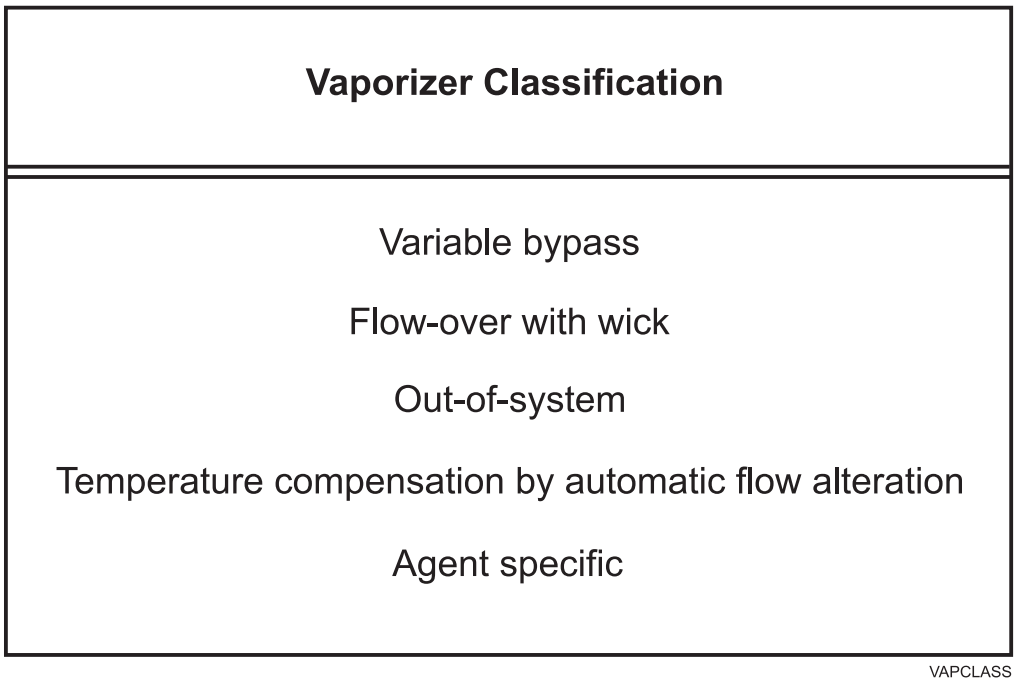


Figure 3-8: Vapor 19.n classification (Dorsch and Dorsch)

Basic Vaporizer Designs

All mechanical/pneumatic vaporizers can be placed in one of four basic design groups. Each design group has specific characteristics. In addition, the four basic design groups can be further reduced to only two classifications: designs featuring flow-over with wick and designs using a gas-through-agent principle. The four basic designs are illustrated in Figure 3-10.

TYPE A
This type of vaporizer uses a wick saturated with anesthetic agent. Fresh gas enters the vaporizer and enters a bypass; gas that gets through the bypass continues on to the patient breathing circuit unchanged. The remainder flows to a calibration device that controls the amount of fresh gas entering the vaporization chamber. The gas that passes through the calibration device now flows over the wick, combines with anesthetic agent, and rejoins the fresh gas flow going to the patient breathing circuit.

TYPE B
These vaporizers work the same as Type A vaporizers, except for the calibration device. In this design, the calibration device is located on the output side of the vaporization chamber. This results in improved flow characteristics when compared to Type A.

TYPE C
This design uses two gas streams: a high fresh gas flow that contains O_2, N_2O, and/or other fresh gases, and a very low flow of oxygen that is diverted through the vaporizer. The oxygen that flows into the vaporizer is directed through a tube to a point below the surface of the liquid anesthetic. The oxygen then passes through a filter that breaks it into very small bubbles. These bubbles escape through the filter and rise directly through the liquid agent. As the oxygen passes through the agent, it becomes 100% saturated with agent and carries it out of the vaporizer. As it leaves the vaporizer, it is combined with the high fresh gas flow from the other flowmeters. The high fresh gas flow dilutes the saturated oxygen and produces the desired final percent volume concentration.

TYPE D
In this design, the functions of the bypass and the calibration device in Types A and B are combined to vary the amount of gas that will pass directly through the anesthetic agent. By varying the proportion of gas that combines with agent and the gas that dilutes the agent/gas mixture, the final concentration output of the vaporizer can be controlled.

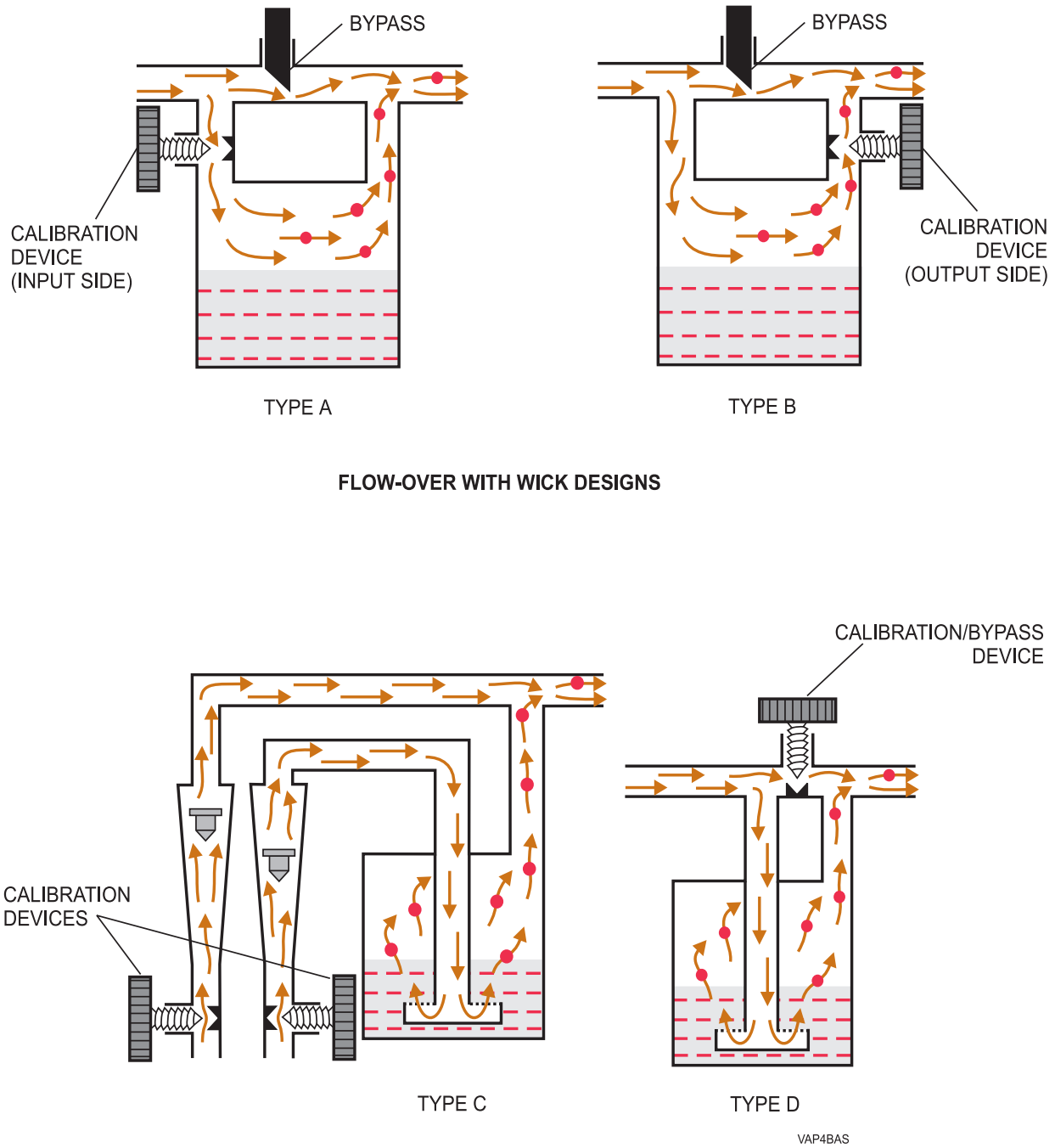


Figure 3 -10: Design principles for vaporizers: the four basic designs.

RETURN TO THIS BOOK'S TABLE OF CONTENTS
RETURN TO CD-ROM TABLE OF CONTENTS

4: The Absorber System and Breathing Circuits

The fundamental components of the patient breathing circuit on Narkomed anesthesia systems include a carbon dioxide absorber, a positive end-expiratory pressure valve, an adjustable pressure limiter valve, and a scavenger system. Each component has a specific function and safety features associated with its function. In this chapter, we will discuss the absorber system and various types of breathing circuits.

Absorber Assembly

The main function of the absorber is to remove exhaled carbon dioxide from the patient breathing circuit of the anesthesia system. The absorber assembly consists of two canisters to hold carbon dioxide absorbent, two unidirectional flow valves, a pressure gauge, a fresh gas connector, and a manual/automatic selector valve (Figure 4-1). The absorber permits spontaneous, manually assisted, or mechanical ventilation of the patient, while allowing any unused fresh gas mixture to be recirculated to the patient after the carbon dioxide is removed.

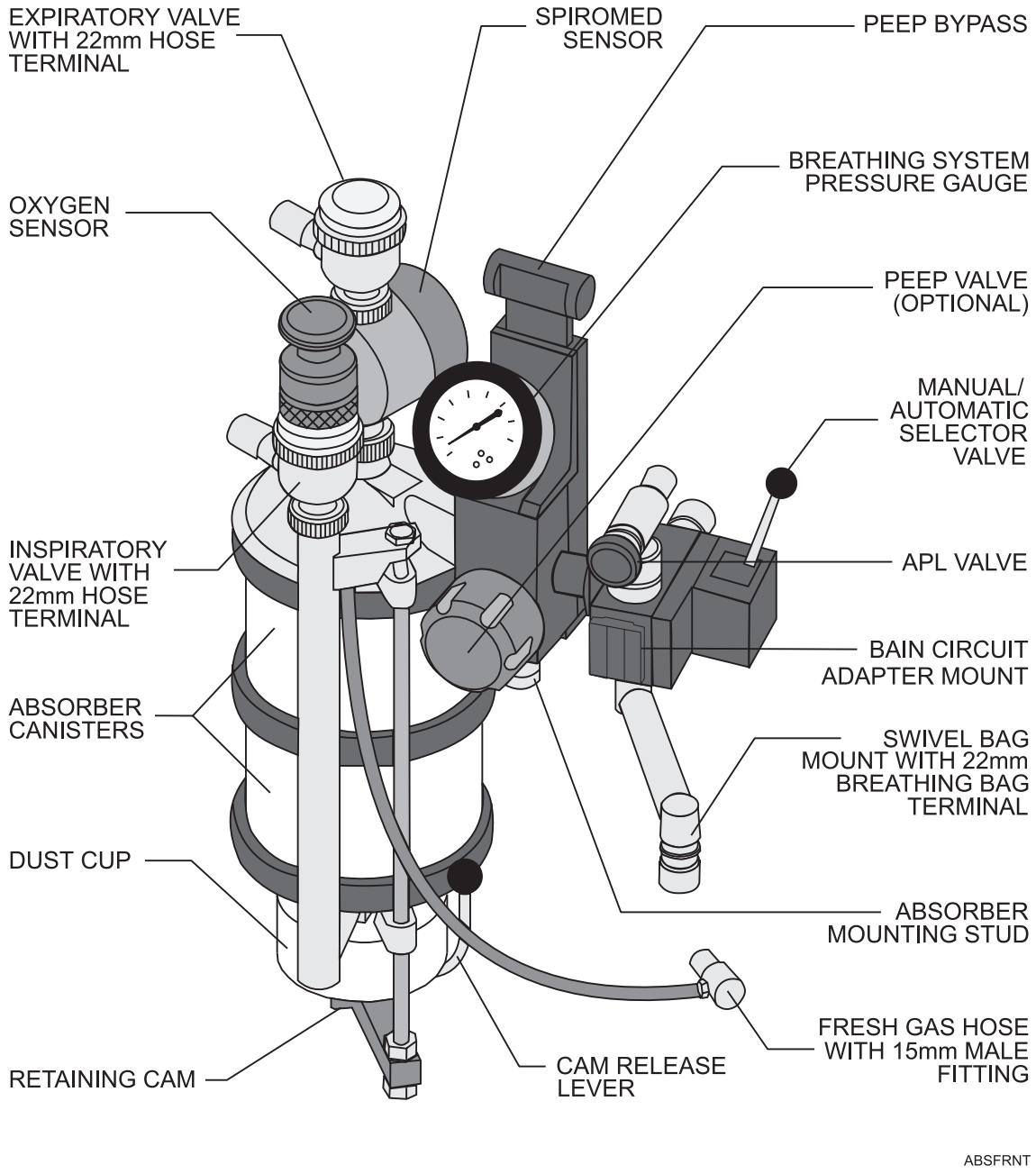


Figure 4-1: Narkomed absorber system - front view.

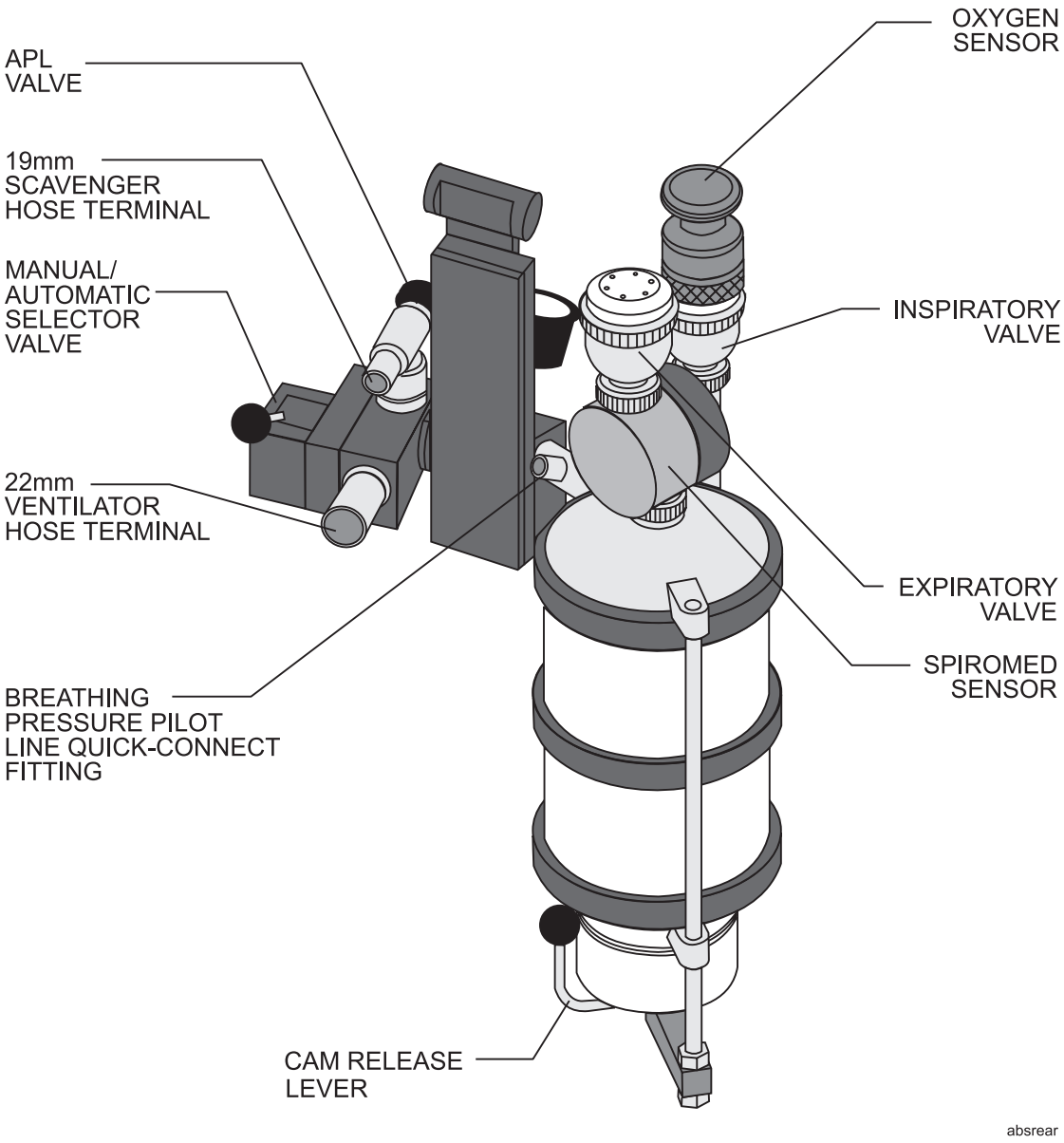


Figure 4-2: Narkomed absorber system - rear view.

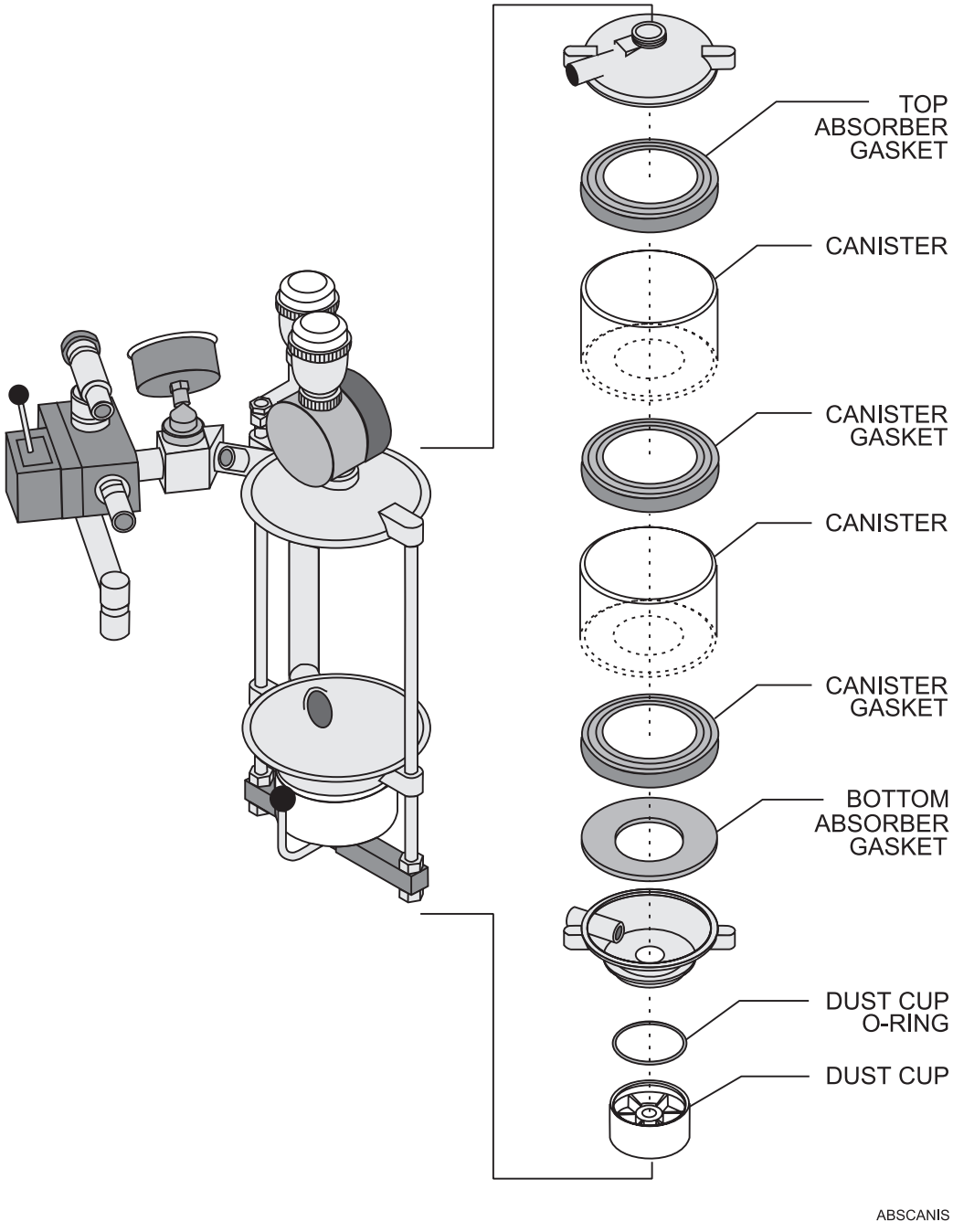


Figure 4-3: Disassembly of the canisters.

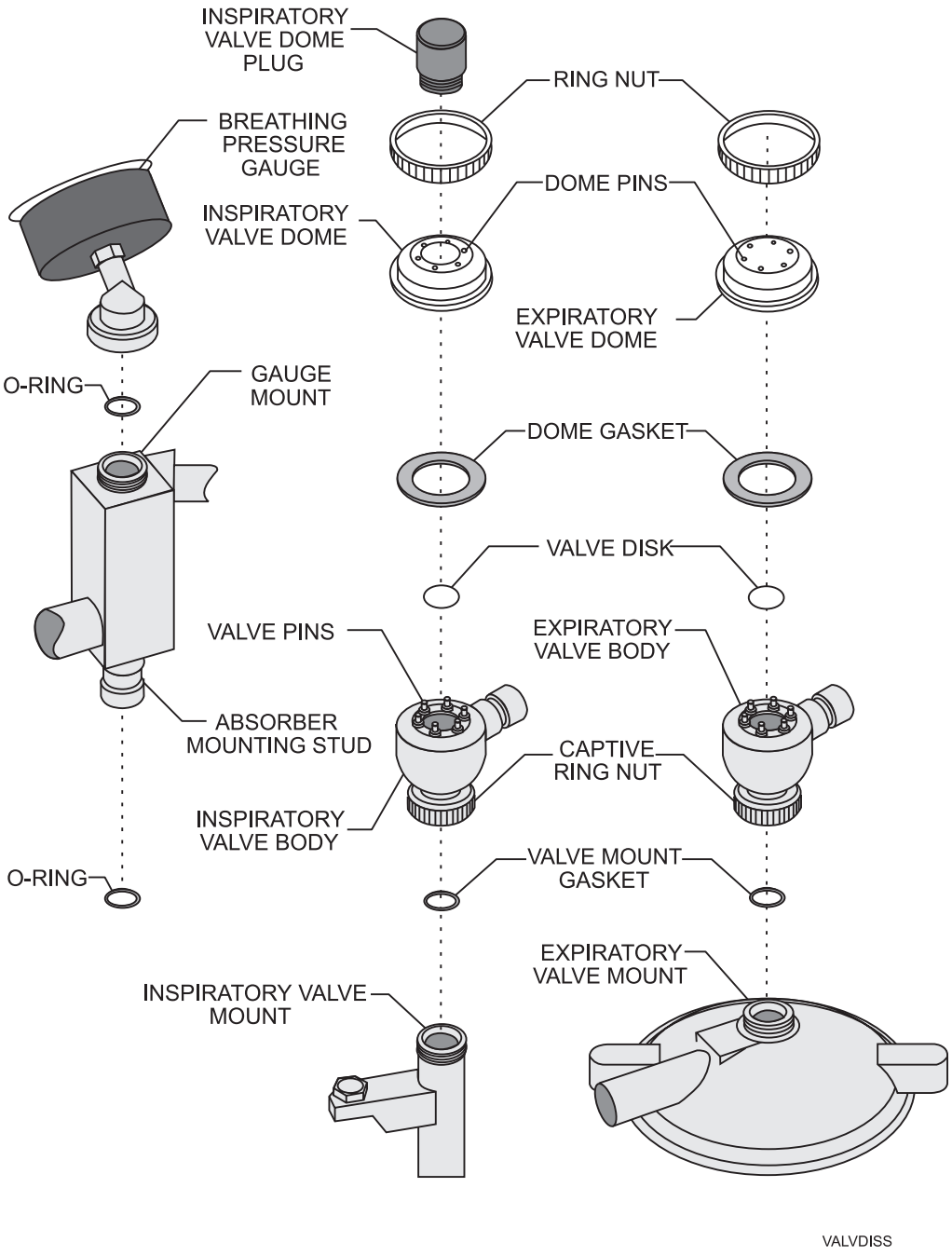


Figure 4-4: Disassembly of the unidirectional valves and the breathing pressure gauge.

Unidirectional Valves

The unidirectional valves direct the gas flow between the absorber and the patient. The inspiratory valve controls gas flow to the patient from the absorber. The expiratory valve controls gas flow to the absorber from the patient.

During inspiration, the fresh gas mixture flows upward through the inspiratory valve, raising the valve disc from the valve seat, and then flows down and out to the patient. At the same time, gas flows into the expiratory valve and exerts a positive pressure on the valve disc, keeping the valve closed.

During expiration, the gas flows from the patient to the expiratory valve, lifting the valve disc from the valve seat, and flows back into the absorber. At the same time, the gas flows into the inspiratory valve and exerts a positive pressure on the valve disc, keeping the valve closed. Both discs lift when activated, the inspiratory valve disc lifts during inspiration and the expiratory valve disc lifts during expiration (Figure 4-5). Valve construction enables gas to flow in one direction only, so it is vital that the valves are not interchangeable. The ring nuts that attach the valves to the absorber are different diameters, preventing misconnections.

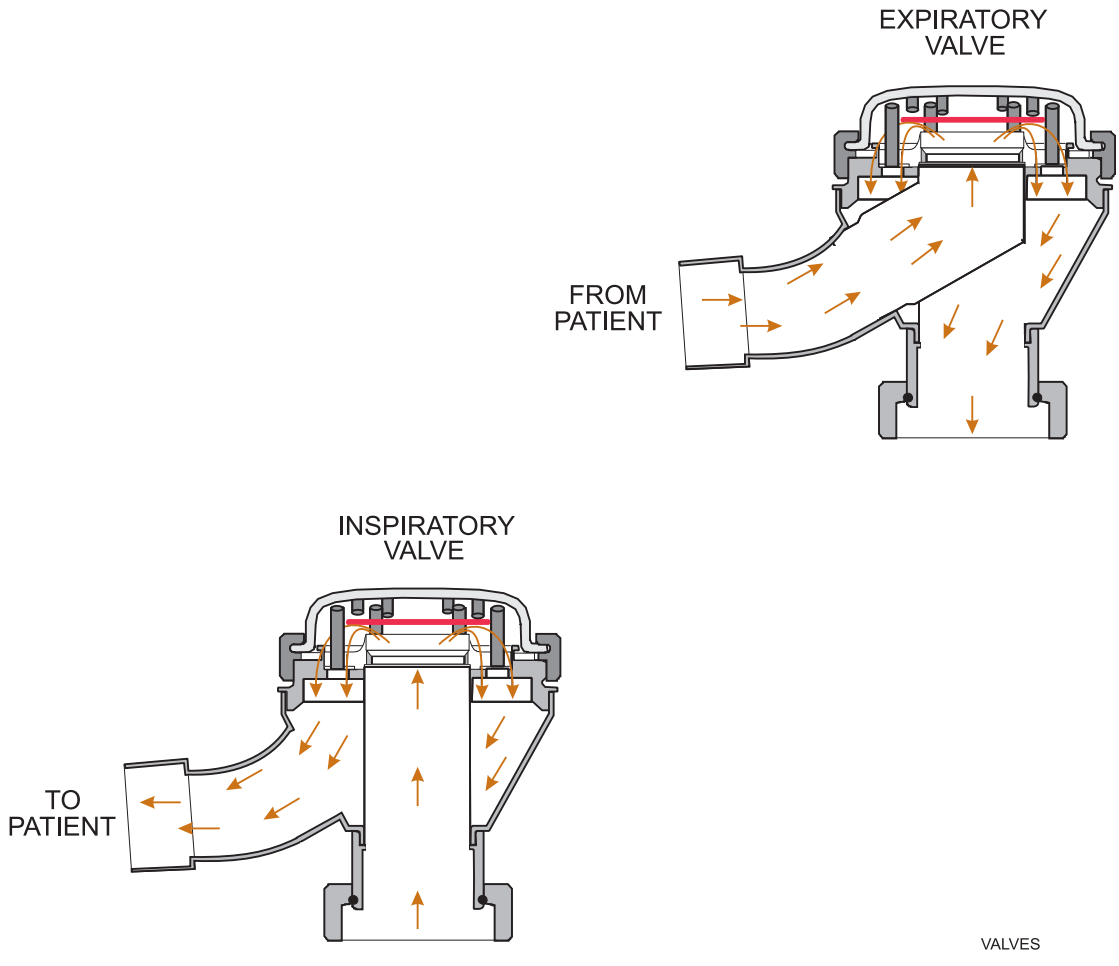


Figure 4-5: Gas flow through the inspiratory and expiratory valves.

Adjustable Pressure Limiter Valve

The Adjustable Pressure Limiter (APL) valve, located downstream of the PEEP valve on the absorber mounting block, releases excess gas to the scavenger system while in the manual (bag) ventilation mode. A check valve inside the APL valve prevents scavenged gas from reentering the absorber system.

Rotating the adjustment knob varies the opening between the needle valve and the needle valve seat (Figure 4-6). The size of the opening between the needle valve and its seat determines two parameters: the volume of gas exhausted to the scavenger and the inspiratory pressure during manual ventilation. The APL valve functions only during spontaneous or manually assisted ventilation.

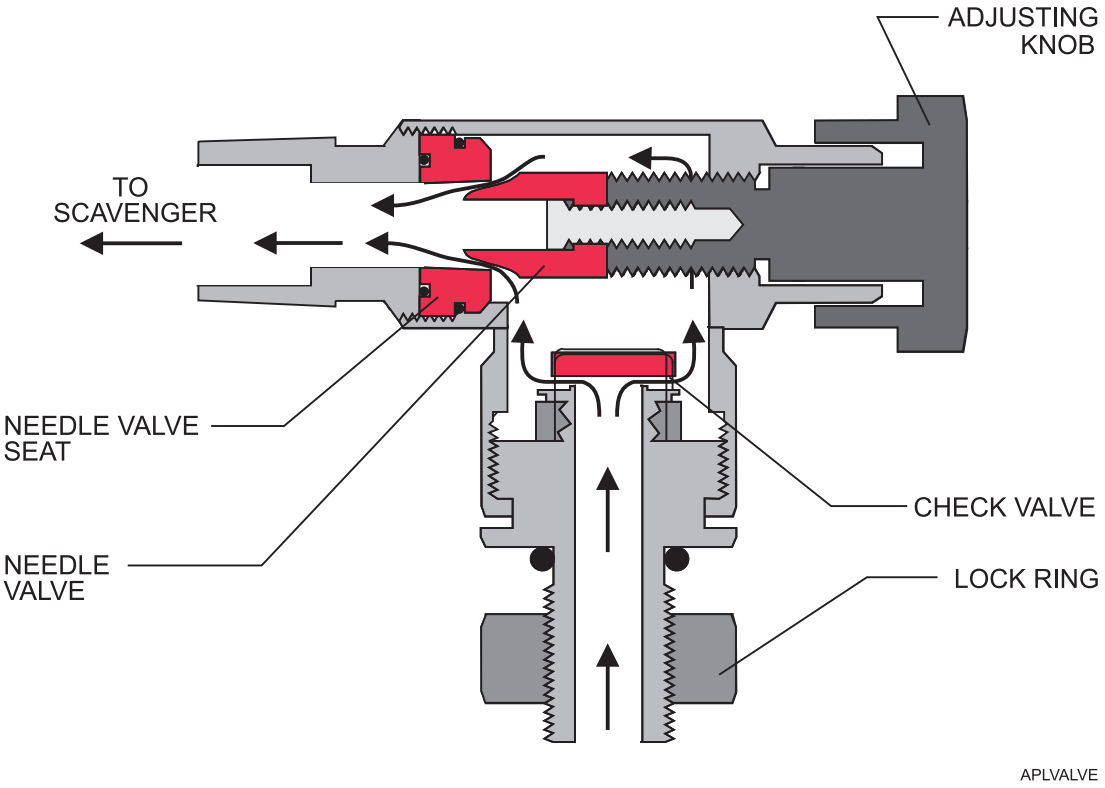


Figure 4-6: The adjustable pressure limiter valve.

Manual/Automatic Selector Valve

The manual/automatic selector valve has two positions, BAG and AUTO. When the handle is rotated, it moves a piston/seal assembly laterally by means of a post mounted eccentrically to the handle assembly. When the handle is placed in the BAG position the piston/seal assembly is pressed against the port for the ventilator and all gases flow to the bag mount assembly (Figure 4-7). The handle assembly utilizes a limited slip spring action to secure the piston in one position or the other and to eliminate the possibility that the handle could be inadvertently left in a "middle" position.

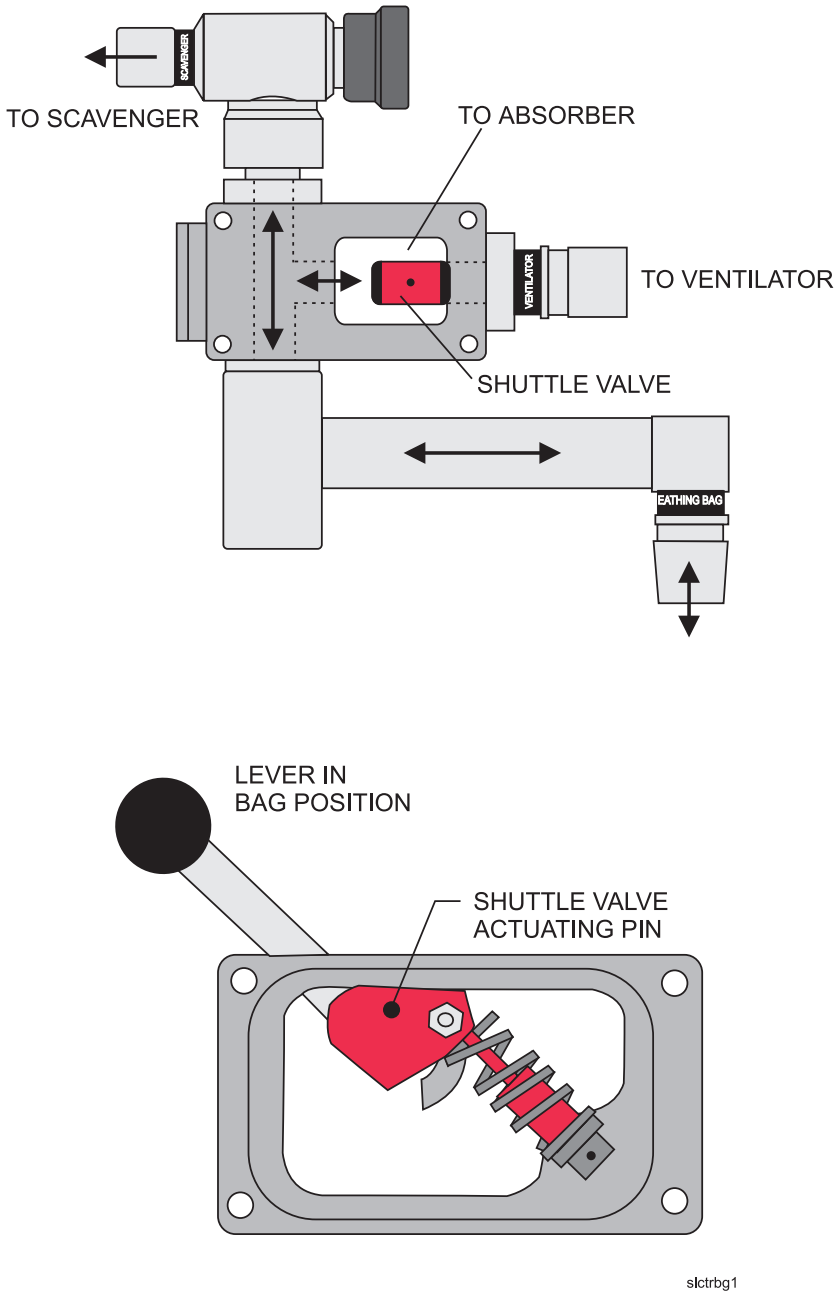


Figure 4-7: Manual/automatic selector valve in the BAG mode.

When the lever is shifted to the AUTO position (Figure 4-8), the handle assembly moves the piston to, and seals against, the port for the bag mount assembly. In this position, all gas flows to the ventilator circuit.

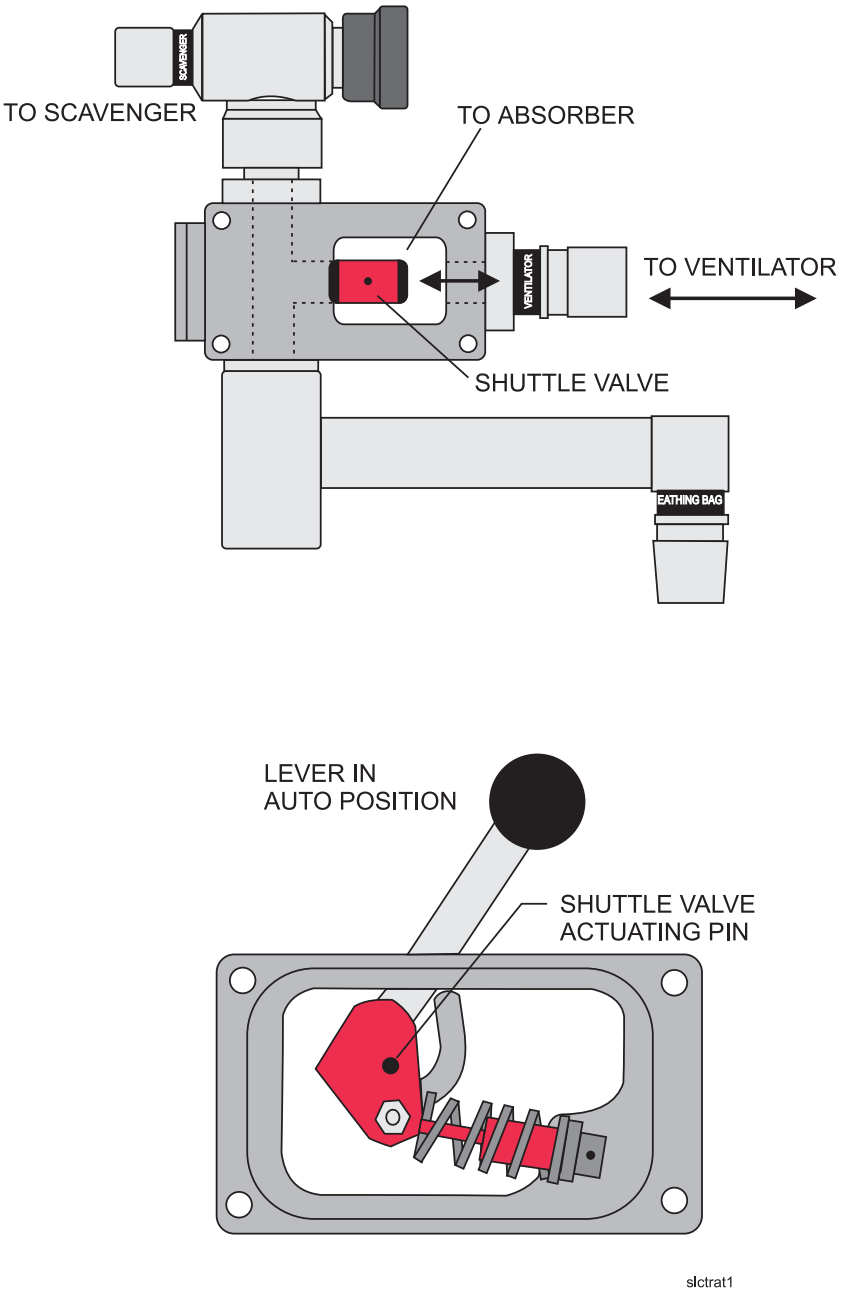


Figure 4-8: Manual/automatic selector valve in the AUTO mode.

Breathing Pressure Gauge

A diaphragm gauge (Figure 4-9) is used to measure the gas pressures found in the patient breathing circuit. This type of gauge is very useful because it can measure both positive and negative pressures. As gas enters the metal diaphragm, it causes the diaphragm to distend, which in turn activates a series of levers and gears, causing the indicator needle to move around the face of the gauge. In the absorber system, the diaphragm gauge indicates pressure in cmH_2O.

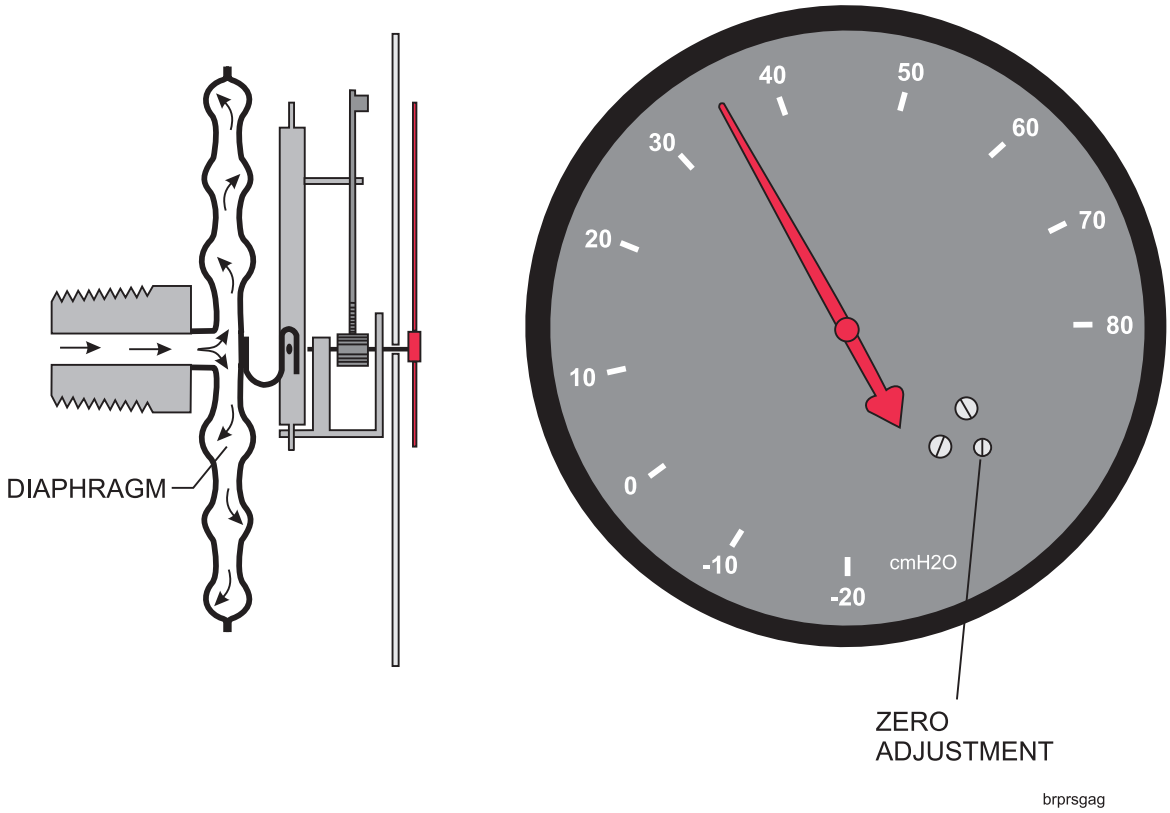
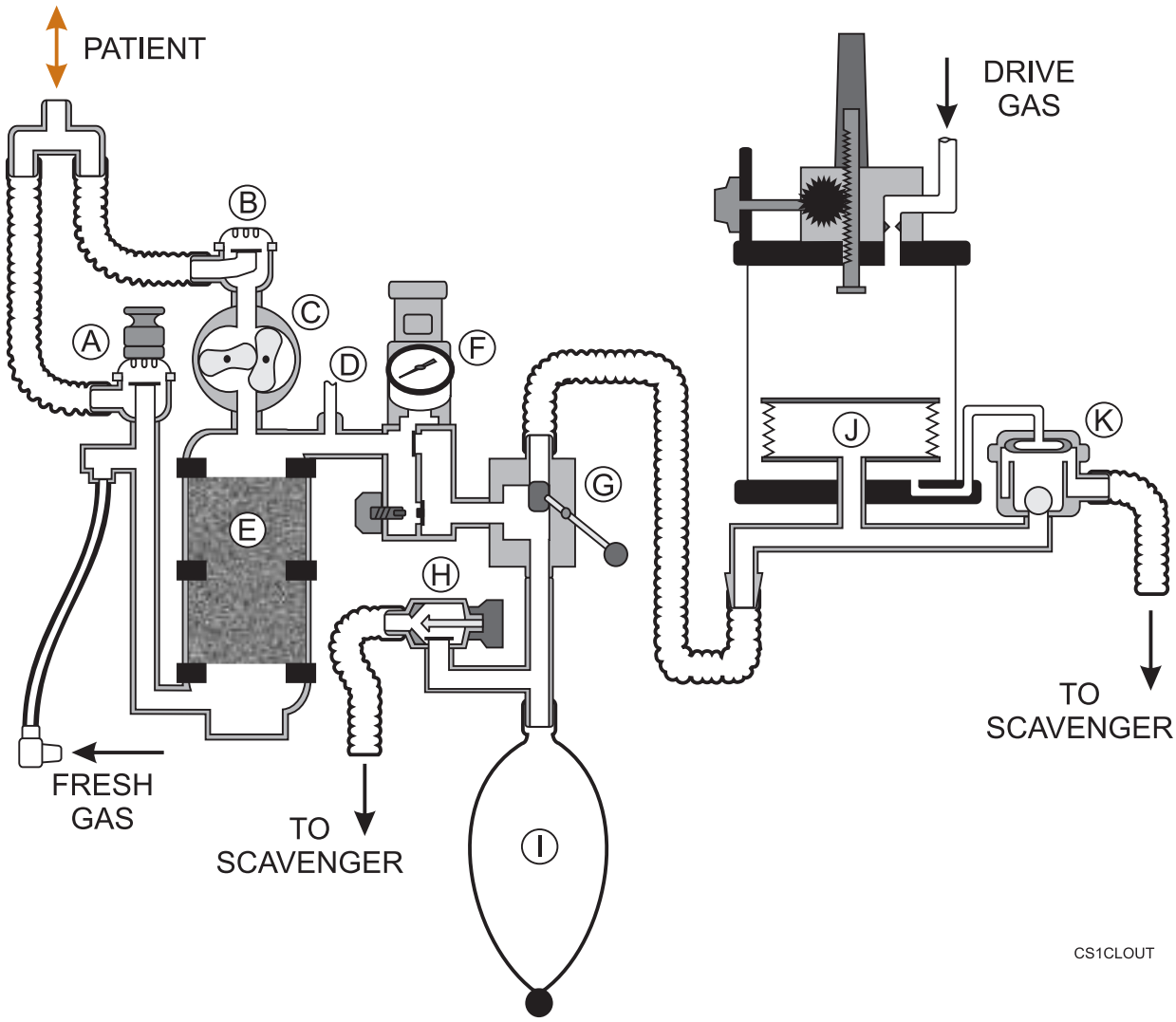


Figure 4-9: Breathing pressure gauge.

Narkomed Absorber Circle System

The Narkomed absorber circle system allows three modes of patient ventilation: spontaneous, manually assisted, or mechanically assisted ventilation.



A - Inspiratory Valve w/O_2 Sensor
B - Expiratory Valve
C - Spiromed Sensor
D - Breathing Pressure Pilot Line
E - Absorbent
F - Absorber Pressure Gauge/ PEEP Valve Assembly
G - Manual/Automatic Selector Valve
H - APL Valve
I - Breathing Bag
J - Ventilator Bellows
K - Ventilator Relief Valve

Spontaneous Ventilation

In spontaneous ventilation, patients control their own respiratory rate and tidal volume. During spontaneous inspiration (Figure 4-11), the patient inhales from the breathing circuit, creating a partial vacuum that lifts the valve disc in the inspiratory valve, opening the valve. Because this partial vacuum is also felt on the bottom of the expiratory valve disc, the valve remains closed. Gas flows from the breathing bag through the absorber and is joined by fresh gas supplied by the anesthesia system just below the inspiratory valve.

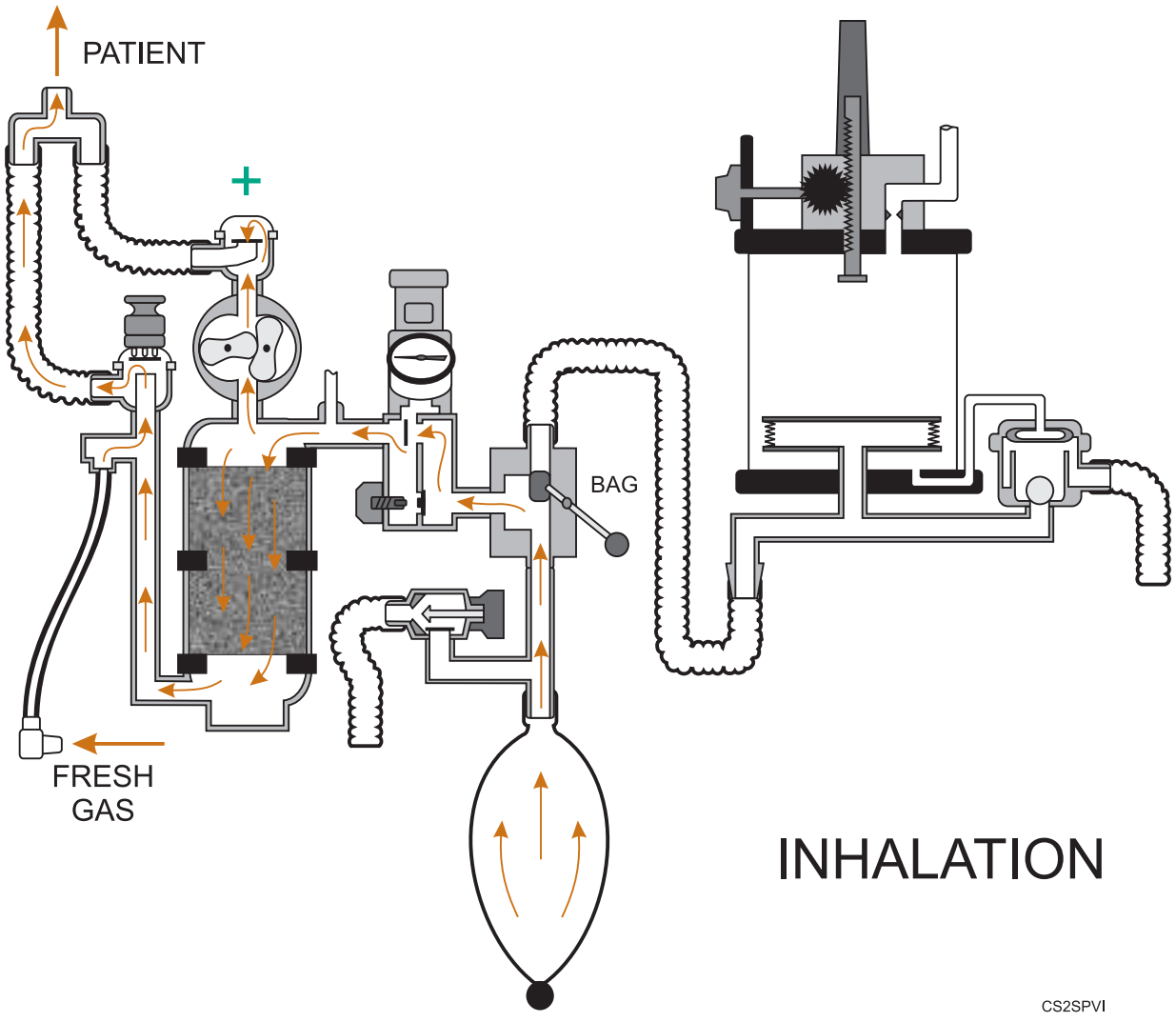


Figure 4-11: Spontaneous inspiration in a Narkomed absorber circle system.

During spontaneous exhalation, the patient exhales into the breathing circuit forcing the exhalation valve disc from its seat, opening the valve and allowing the exhaled gases to flow into the breathing bag. At the same time, the patient's exhalation is creating a positive pressure on the valve disc in the inspiratory valve, forcing this valve to remain closed. During this phase, fresh gas from the anesthesia system continues to flow into the absorber, but can flow only into the breathing bag. When the pressure in the breathing bag exceeds the preset pressure of the APL valve, excess gas flows to the scavenger system.

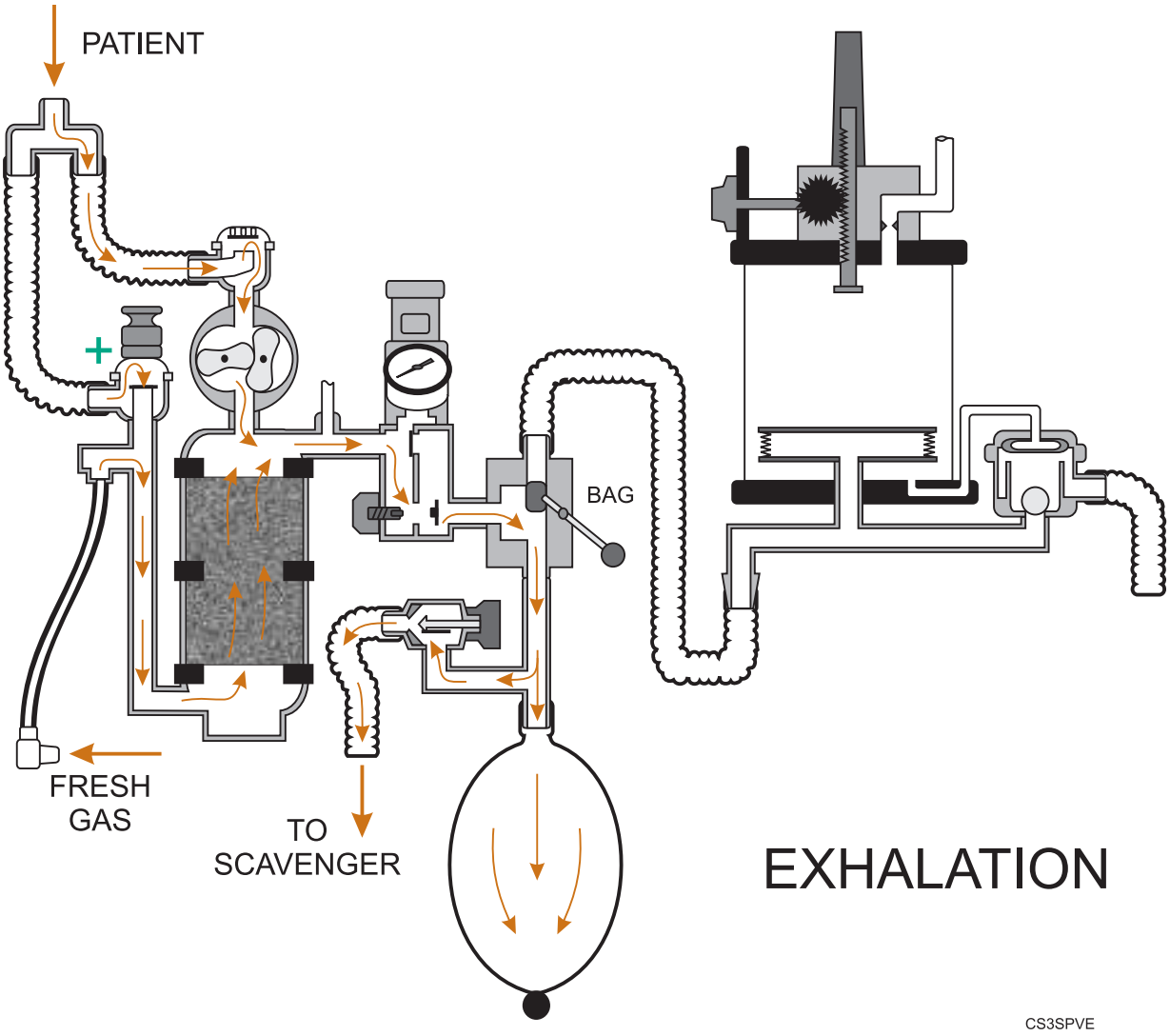


Figure 4-12: Spontaneous exhalation in a Narkomed absorber circle system.

Manually Assisted Ventilation

During manually assisted ventilation, the clinician compresses the breathing bag during inspiration, creating a positive pressure in the absorber circle system. The positive pressure closes the expiratory valve and opens the inspiratory valve. The gas mixture in the breathing bag flows through the manual/automatic selector valve, the breathing pressure gauge, and through the CO_2 absorbent to the patient breathing circuit. When the gas mixture flows from top to bottom through the absorbent canisters during inhalation, the CO_2 is scrubbed from the gas mixture by the absorbent material. Some of this gas mixture may exit to the scavenger depending upon the setting of the APL valve. The manual/automatic selector valve prevents any gas flow to the ventilator.

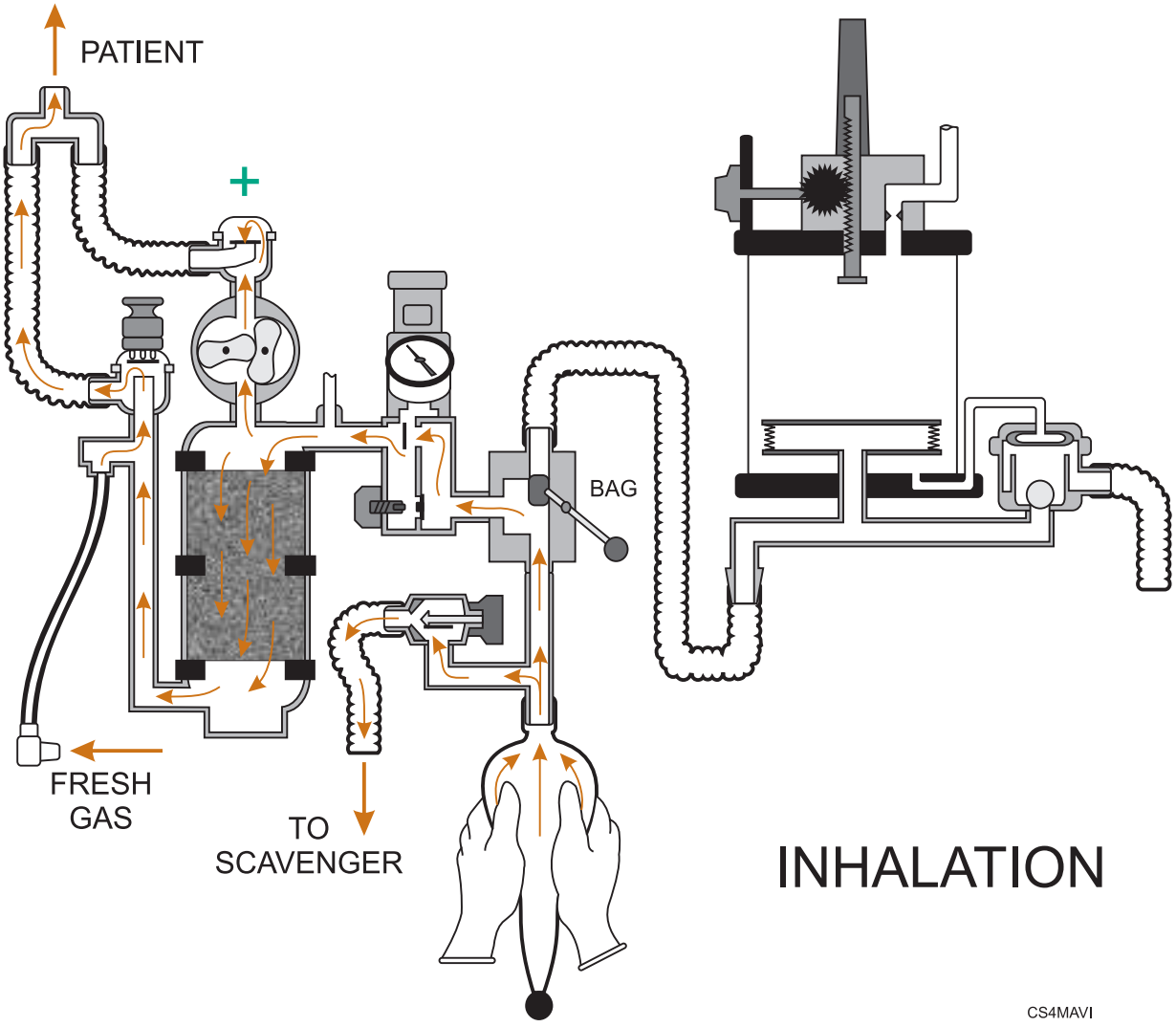


Figure 4-13: Inhalation in an assisted manual ventilation mode.

During manually assisted ventilation, the patient "exhales" into the breathing circuit (Figure 4-14). The exhalation creates a positive pressure that closes the inspiratory valve and opens the expiratory valve. Exhaled patient gas containing carbon dioxide flows through the spiromed sensor, across the top of the absorber canisters, past the breathing pressure gauge, through the manual/automatic selector valve, and fills the breathing bag. Fresh gas from the anesthesia system continues to enter the absorber and flows from bottom to top through the absorbent canisters, mixing with the exhaled patient gas as it flows across the top of the absorber. When the pressure in the breathing bag exceeds the preset limit of the APL valve, exhaled gas flows through the APL valve and into the scavenger system.

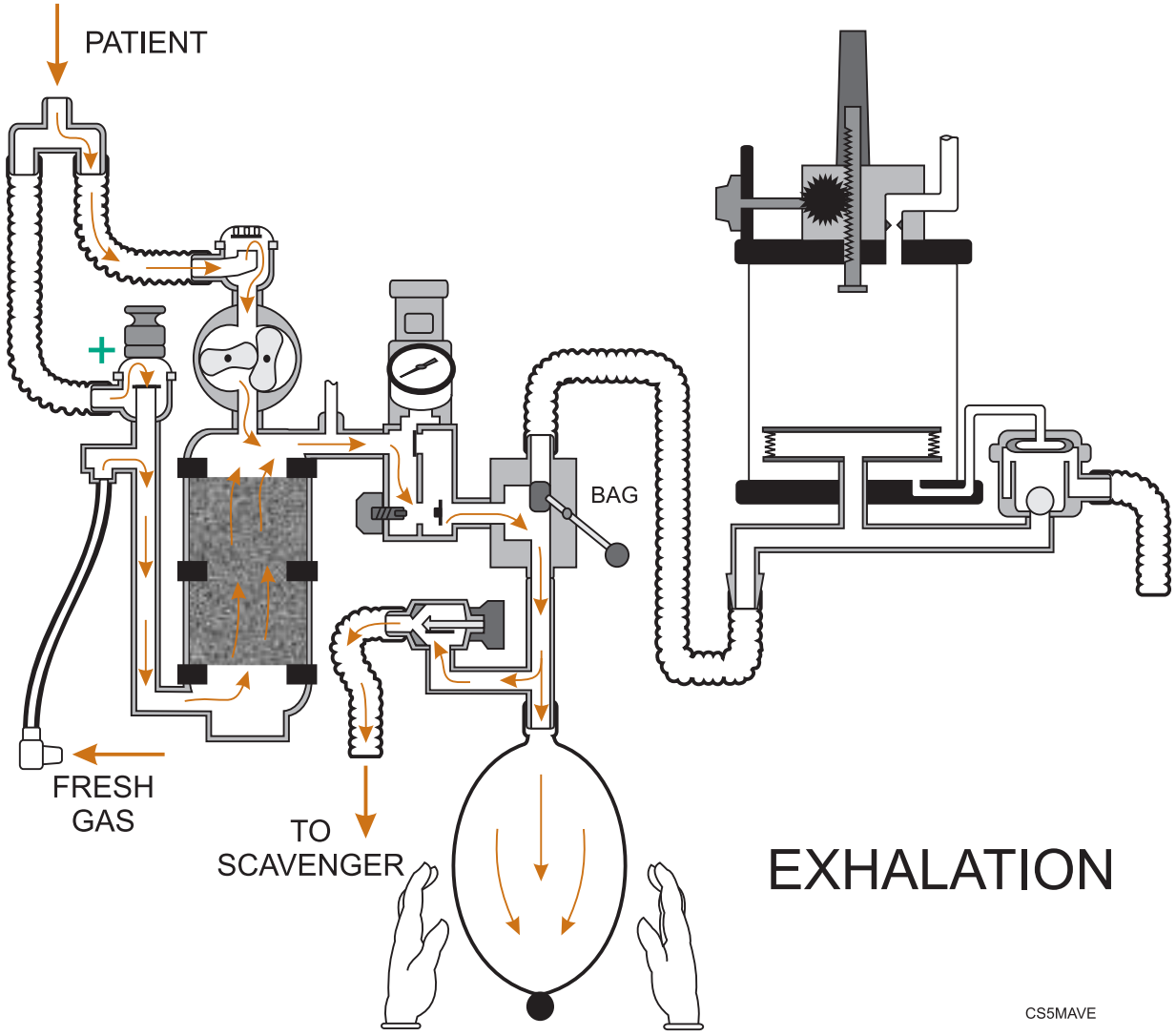


Figure 4-14: Exhalation in an assisted manual ventilation mode.

Mechanically Assisted Ventilation

During mechanically assisted ventilation, the ventilator controls all factors relating to the patient's breathing. The manual/automatic selector valve is rotated to the auto mode, and the gas mixture now flows to the ventilator circuit, bypassing the APL valve and the breathing bag. During inspiration (Figure 4-15), the ventilator drive gas compresses the bellows, creating a positive pressure within the patient breathing circuit. This pressure closes the expiratory valve and opens the inspiratory valve. The gas mixture inside the bellows flows through the manual/automatic selector valve, past the breathing pressure gauge, from top to bottom through the absorbent canisters, and into the patient breathing circuit. The ventilator relief valve is also pressurized by the ventilator drive gas and closes, preventing any of the gas mixture from entering the scavenger system.

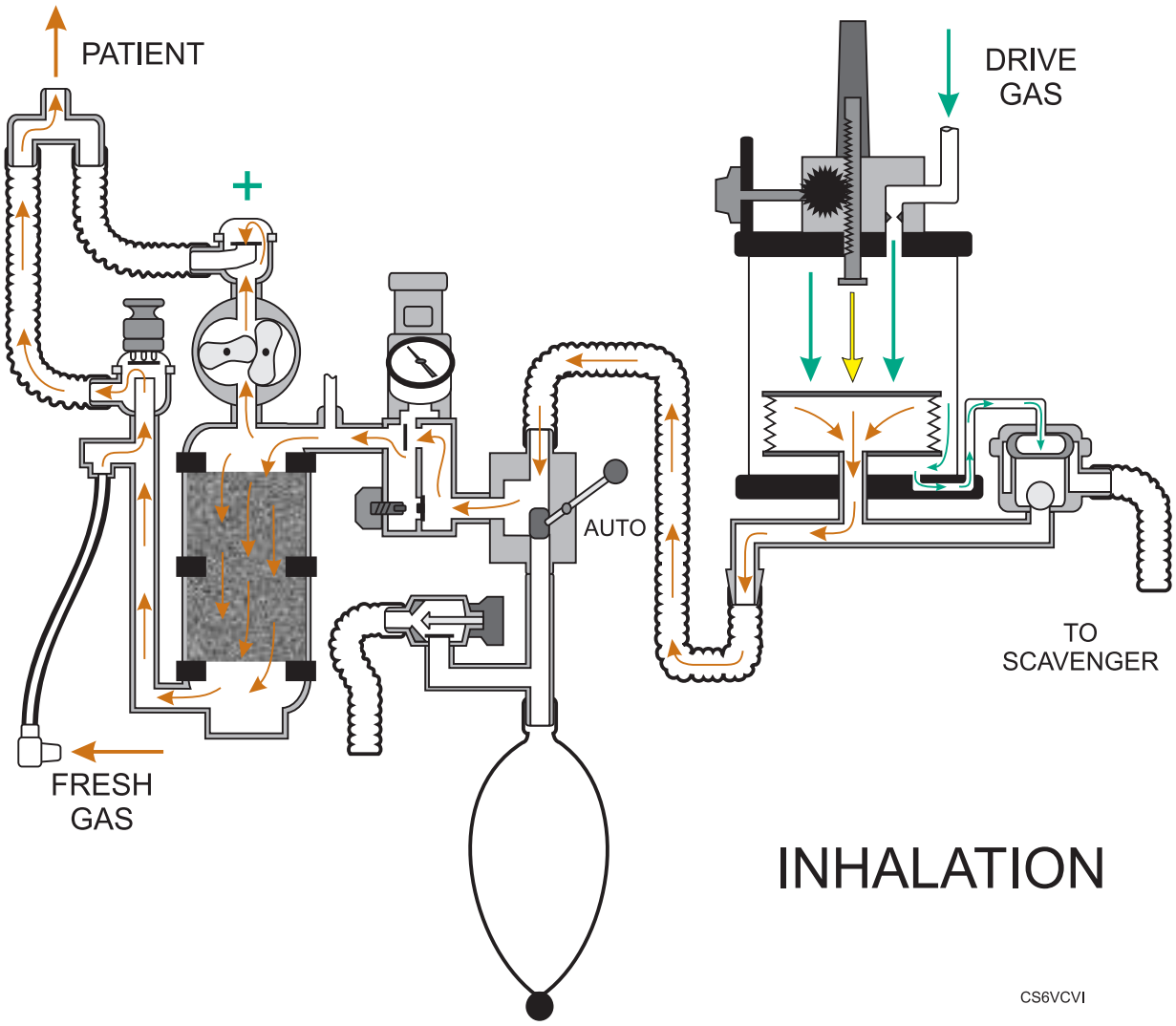


Figure 4-15: Inhalation during the mechanically assisted ventilation mode.

During exhalation (Figure 4-16), the ventilator drive gas ceases to flow into the canister, ending the positive pressure that was compressing the bellows. When the positive pressure is terminated, the patient can exhale into the breathing circuit. This causes a positive pressure that closes the inspiratory valve and opens the expiratory valve. Exhaled gas flows through the spiromed sensor, across the top of the absorbent canisters, past the breathing pressure gauge, through the manual/automatic selector valve, and fills the ventilator bellows. Excess gas from the patient breathing circuit enters the scavenger through the ventilator relief valve only after the bellows fills completely and the pressure of the patient's exhalation lifts the ball valve.

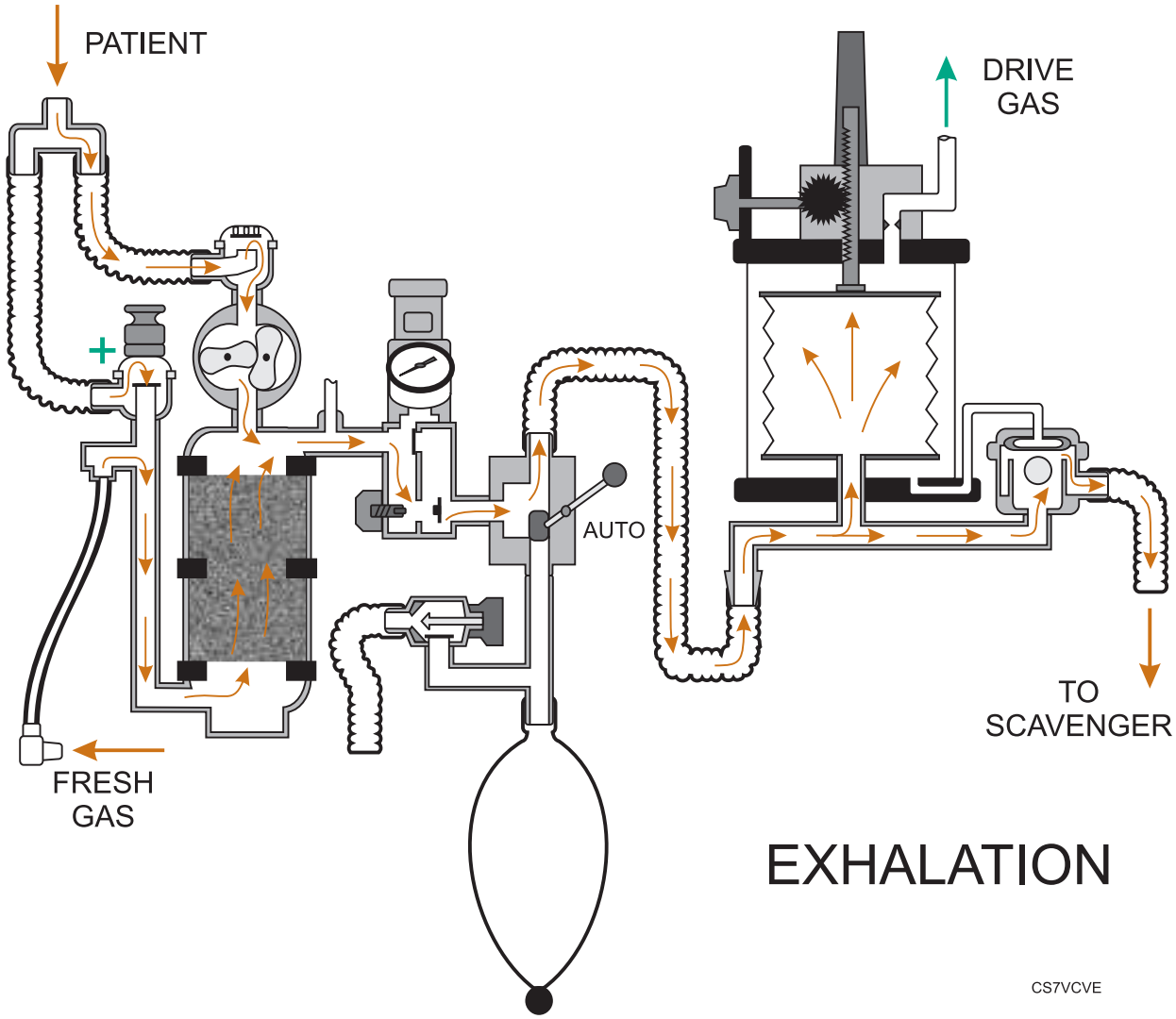


Figure 4-16: Exhalation during the mechanically assisted ventilation mode.

Oxygen Flush

The following illustrations demonstrate how the oxygen flush removes waste gases from the patient breathing circuit and the absorber system. In the first phase (Figure 4-17), activating the oxygen flush valve allows a flow of approximately 55 l/min of 100% oxygen into the absorber system. At this point, any exhaled gases are forced back through the absorber toward the breathing bag.

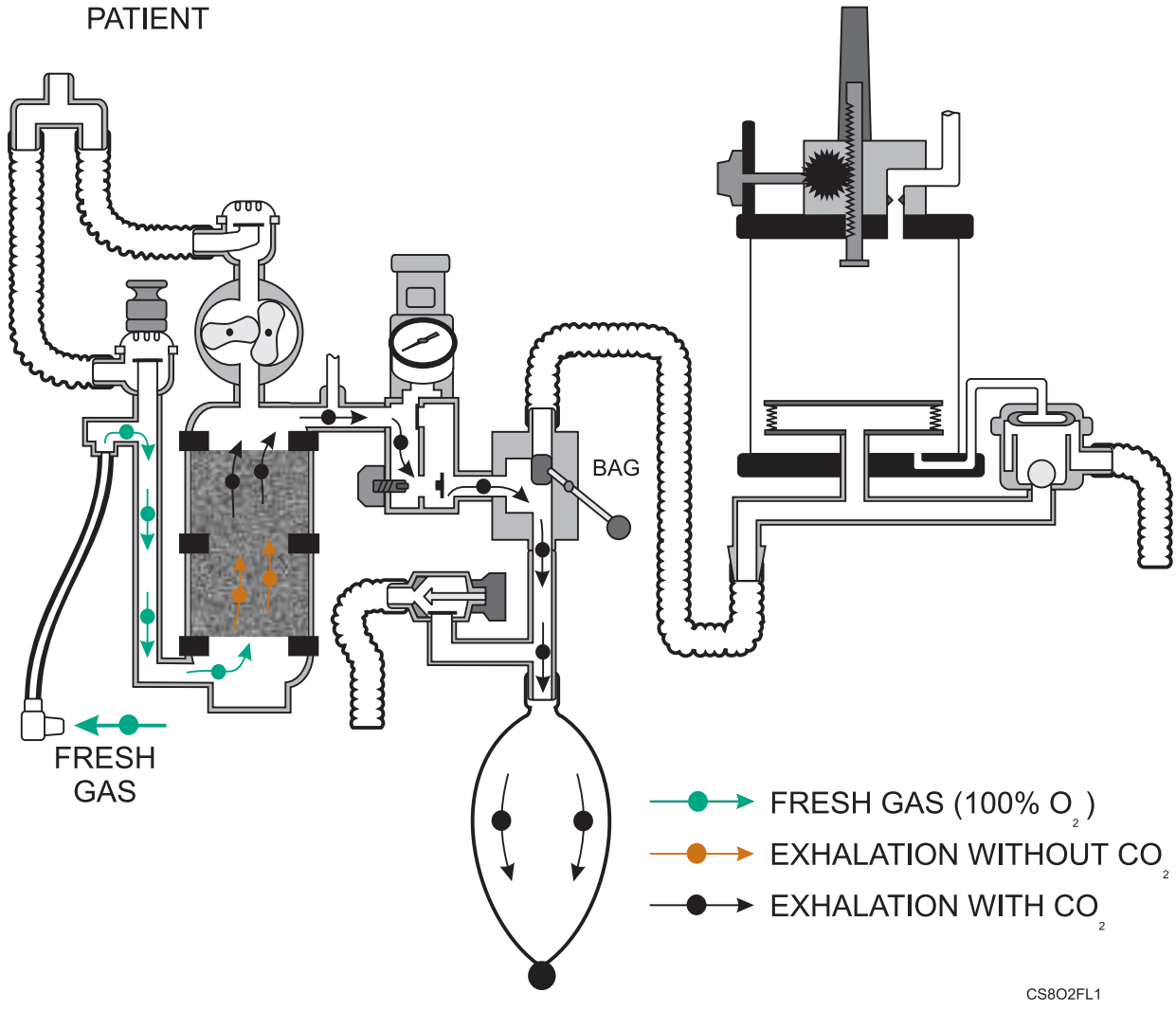


Figure 4-17: Phase one of the oxygen flush.

In the second phase of the oxygen flush (Figure 4-18), a minimal positive pressure is created in the absorber system and the inspiratory valve opens. With the inspiratory valve open, 100% oxygen now flows to the patient breathing circuit and the breathing bag.

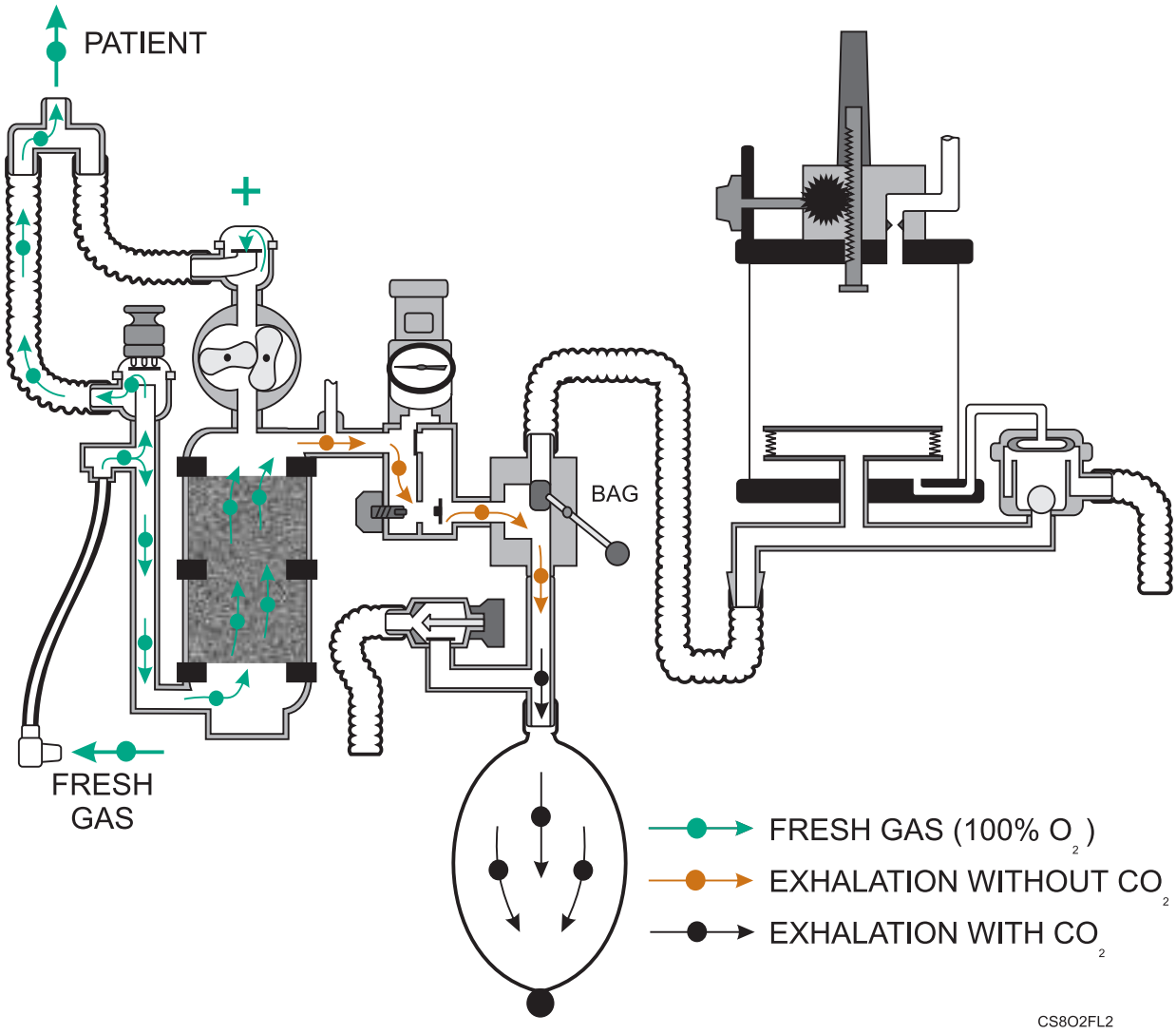


Figure 4-18: Phase two of the oxygen flush.

During phase three of the oxygen flush (Figure 4-19), a positive pressure builds up in the absorber system, the patient breathing circuit, and the breathing bag. When this pressure exceeds the preset limit of the APL valve, gases begin to flow to the scavenger system.

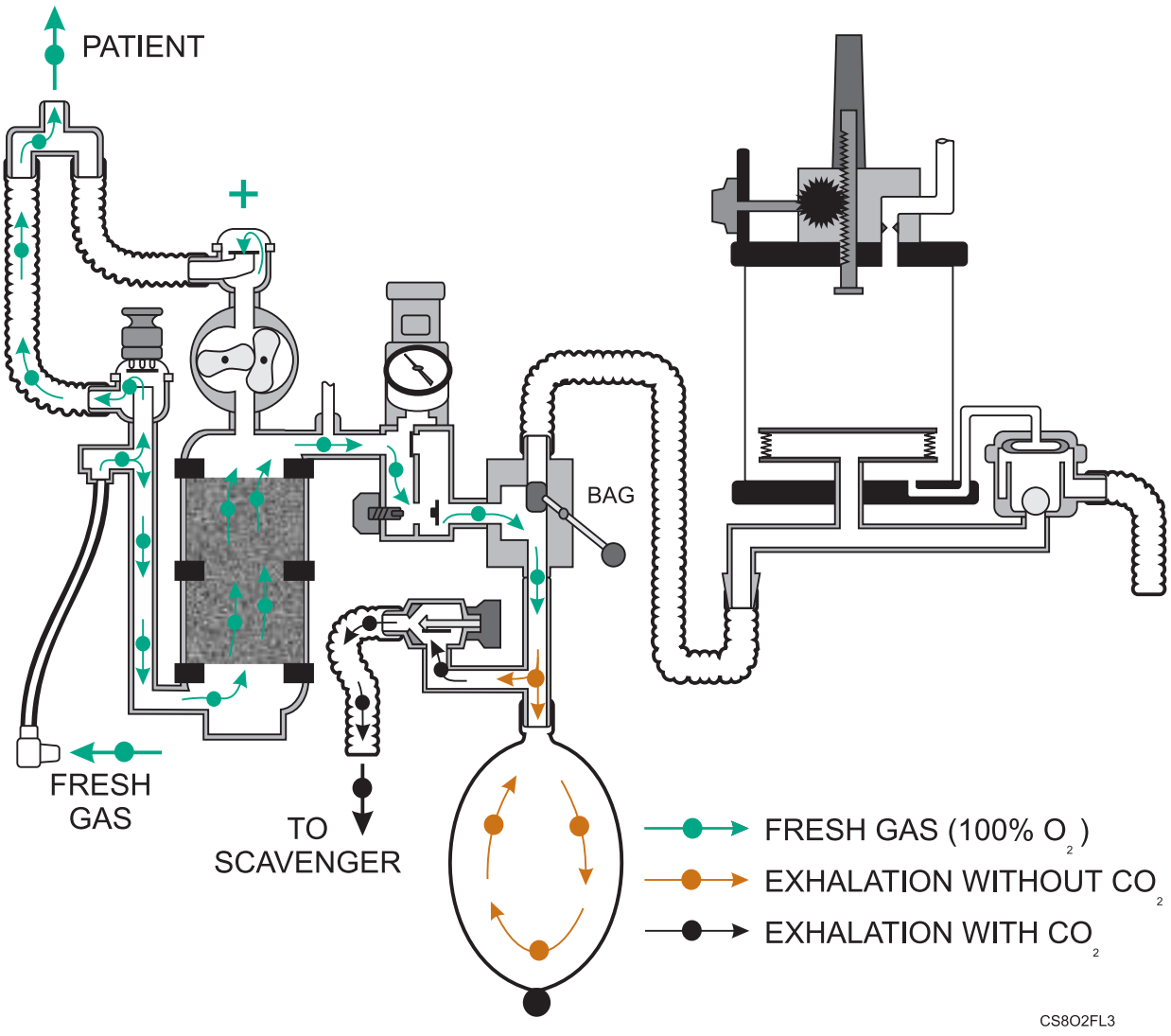


Figure 4-19: Phase three of the oxygen flush.

In the fourth and final phase of the oxygen flush (Figure 4-20), all exhaled gas containing carbon dioxide and anesthetic agent is flushed from the patient breathing circuit, the absorber system, and the breathing bag. All gases are replaced with 100% oxygen. The APL valve continues to vent excess gas to the scavenger system while sufficient pressure remains in the system.

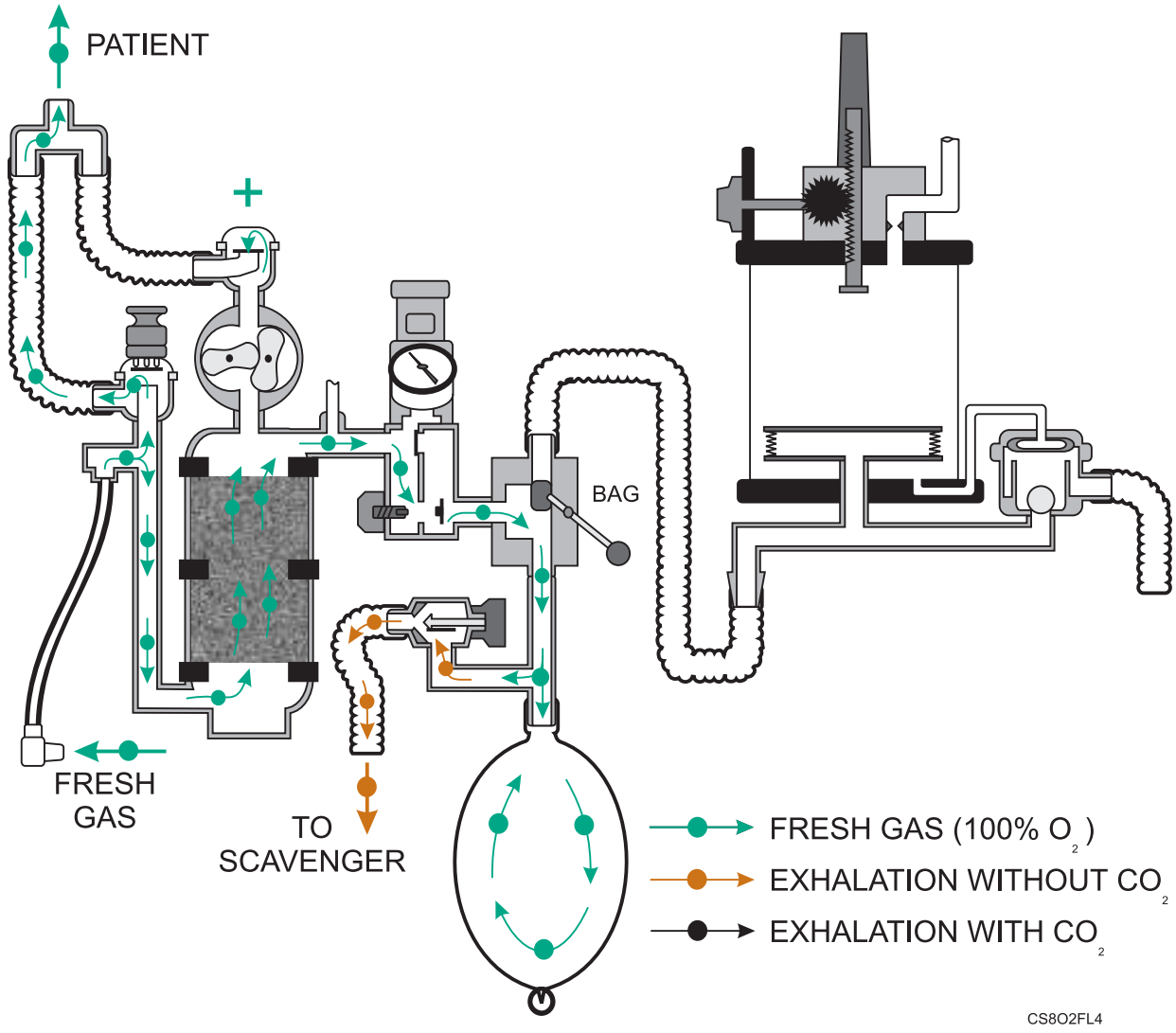


Figure 4-20: The fourth phase of the oxygen flush.

Supplement to Chapter 4

Classification of Breathing Systems

Many books have been written about anesthesia and many authors have devised their own classification systems for anesthesia breathing circuits. The classification system cited below (Figure 4-21) is representative of the various types of classification systems, but it is not the only way breathing systems can be classified. Under the system, the absorber circle system used on Narkomed anesthesia systems is classified as "closed" and the Bain system is classified as "semi-closed".

	Reservoir	Rebreathing	Access to Atmosphere	
			Inspiratory	Expiratory
Open	No	No	Yes	Yes
Semi-open	Yes	No	Yes	Yes
Semi-closed	Yes	No (partial)	No	Yes
Closed	Yes	Yes	No	No

BRSYSCLS

Figure 4-21: Classification of breathing systems.
Source: Ehrenwerth and Eisenkraft, 1993. *Anesthesia Equipment Principles and Applications.* Mosby, New York, Boston.

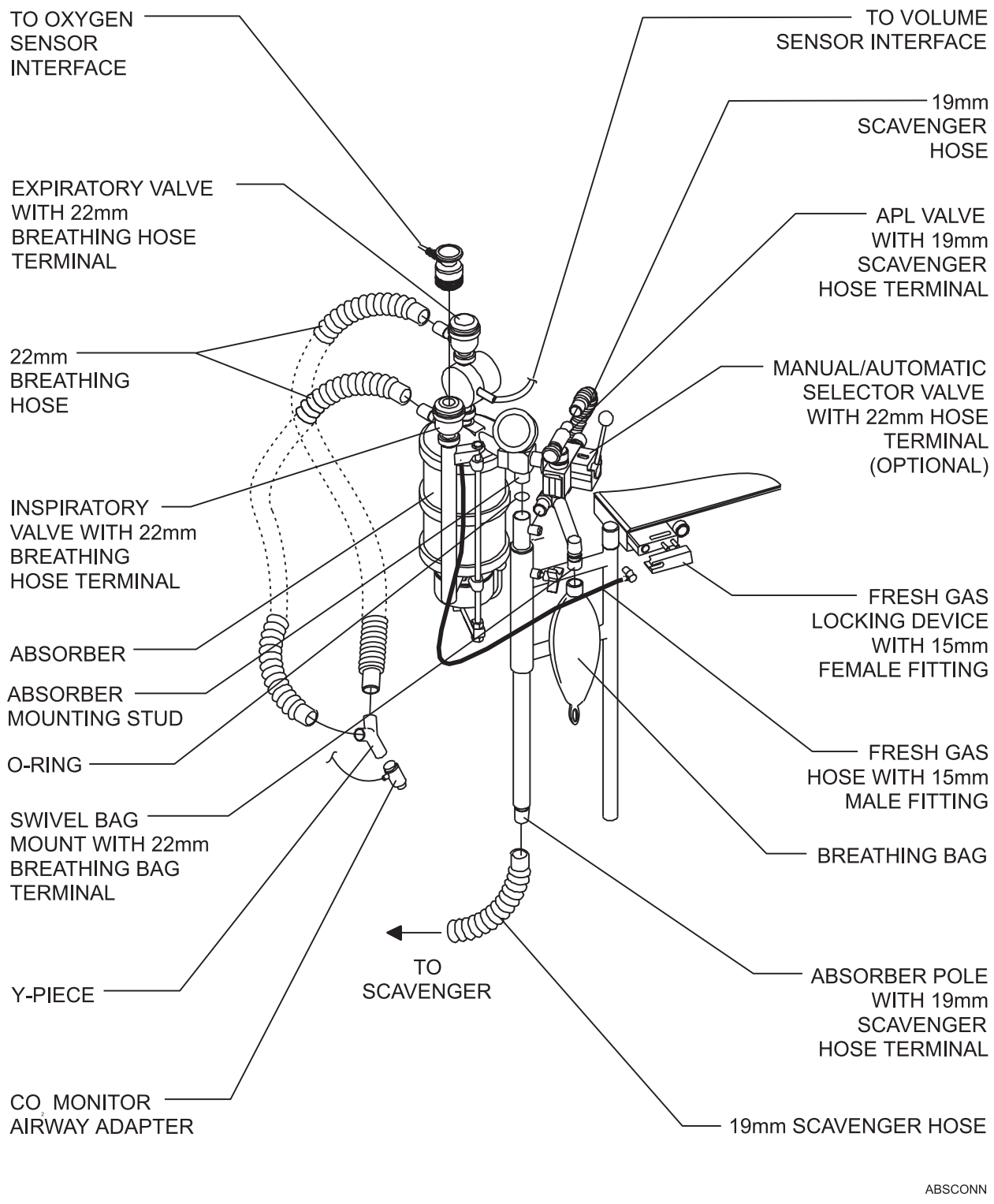


Figure 4-22: Front view of the absorber hose and sensor connections.

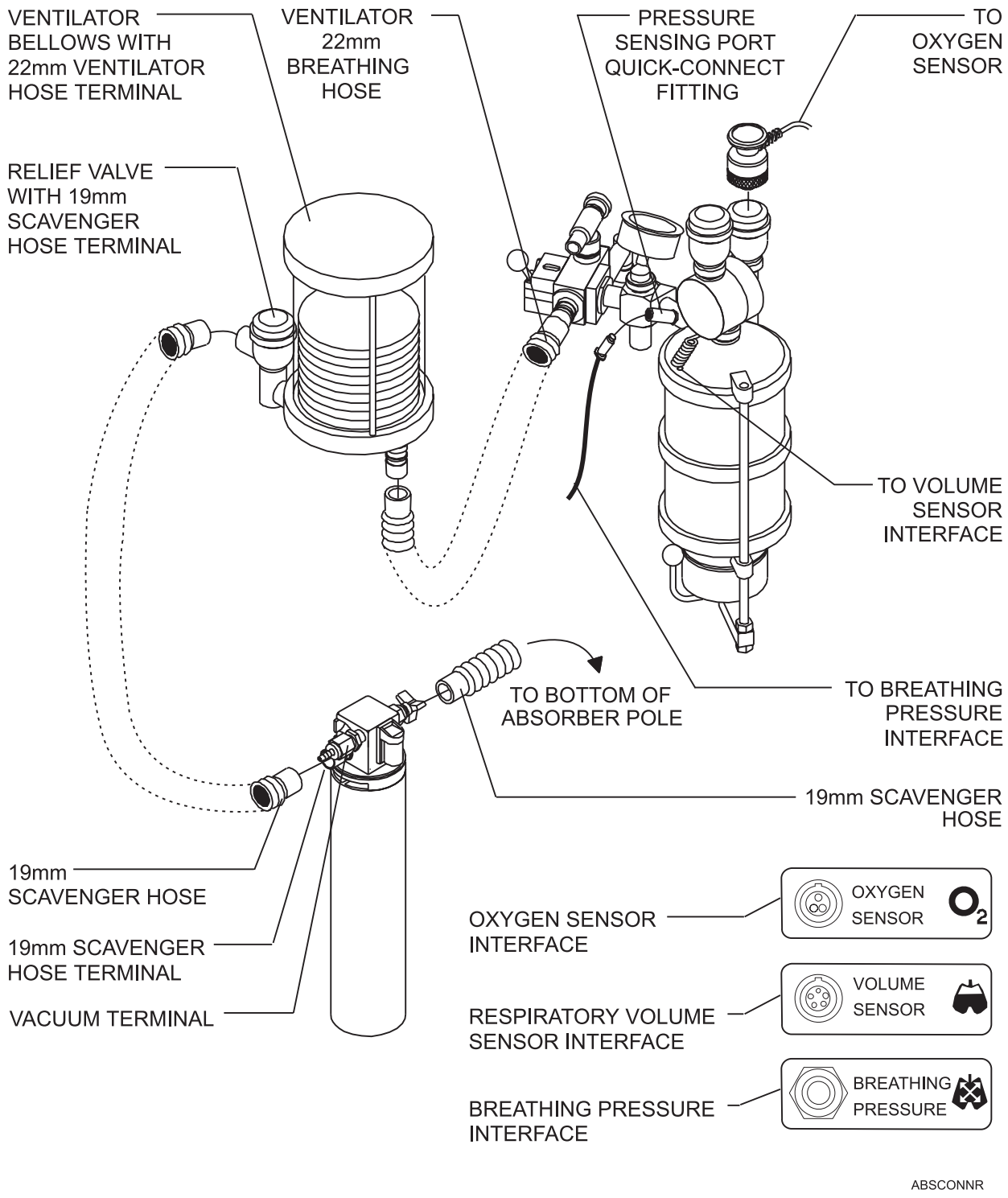


Figure 4-23: Rear view of the absorber hose and sensor connections.

Manual/Automatic Selector Valve

The manual/automatic selector valve has two positions: BAG and AUTO. When the valve's lever is rotated, it moves a cone with several openings. At the same time, the valve's cone opens one pathway and closes another pathway. In the BAG mode (Figure 4-24), the cone opens the pathway to the APL valve and the bag mount while blocking the pathway to the ventilator connection.

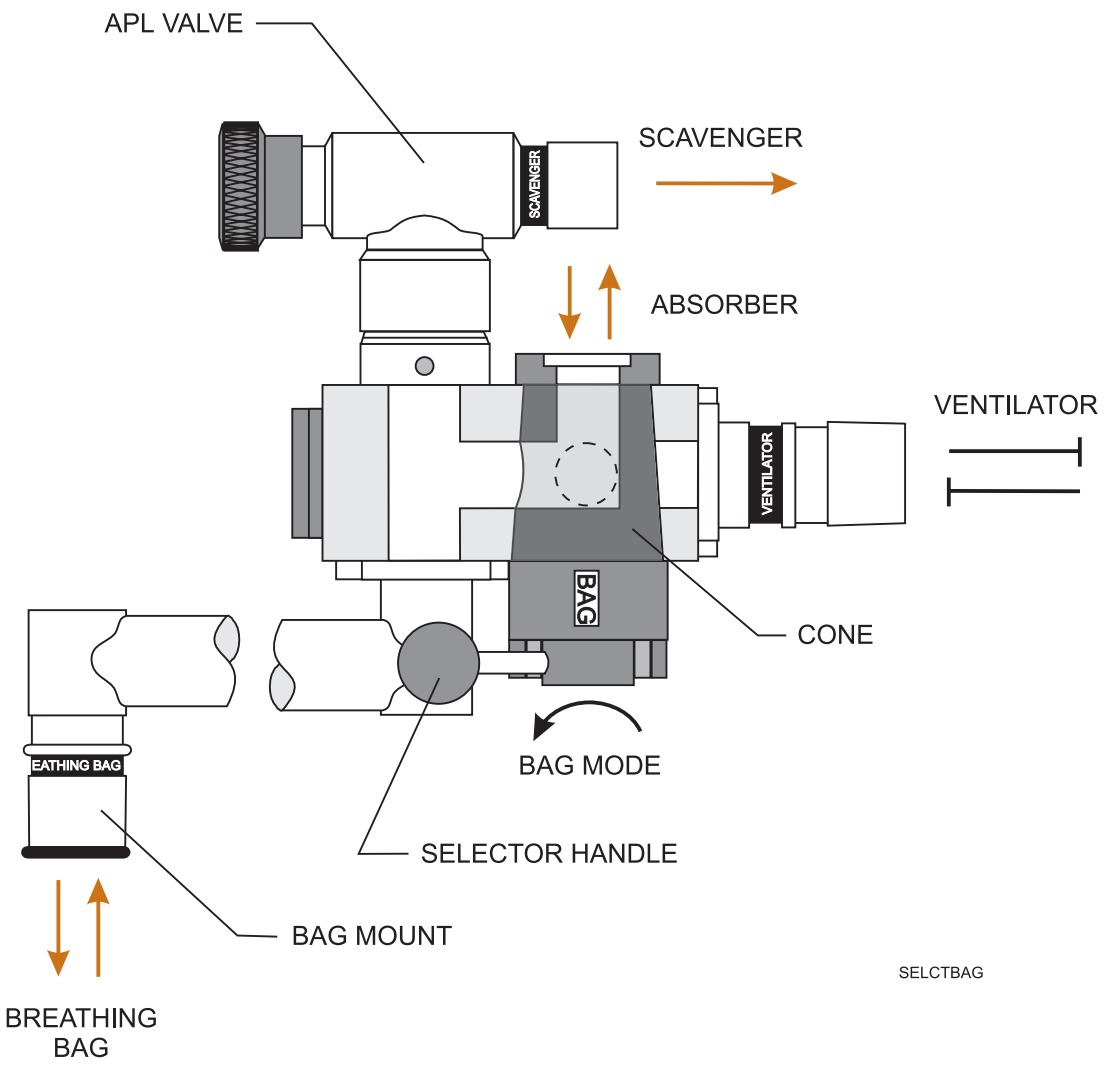


Figure 4-24: Manual/automatic selector valve in the BAG mode.

In the AUTO mode (Figure 4-25), the valve opens the pathway to the ventilator and blocks the path to the APL valve, scavenger, and bag mount.

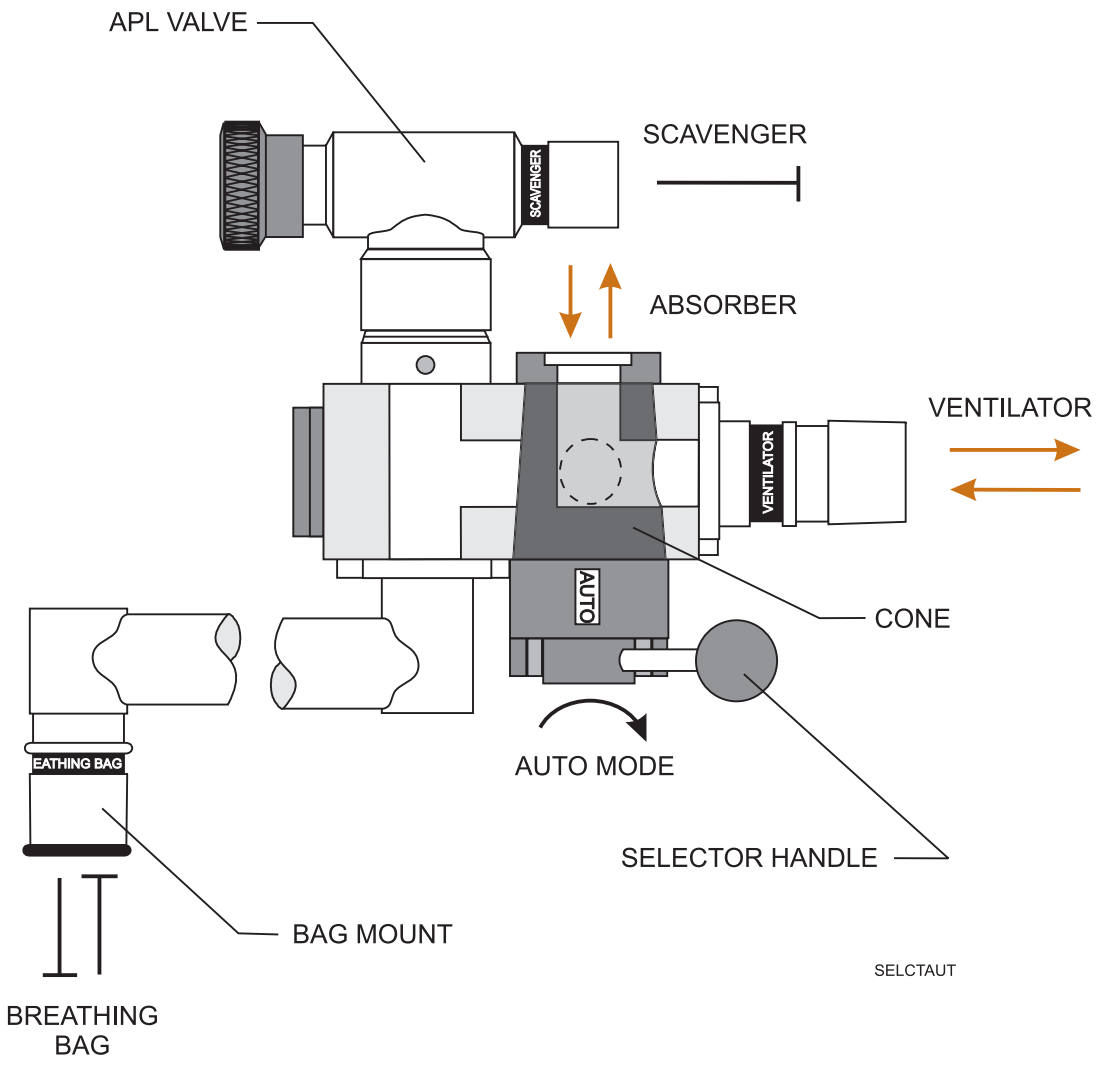


Figure 4-25: Manual/automatic selector valve - ventilator mode.

Mapleson Classification of Breathing Systems

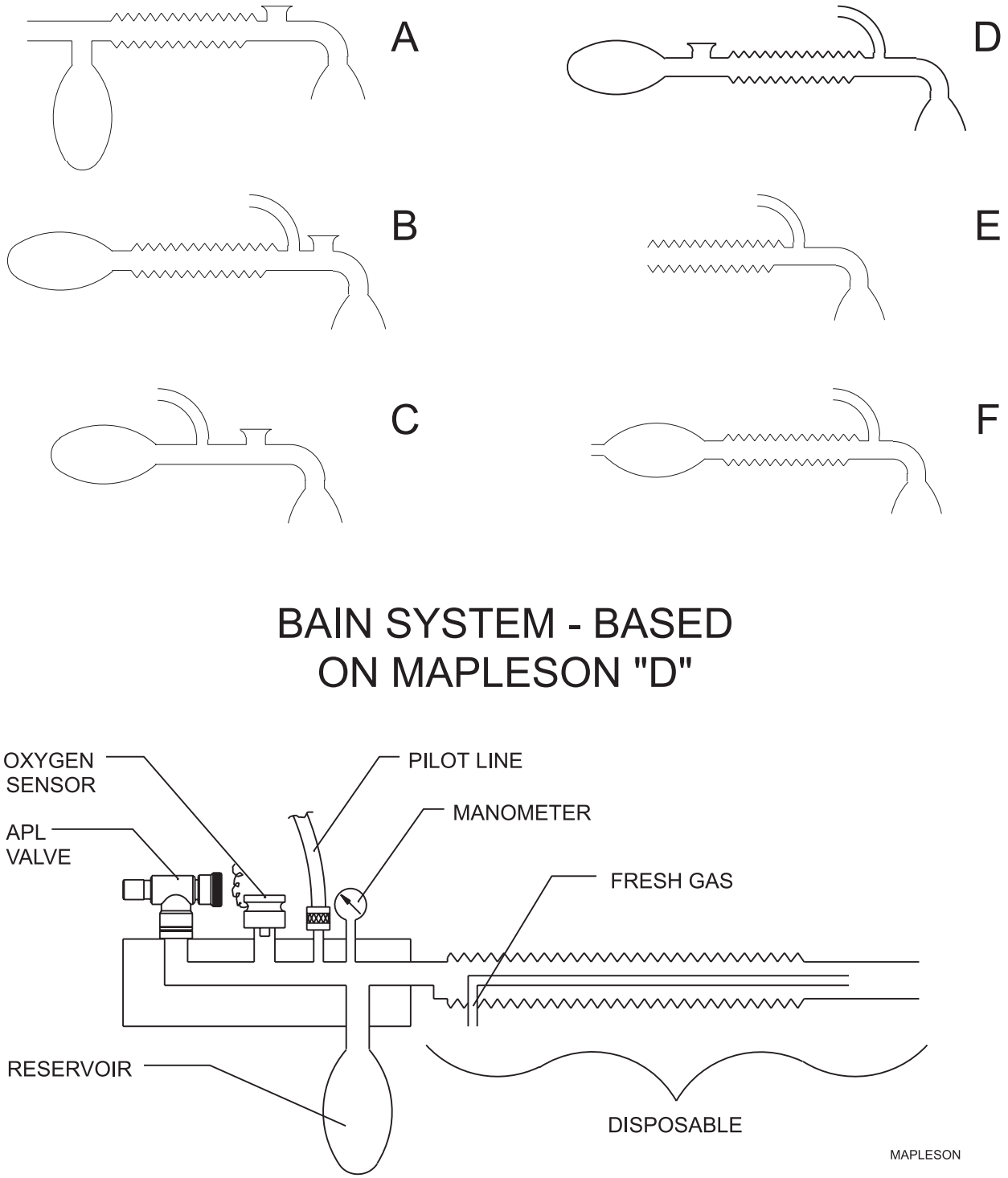


Figure 4-26: Mapleson classification of breathing circuits and the Bain system.

The Bain System

The Bain system (Figure 4-27) was derived from the Mapleson D breathing circuit (see Figure 4-26 in the supplement to chapter 4). The Bain system is classified as a partial rebreathing system and it requires high fresh gas flows to reduce rebreathing of exhaled carbon dioxide.

Some advantages of the Bain system include its low number of components, simplicity of design (no valves, no absorber, and only one tube), and ease of sterilization. Some disadvantages include difficulty in detecting disconnects and the variable quality of its disposable components.

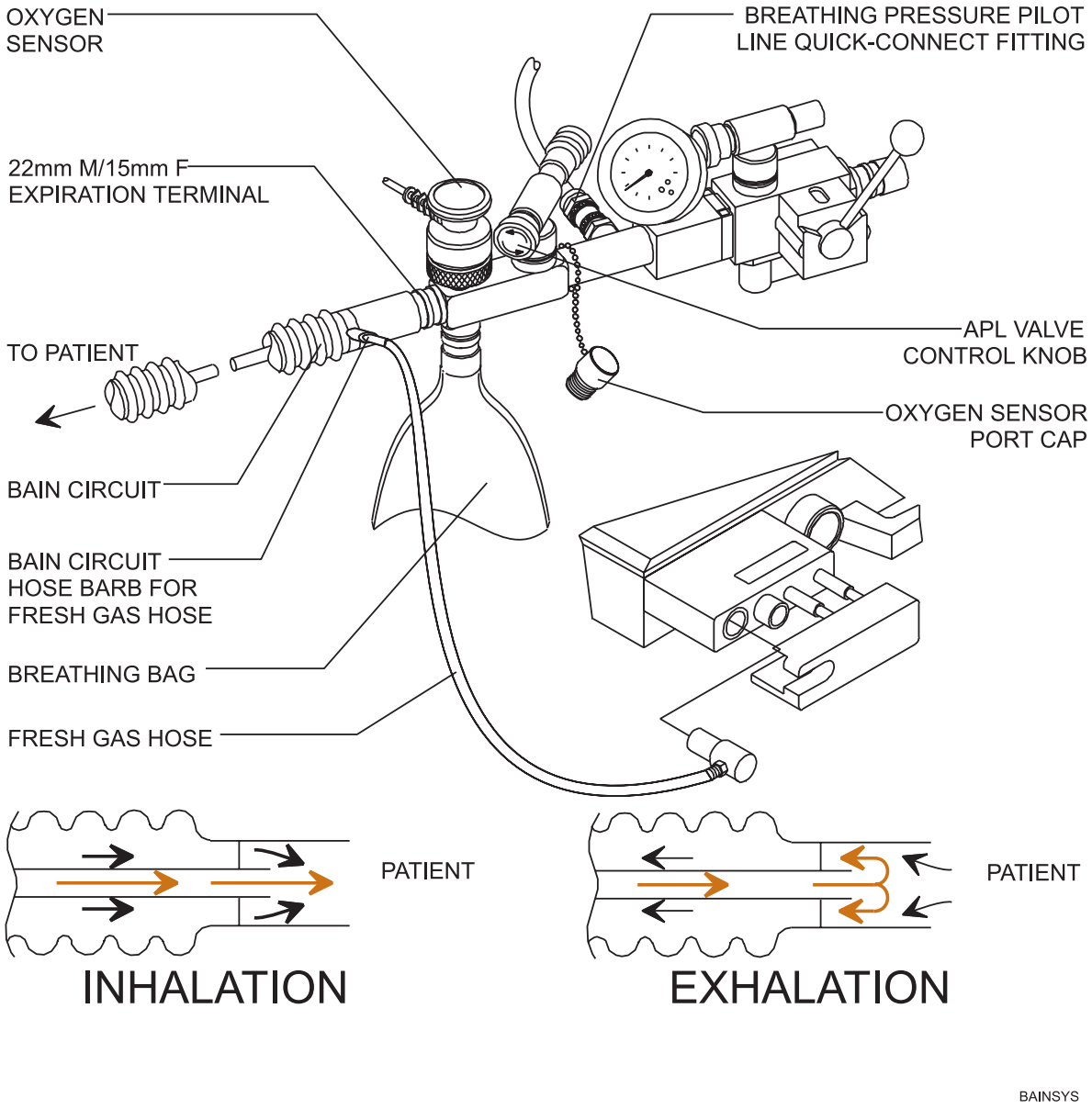


Figure 4-27: The Bain system.

5: The Positive End Expiratory Pressure Valve

The Positive End Expiratory Pressure (PEEP) valve is part of the absorber system mounting block when included in a Narkomed anesthesia system. In this position, it can regulate PEEP in the patient breathing circuit regardless of the ventilation mode employed. The PEEP valve is permanently integrated in the absorber assembly to prevent the inadvertent misplacement of the valve in the inspiratory limb of the patient breathing circuit.

The PEEP valve consists primarily of two valves that affect the flow of gas in the patient breathing circuit during exhalation only. A spring-loaded check valve and a magnetic one-way valve, control the flow of gases during exhalation. The amount of resistance the gas flow must overcome can be varied by the adjustment control as it moves nearer or farther from the magnetic one way valve.

It is possible to turn the PEEP valve OFF (Figure 5-1) if PEEP is not needed for the patient. This is accomplished by pushing the slide catch in at the top and allowing the slide to move down. This brings the slide switch magnet into position opposite the magnetic one-way valve. Because the slide switch magnet is stronger than the control magnet, the magnetic one-way valve will be held in a fully open position. In the fully open position, no PEEP is created during exhalation.

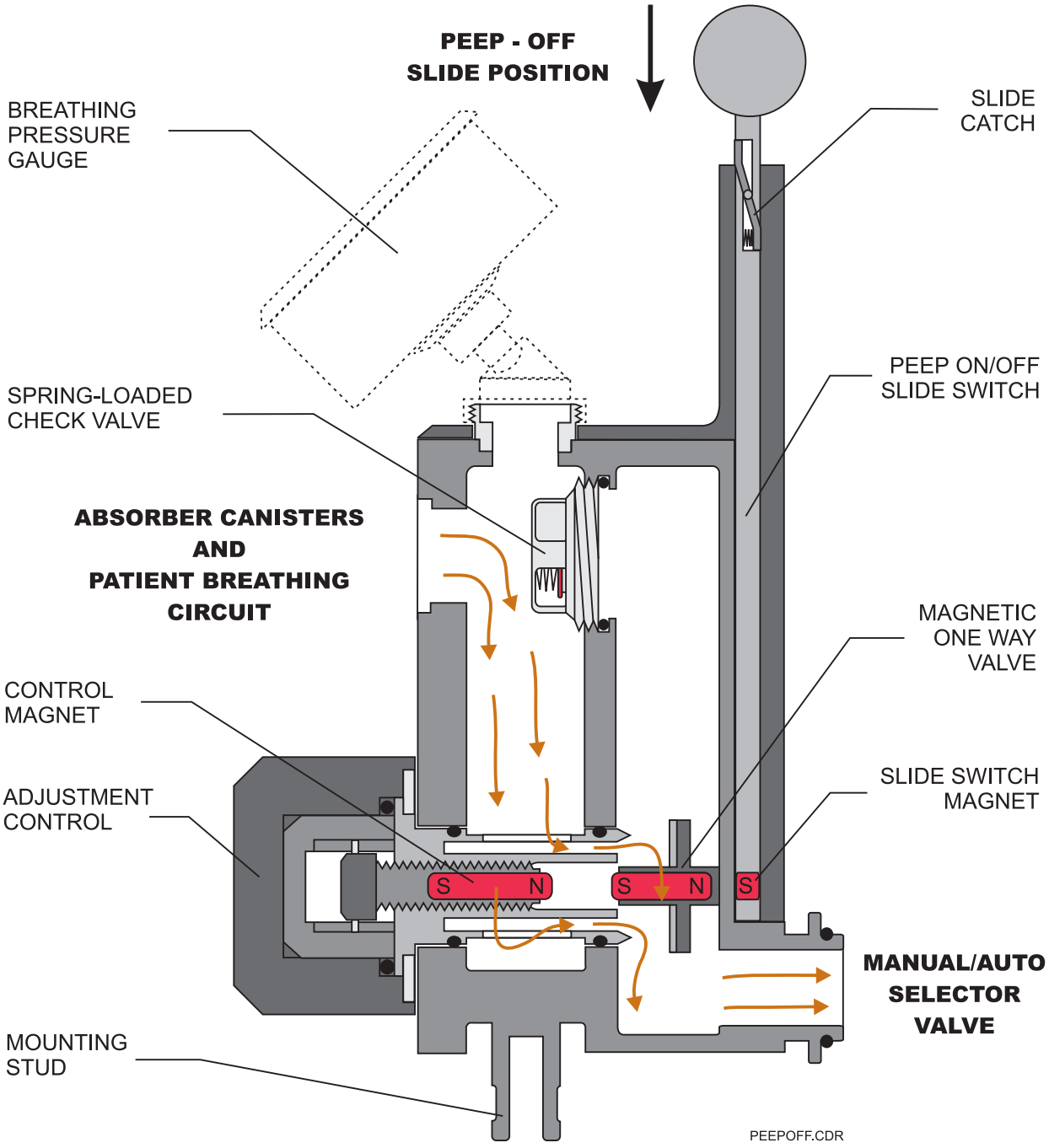


Figure 5-1: The PEEP valve slide switched off.

The PEEP valve operates on the magnetic principle. When the PEEP valve control is rotated, the magnet moves closer to or farther away from the magnetic one-way valve, increasing or decreasing the amount of pressure it takes to open the magnetic valve. During inhalation, the gas flows into the PEEP valve from the manual/automatic selector valve (Figure 5-2). Gas cannot pass through the closed magnetic valve and flows through the spring loaded check valve. The PEEP valve does not interfere with the flow of gas during inhalation.

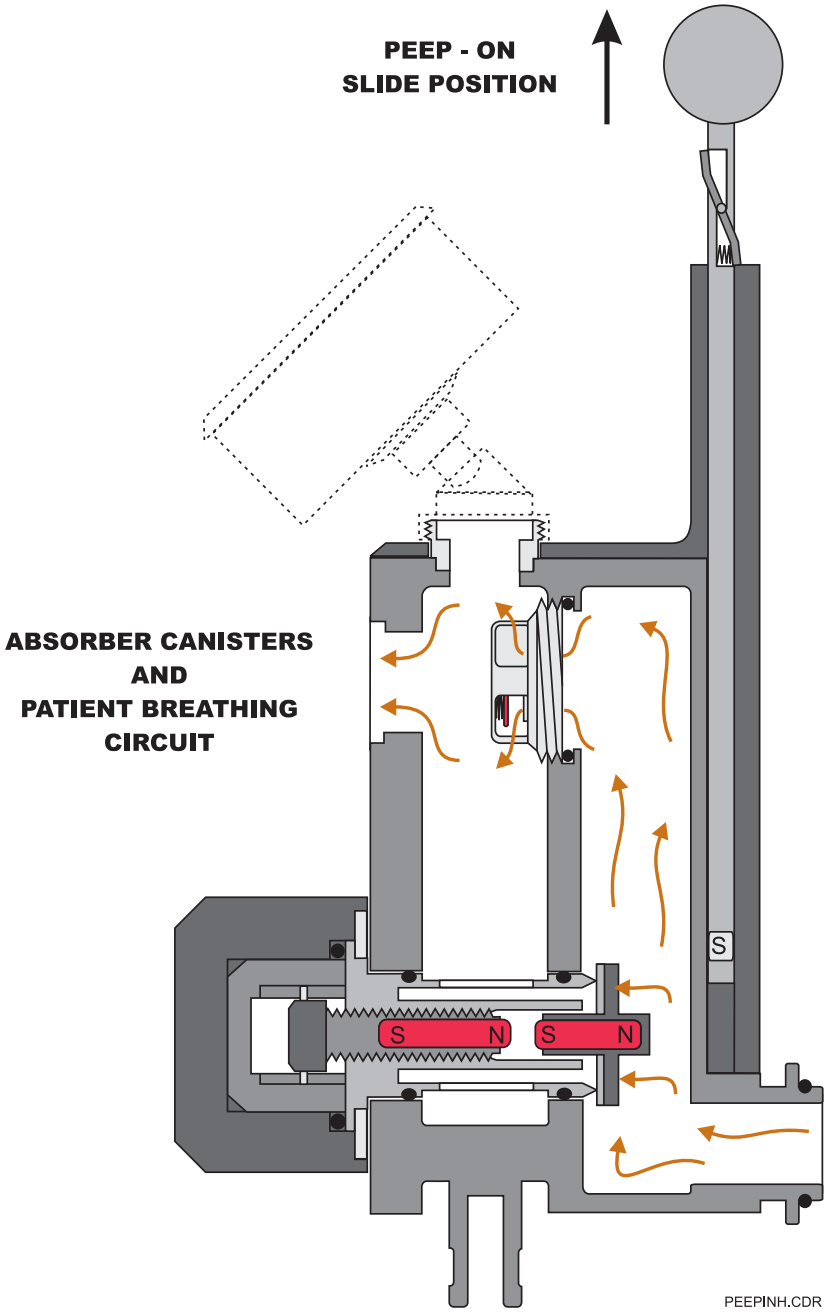


Figure 5-2: Gas flow through the PEEP valve during inhalation.

At the beginning of exhalation (Figure 5-3), exhaled gases flow from the patient breathing circuit into the PEEP valve from the opposite direction. The gas cannot flow through the closed spring-loaded check valve. As exhalation continues, the pressure of the exhaled gases exceeds the magnetic attraction and the magnetic valve opens. Exhaled gas then flows to the manual/automatic selector valve.

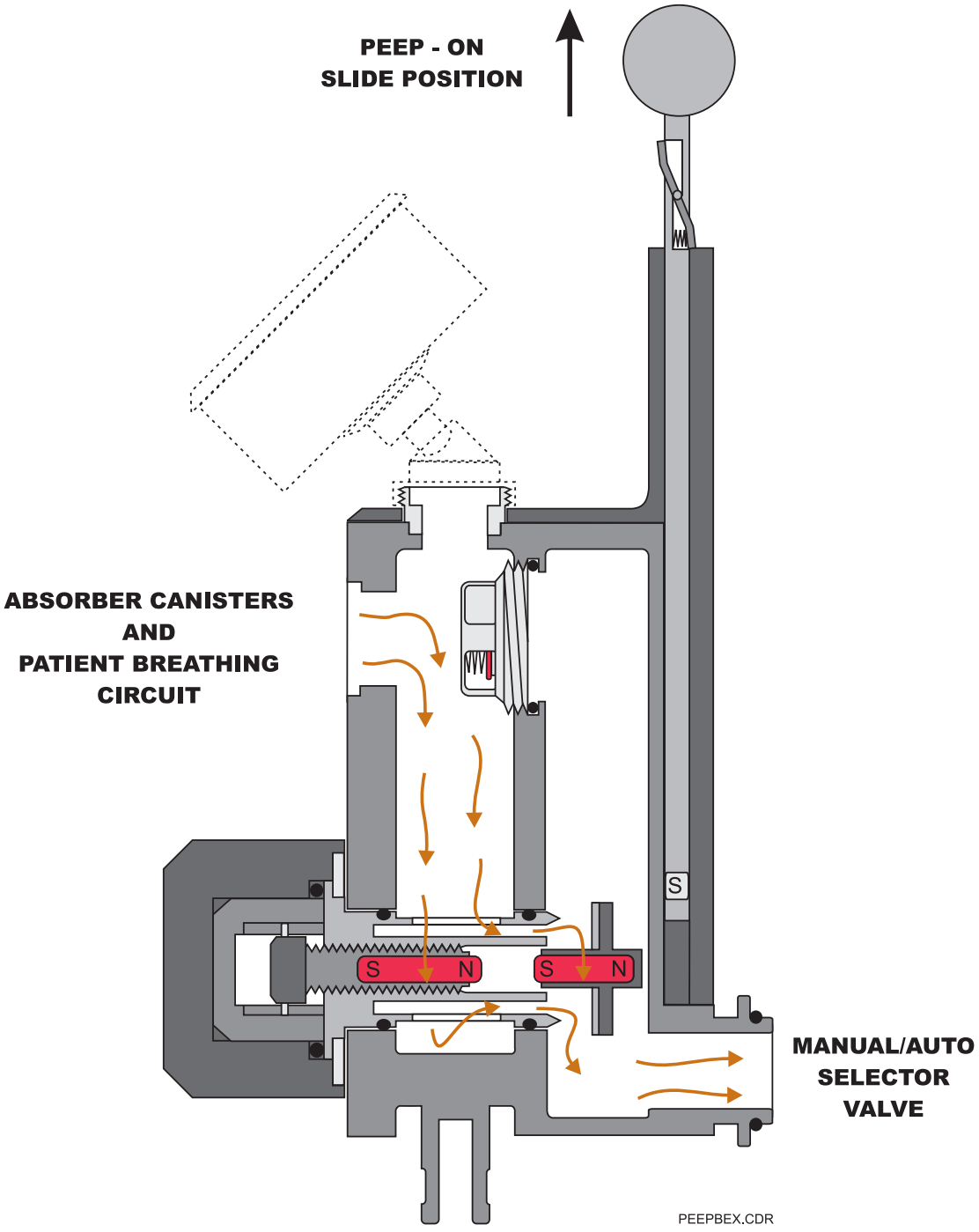


Figure 5-3: Exhaled gases flow through the PEEP valve at the beginning of expiration.

Toward the end of exhalation, the pressure of the exhaled gases begins to decrease. When the pressure of the exhaled gases decreases to a point below the magnetic attraction, the magnetic valve closes (Figure 5-4). When the magnetic valve closes, the exhaled gas cannot flow to the manual/automatic selector valve and the remainder of the patient gas is trapped in the patient's lungs. This trapped gas creates PEEP.

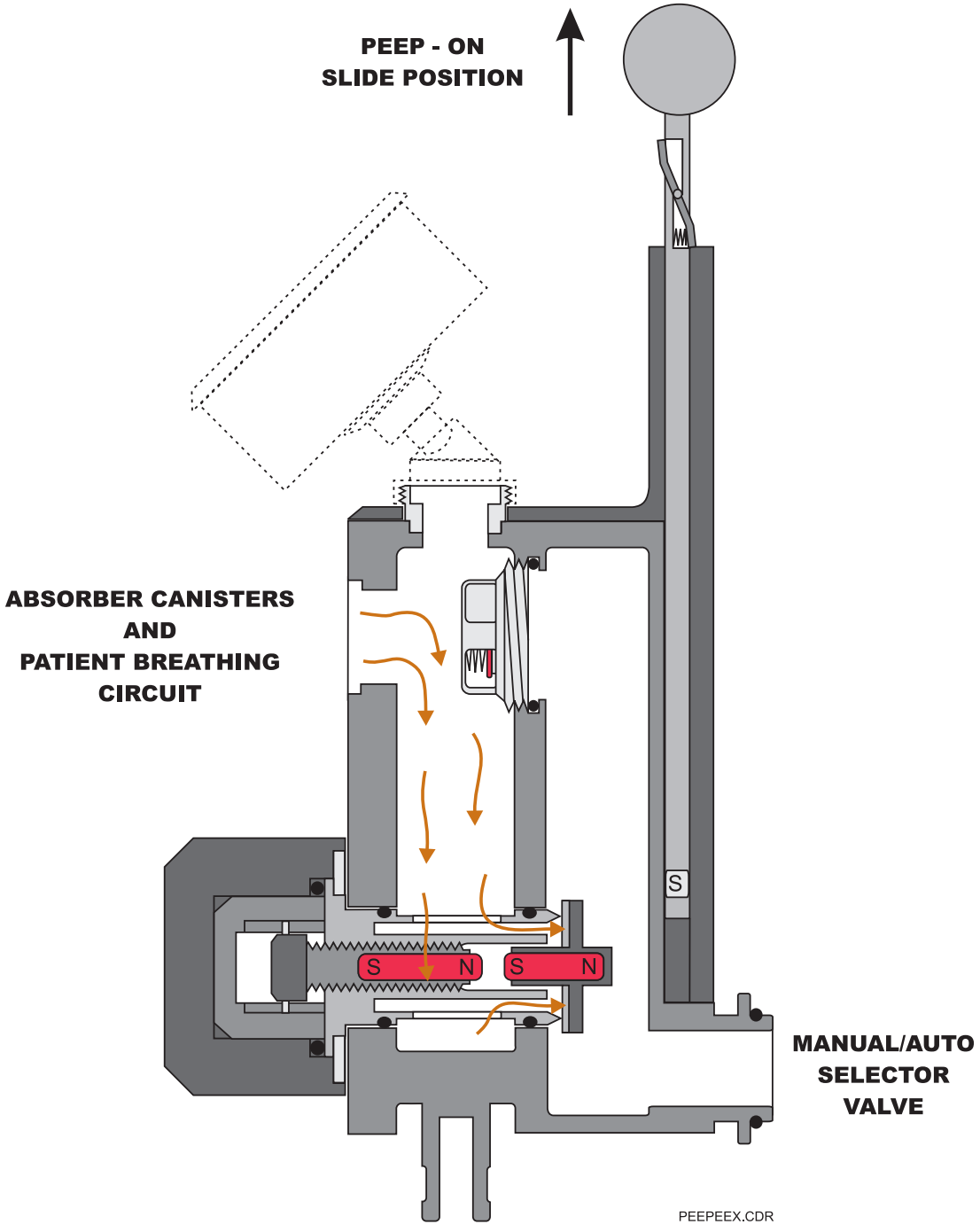


Figure 5-4: Exhaled gases cease to flow through the PEEP valve at the end of expiration.

Supplement to Chapter 5:

Lung Volumes and Capacities

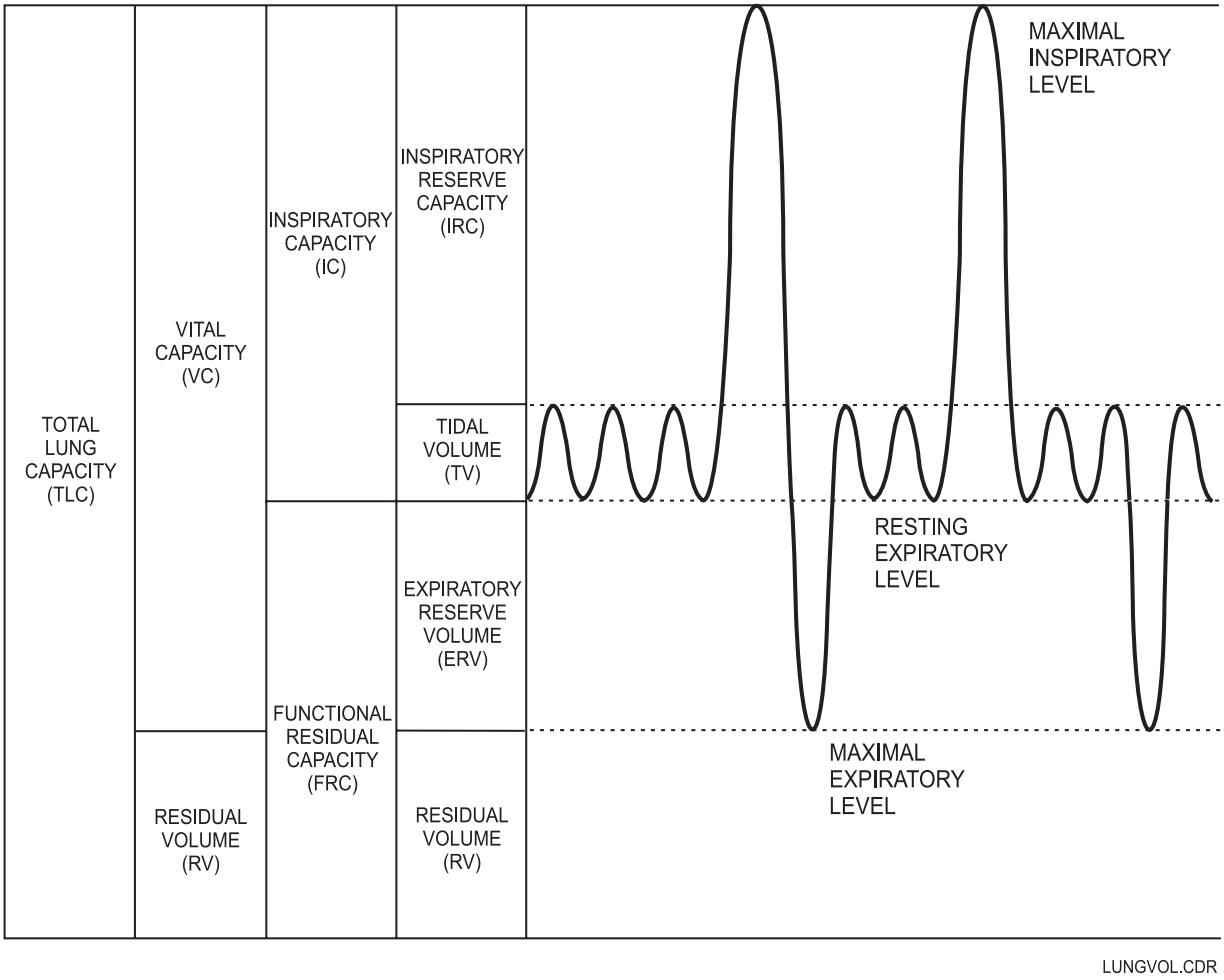


Figure 5-5: Lung volumes and capacities.

6: Scavenger Systems

Scavenging is defined as the collection and removal of exhausted gases from the operating room. Installing an efficient scavenging system is the most important step in reducing trace gas levels in the operating room. Scavenger systems can be divided into two general categories. One category comprises the closed scavenger system of spring-loaded valves for positive and negative pressure relief. The other category is the open reservoir scavenger system that relies on open ports for positive and negative pressure relief.

Open Reservoir Scavenger System

The open reservoir scavenger system is called an "open" system because it relies on open relief ports for positive and negative pressure relief. When the float stays between the lines on the flowmeter, the needle valve is adjusted properly (Figure 6-1). The gas flow from the scavenger to the central vacuum system is approximately 25 l/min.

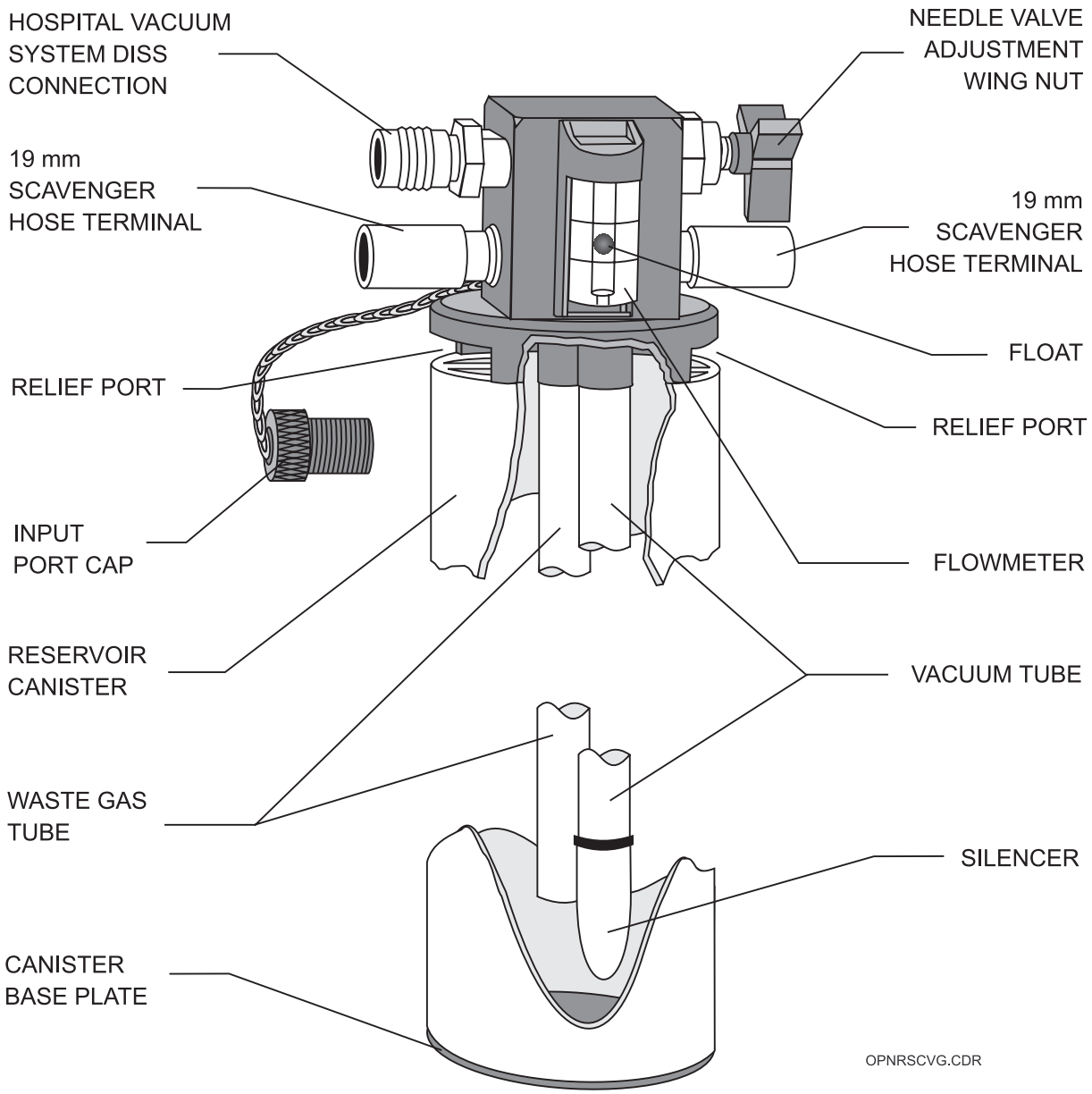


Figure 6-1: The open reservoir scavenger system.

Scavenger Interface for Passive Systems

The scavenger interface for passive systems (Figure 6-2) is called a "closed" system because it relies on a spring-loaded valve for positive pressure relief. This system is typically used in hospitals where scavenging is done through the air conditioning system. A hose connects the exhaust port of the scavenger to the evacuation vent of the air conditioning system. If the hose from the exhaust port becomes blocked, a +5 cmH_2O safety relief valve activates, bleeding excessive pressure into the atmosphere.

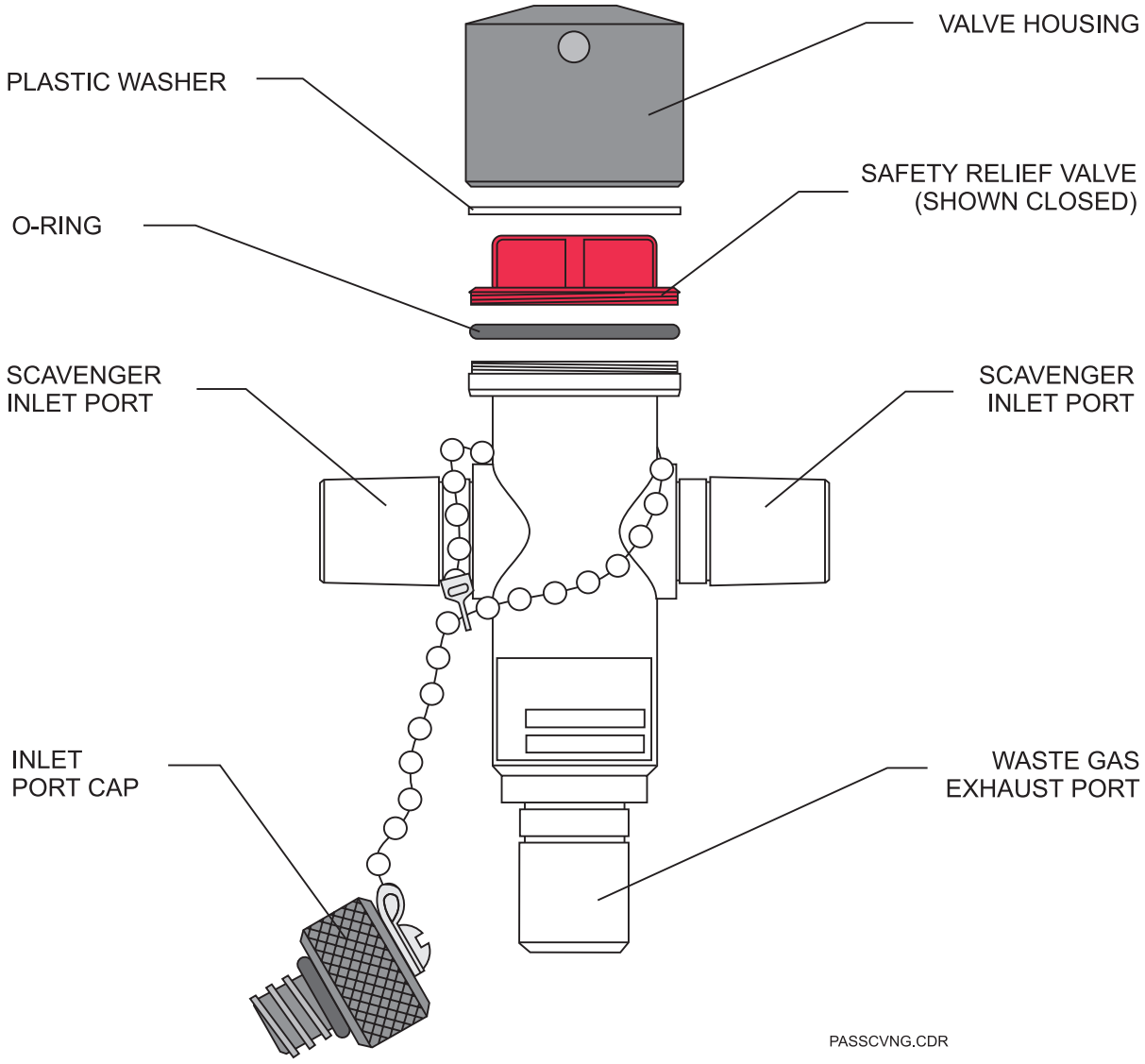


Figure 6-2: A scavenger interface for passive systems.

Supplement to Chapter 6

Scavenger Interface for Active Suction Systems

The scavenger interface for active vacuum systems is also called a "closed" scavenger system (Figure 6-3). This system is generally used with a dedicated vacuum system, a patient vacuum system, or with a central hospital vacuum system. The vacuum source is connected to the scavenger's DISS inlet and a 5-liter bag is attached to the bag mount at the bottom. A needle valve controls the correct adjustment of the vacuum. The needle valve should be adjusted so the reservoir bag is never overinflated (B) or under-inflated (C), but should remain slightly inflated (A). Because the volume of gas being passed into the scavenging system varies, it may be necessary to adjust the needle valve.

Excess PEEP can be caused by an accumulation of exhaled water or humidity within the scavenger. The +5 cmH_2O positive pressure relief valve prevents inadvertent PEEP from exceeding 5 cmH_2O by opening and allowing excess gas to flow to the atmosphere. Conversely, excessive vacuum from the central hospital system can create a subatmospheric pressure in the patient breathing circuit. The -0.5 cmH_2O relief valve allows room air to enter the scavenger system under these conditions. A second relief valve opens at -1.8 cmH_2O and acts as a backup if the -0.5 relief valve is occluded or fails. Manufacture of this type of scavenger was discontinued for Narkomed anesthesia systems in 1991.

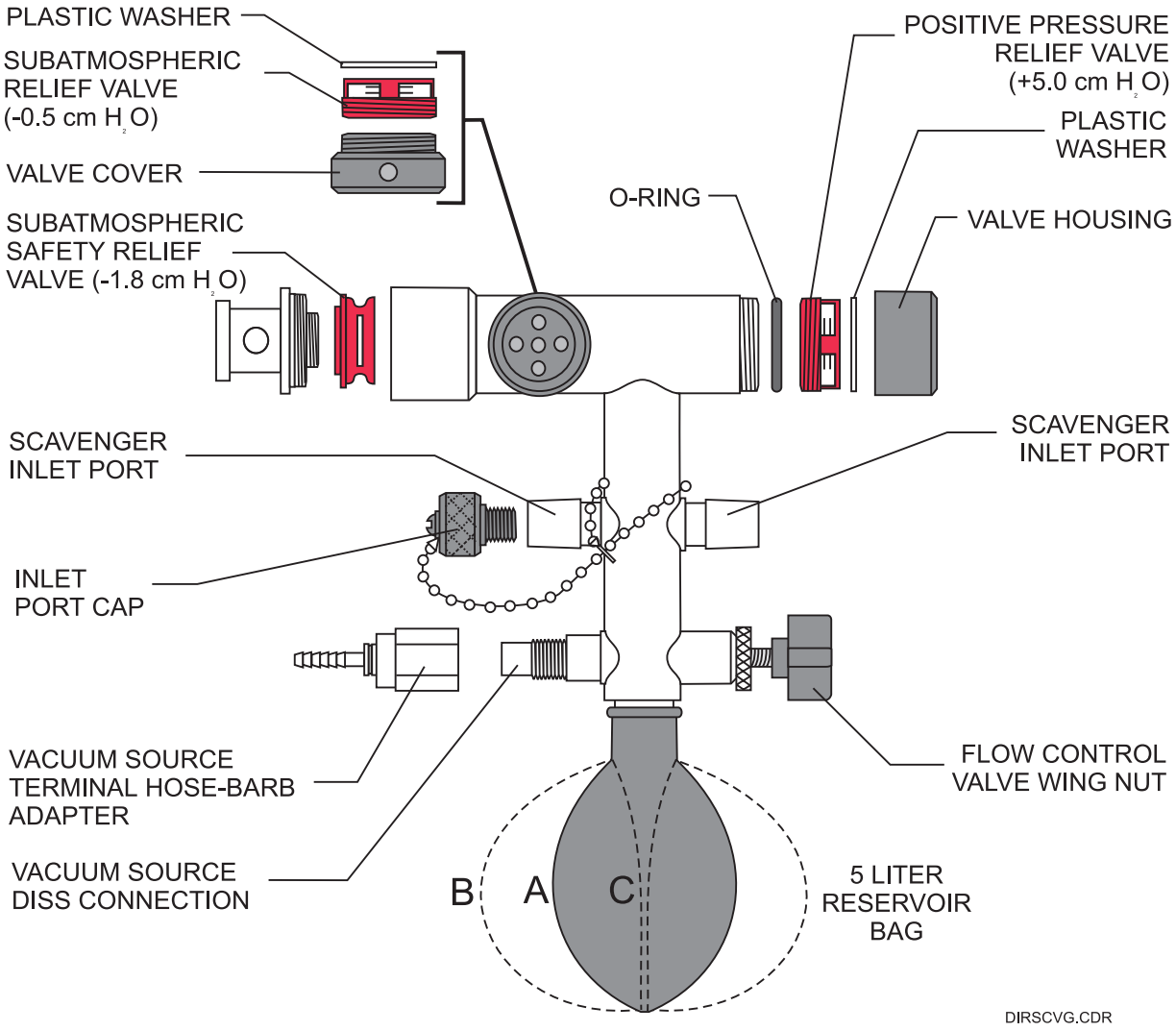


Figure 6-3: The scavenger interface for active suction systems.

RETURN TO THIS BOOK'S TABLE OF CONTENTS
RETURN TO CD-ROM TABLE OF CONTENTS

7: The Electronic Anesthesia Ventilator

When the level of anesthesia begins to affect the respiratory drive in the patient, the anesthesiologist may elect to use an automatic ventilator to ensure that the patient remains adequately ventilated. To provide for this choice Narkomed anesthesia systems are equipped with the AV2+ (Anesthesia Ventilator 2+).
Using a standard classification for ventilators, the AV2+ is a controller. It does not provide for other modes of ventilation more commonly seen on respiratory care ventilators. It is a double-circuit device. The gas driving the bellows is separate from the gas within the bellows. The AV2+ is pneumatically powered and electronically controlled by time-cycled circuitry. During each cycle, the patient gas volume is preset with the flexibility of variable pressure. Additionally, all AV2+ ventilators have an auto-ranging venturi system for the drive gas and a pressure limiter for the inspired gas.

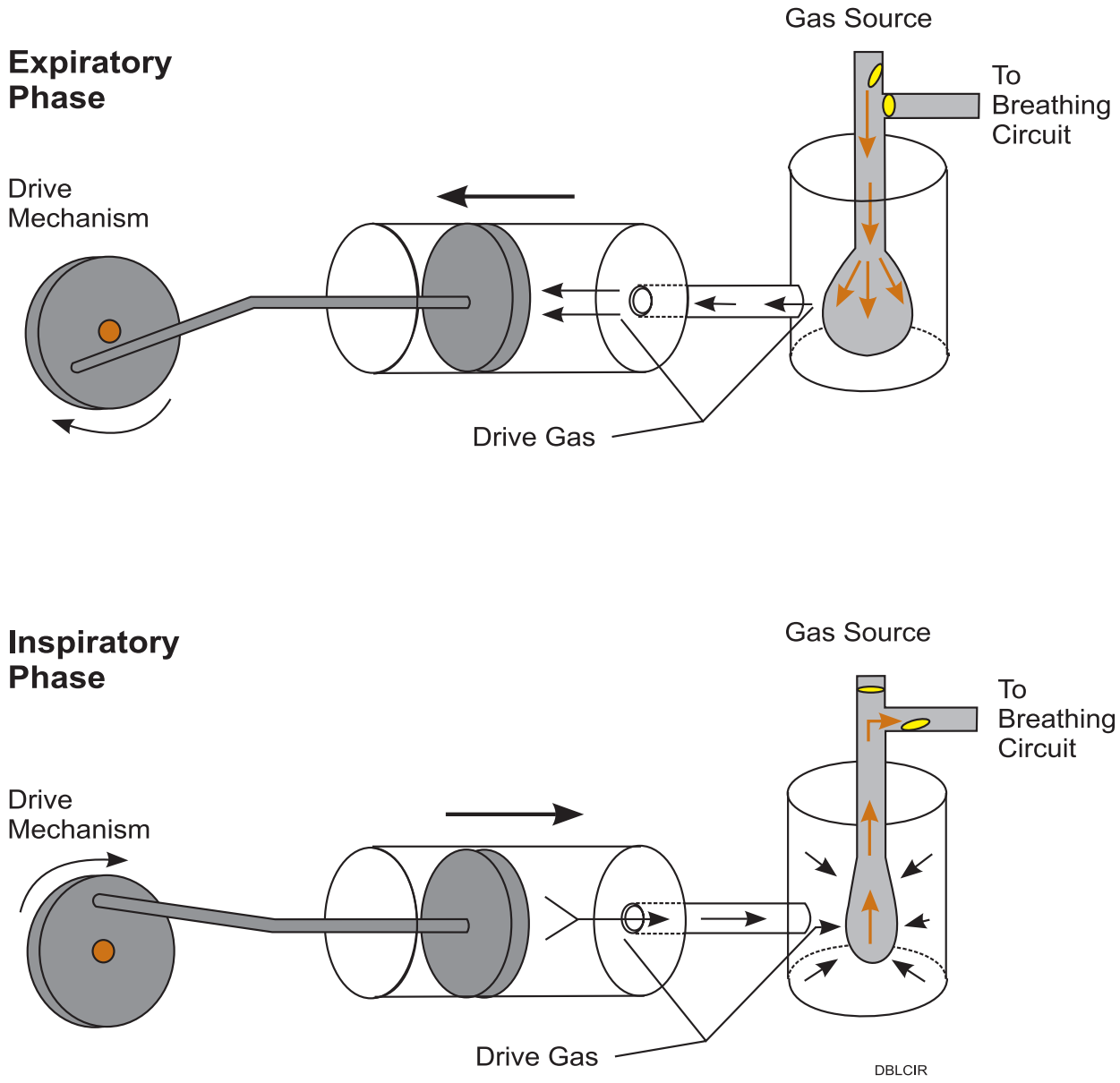


Figure 7-1: Double-circuit ventilator in the inspiratory and expiratory phases.

Bernoulli's Law

First stated by Daniel Bernoulli, expresses the relationship between pressure and velocity of moving fluids (liquids or gases). As the speed of a fluid increases, the pressure inside the fluid, or exerted by the fluid, decreases. If gas, for example, flows through a horizontal pipe of varying cross-section, the gas must flow faster in the narrower regions. The pressure on the gas must be greater in the wider regions, because the walls of the pipe must exert a force to accelerate the gas on its way to the constriction.

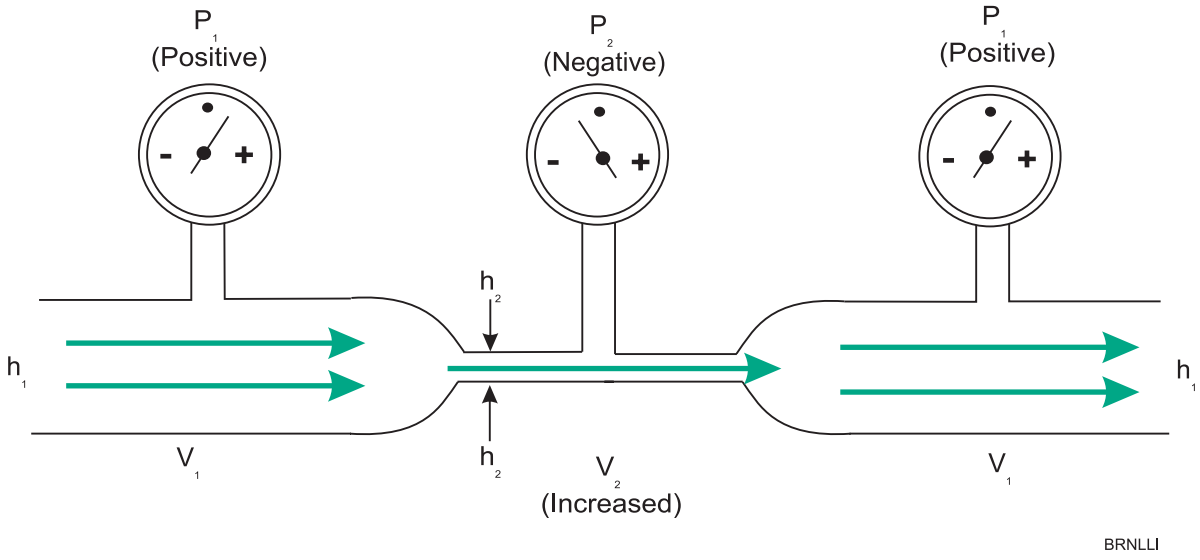


Figure 7-2: Bernoulli's Law

Air Injector

As oxygen flows through the air injector, it is forced through a narrow aperture, causing a significant increase in the velocity of the oxygen flow. The increased velocity causes a pressure drop as the oxygen enters the entrainment port. This pressure drop allows room air to enter the gas stream at the entrainment port and increase the volume of this gas flow. The combined flow of oxygen and entrained room air is the drive gas.

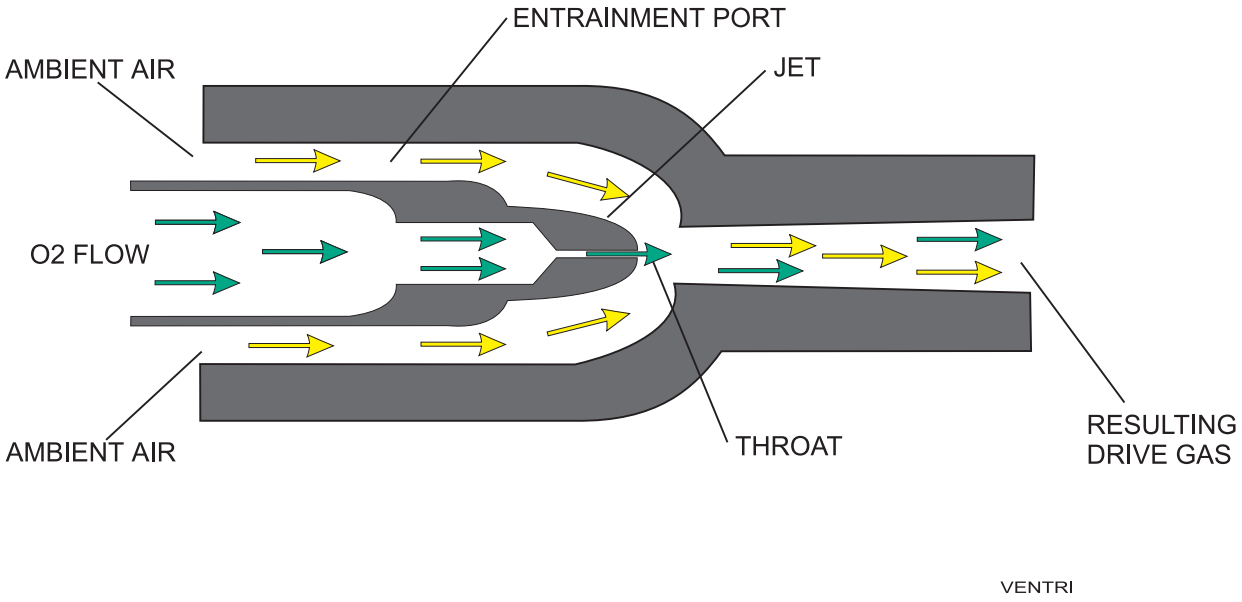


Figure 7-3: Venturi effect used for an air injector.

Drive Gas

The air injector increases the volume of drive gas that acts on the bellows assembly. The ambient air enters the ventilator through an unrestricted port and is conducted through a tube to the entrainment port of the air injector. As oxygen is forced through the small nozzle, it must travel at a higher rate of speed. When the fast moving oxygen exits the nozzle, its speed creates a negative pressure in and surrounding the nozzle. This negative pressure draws the ambient air into the oxygen stream and both gases enter the bellows canister.

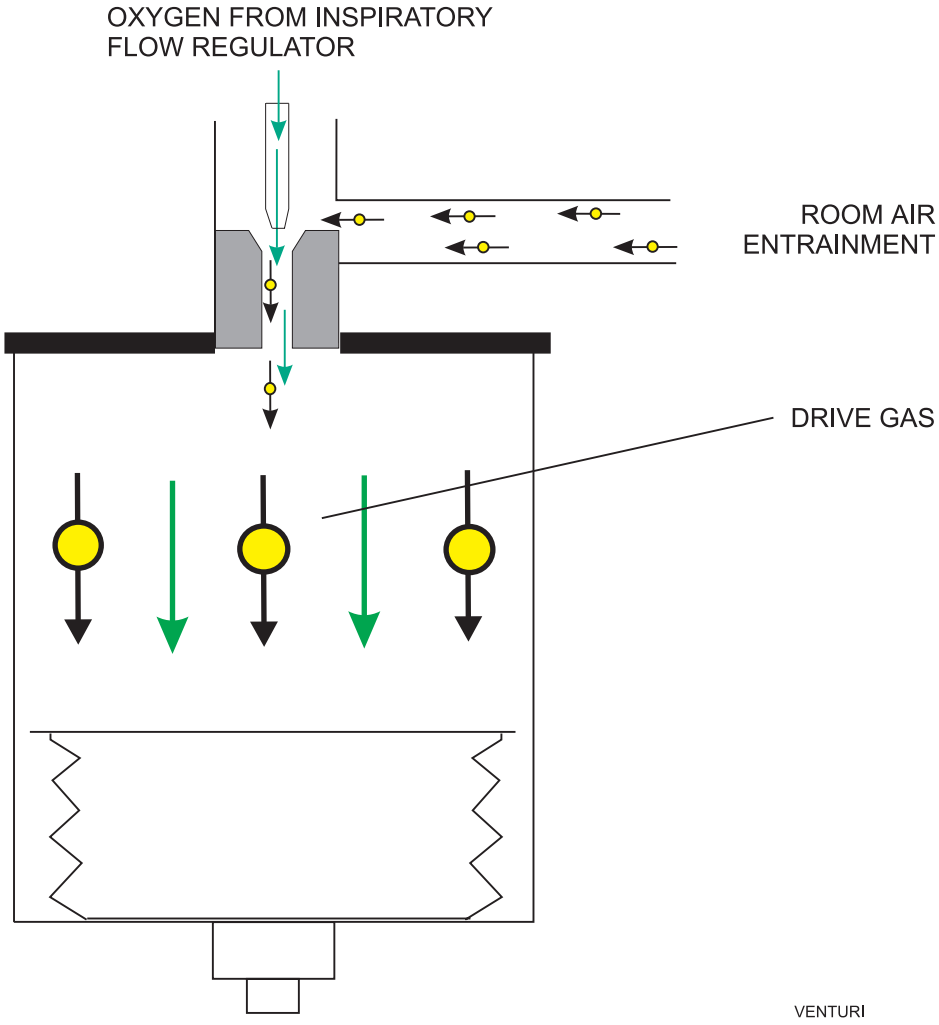


Figure 7-4: Air injector using the venturi effect to create drive gas. (AVE)

The auto-ranging valve controls the amount of ambient air that is entrained by the air injector at any given inspiratory flow setting. To accomplish this, a tee fitting with a small diameter tube carries oxygen flow from the output side of the inspiratory flow regulator to the diaphragm of the auto-ranging valve. This gas pressure exerts a downward force on the diaphragm and causes the valve to open by compressing the spring on the opposing side of the piston and seal assembly. At high inspiratory flows, the valve allows the maximum amount of ambient air to flow to the air injector for entrainment

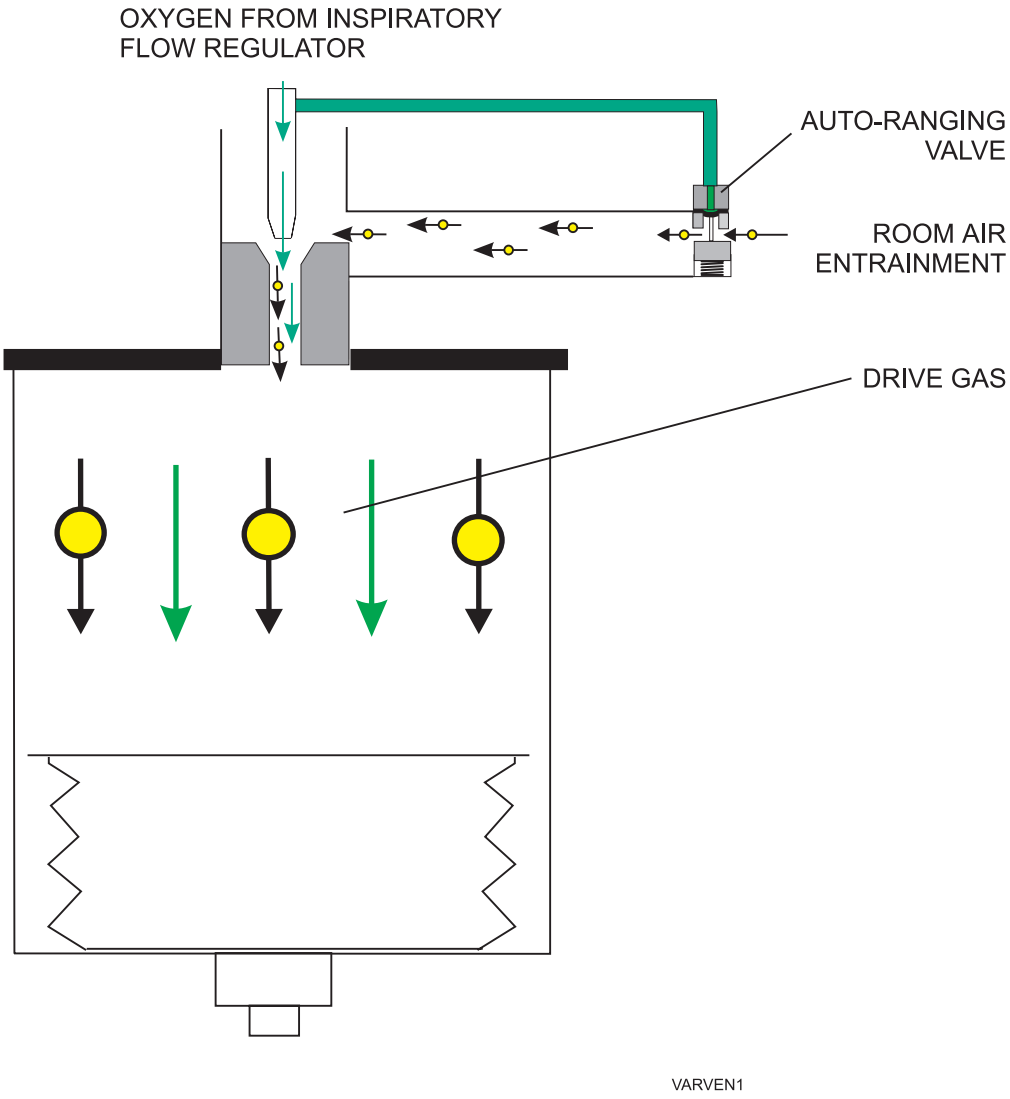


Figure 7-5: Development of drive gas with a variable entrainment port opening (AV2/AV2+)

When the inspiratory flow is low (Figure 7-6), the auto-ranging valve restricts the flow of ambient air to the air injector. With a low flow, the pressure on the diaphragm is decreased and the spring on the opposing side of the valve expands. As the valve moves upward, it partially blocks the valve opening. This restricts the flow of ambient air through the valve and decreases the volume of ambient air available for entrainment by the air injector. This device expands the capabilities of the AV2+ ventilator at low flow settings.

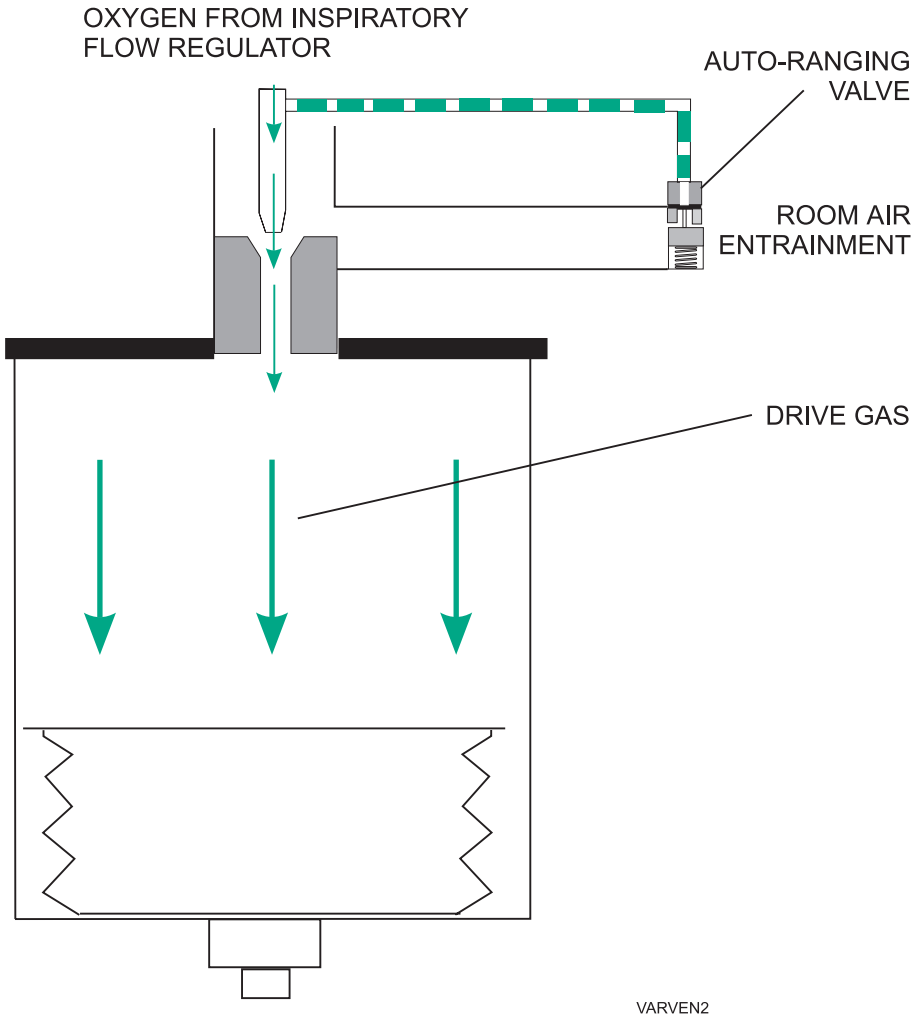


Figure 7-6: Air injector using the venturi effect to create drive gas. (AV2/AV2+)

Pressure Limit Controller

The ventilator is also equipped with an integral pressure-limit control that allows the clinician to limit the peak inspiratory pressure that the ventilator delivers to the patient breathing circuit.

The inspiratory pressure limit threshold is set by a control knob on the front of the ventilator. When the operator rotates the knob to the desired position, spring tension is applied to a diaphragm, which sets the pressure limit.

Rotating the knob on the front of the ventilator marked "Inspiratory Pressure Limit" to the preferred setting, regulates spring pressure accordingly. The spring seats against a diaphragm that is connected by a shaft to a valve. The diaphragm and valve assembly are in a chamber that is open to the drive gas as it fills the canister. When the drive gas pressure that acts on the diaphragm is less than the preset limit, the spring pressure keeps the valve closed and the pressure limit control remains inactive. In this inactive condition, the pressure limit control has no effect on the drive gas as it compresses the bellows.

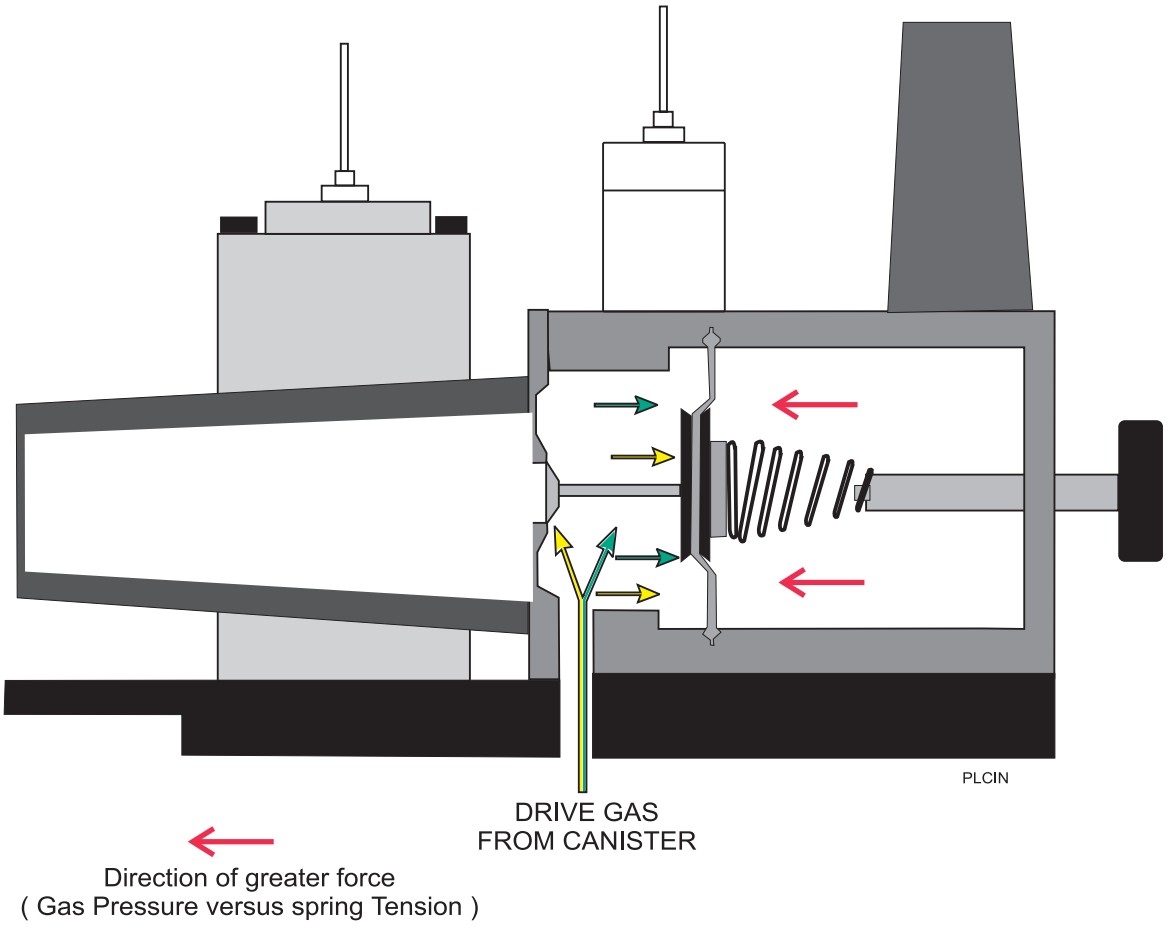


Figure 7-7: AV2/AV2+ pressure limit control (inactive)

When the drive gas pressure that acts on the diaphragm is greater than the preset limit, the valve opens, allowing some of the drive gas to escape. This limits the pressure exerted on the bellows.

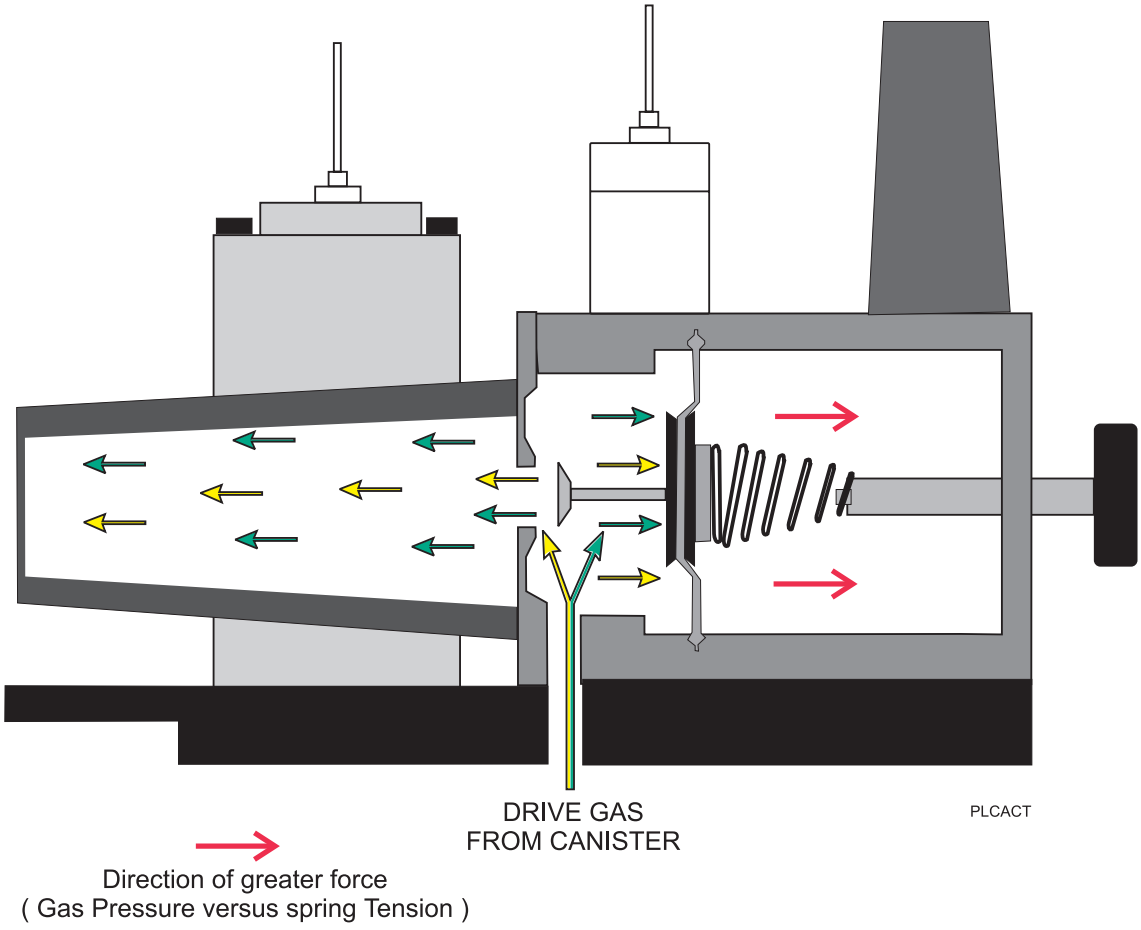


Figure 7-8: AV2/AV2+ pressure limit control (active)

The AV2+ Ventilator

The AV2+ ventilator is a time-cycled, pressure-limited, volume-preset ventilator with independent controls for tidal volume, pressure limiting, I:E ratios and inspiratory flow. The AV2+ has two controls that are utilized to activate the ventilator. The Manual/Auto selector switch has to be shifted to Auto and the Ventilator knob has to be turned to the on position.

The AV2+ provides clinicians with the advantage of only having to shift the Manual/Auto selector valve to Auto to activate the AV2+ ventilator. Shifting the Manual/Auto selector switch to Manual will turn off the ventilator. The ventilator control knob can also be used to turn the ventilator on and off (with the selector in the Auto position). Either way, a green LED, next to the ventilator on label, is illuminated when the ventilator is turned on.

A second feature of the ventilator provides clinicians with the capability of using Inverse I:E ratios for performing extended inspiratory time ventilation. The inverse ratio settings include 2:1, 3:1 and 4:1. This type of ventilation is referred to as Inverse Ratio Ventilation or IRV.

A safety mechanism is built into the AV2+ to prevent unintentional use of inverse ratio modes. A button, located on the bottom left-hand side of the I:E ratio knob, must be pressed when the I:E ratio knob is turned to the inverse ratio settings.

Classification of the AV2/AV2+ Ventilators

Controller

I.M.V. Capable

Double-Circuit

Pneumatically Powered

Electronically Controlled

Time-Cycled

Volume-Preset

Pressure-Variable

Pressure-Limited

AV2PCLF

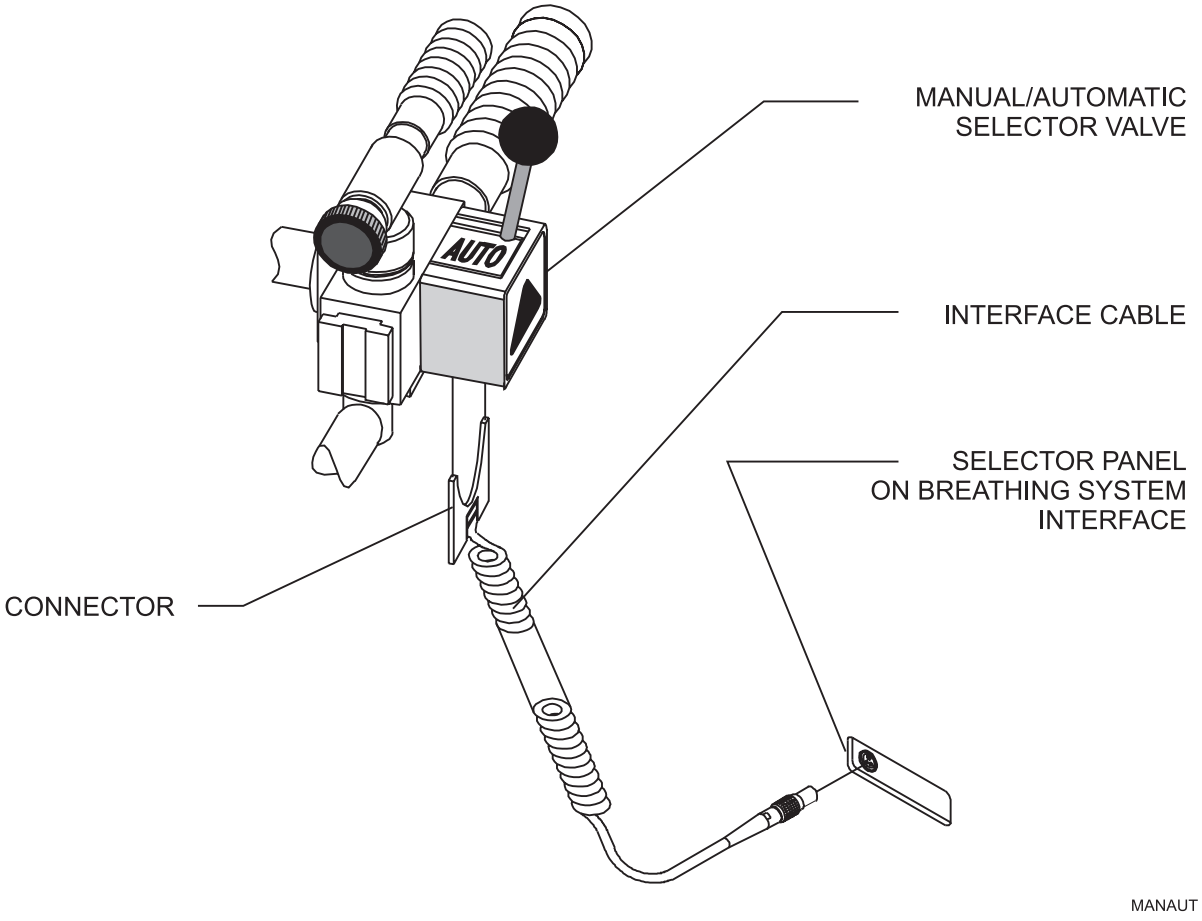


Figure 7-9: AV2+ Manual/Automatic Selector Valve Connection

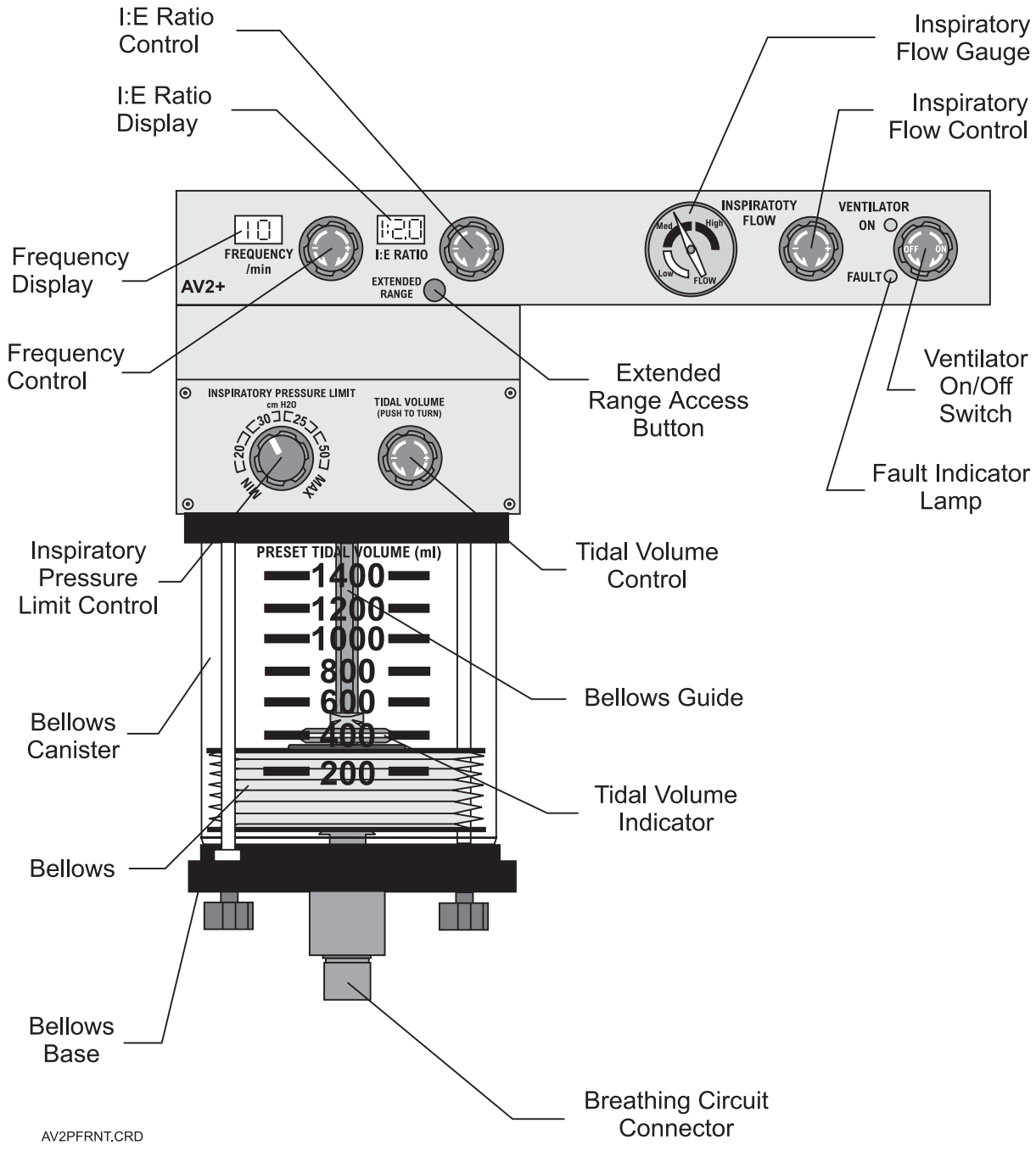
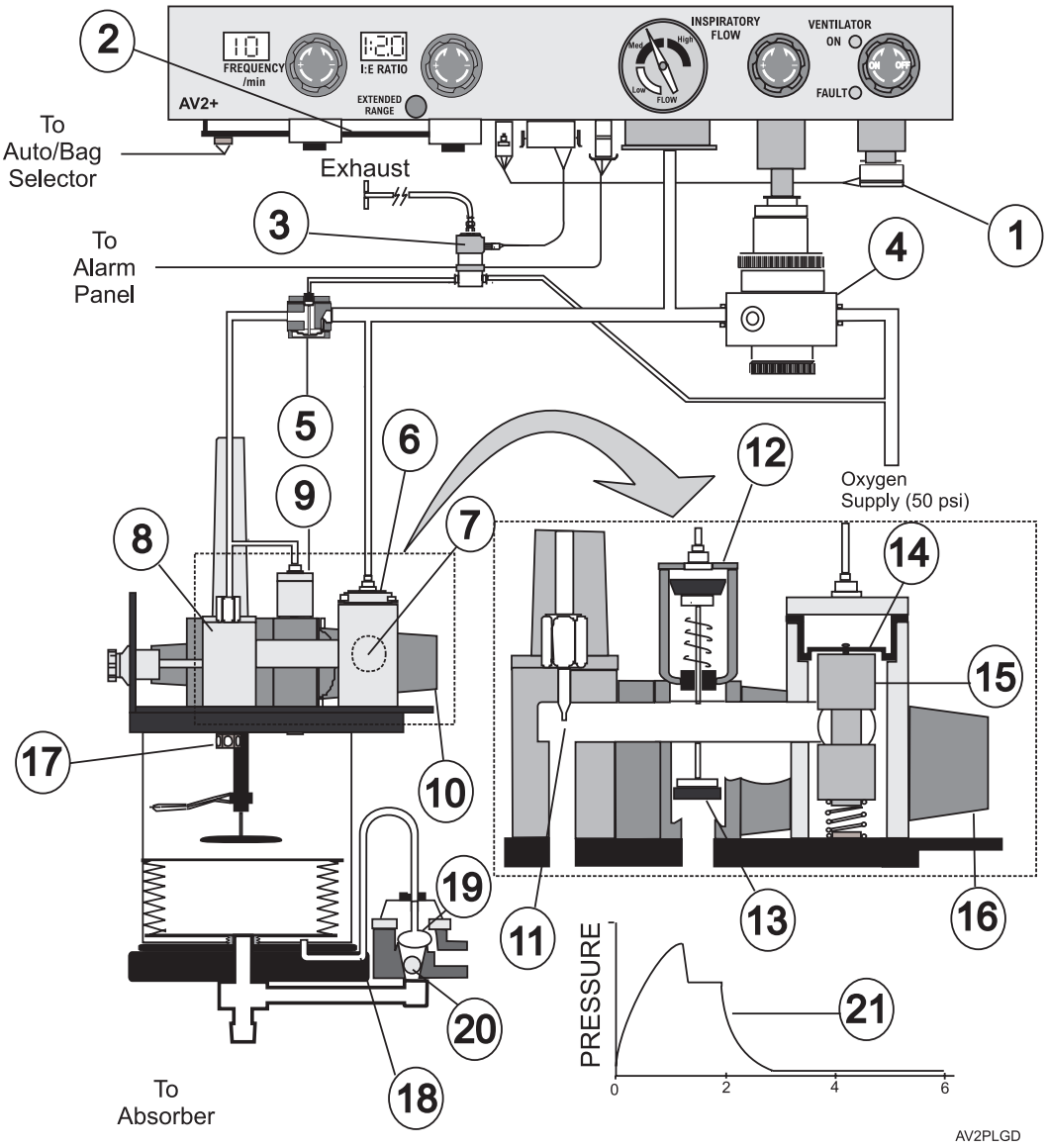


Figure 7-10: The AV2+ Ventilator



LEGEND

1. ON/OFF Switch
2. Vent Controller PCB
3. Solenoid
4. Inspiratory Flow Regulator
5. Control Valve
6. Auto Ranging Valve (ARV)
7. ARV intake (not shown)
8. Venturi Housing
9. Pilot Actuator
10. Exhaust Port
11. Venturi
12. Pilot Actuator
13. Exhaust Valve
14. Diaphram
15. Plunger
16. Exhaust Port
17. Diffuser
18. Pilot Line
19. Balloon Diaphram
20. Ball
21. Breathing Pressure Waveform

Figure 7-11: AV2+ Ventilator Legend

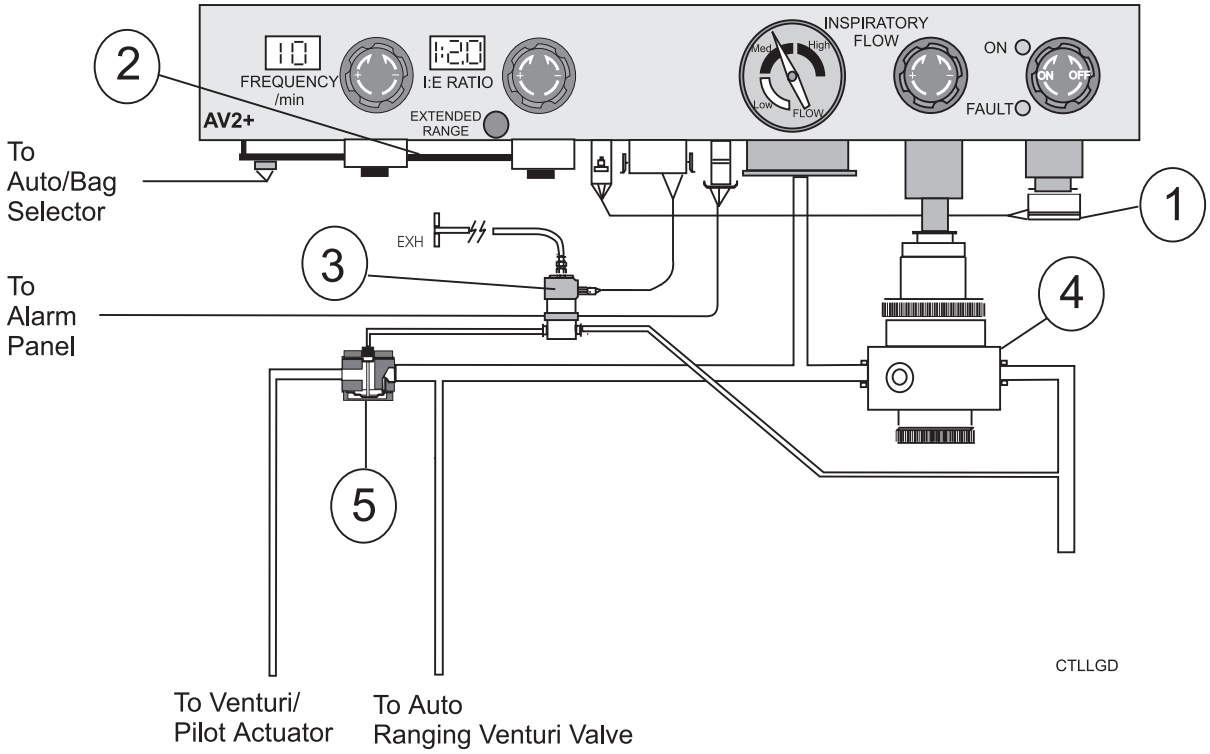


Figure 7-12: AV2+ Controller Assembly Legend

1. **ON/OFF Switch** - Momentary switch.

2. **Vent Controller PCB** - Controls frequency, I:E Ratio, power and signal to alarm channel.

3. **Solenoid** - Link between pneumatics and electronics; when energized, allows gas flow.

4. **Inspiratory Flow Regulator** - Pressure reducing regulator; reduces 50 psi gas source to a value represented as Low, Med, or High on the inspiratory flow gauge.

5. **Control Valve**- Diaphragm poppet valve, often referred to as a Humphrey valve, after its manufacturer. A normally closed valve that allows gas flow when pressure is applied to the top of the valve.

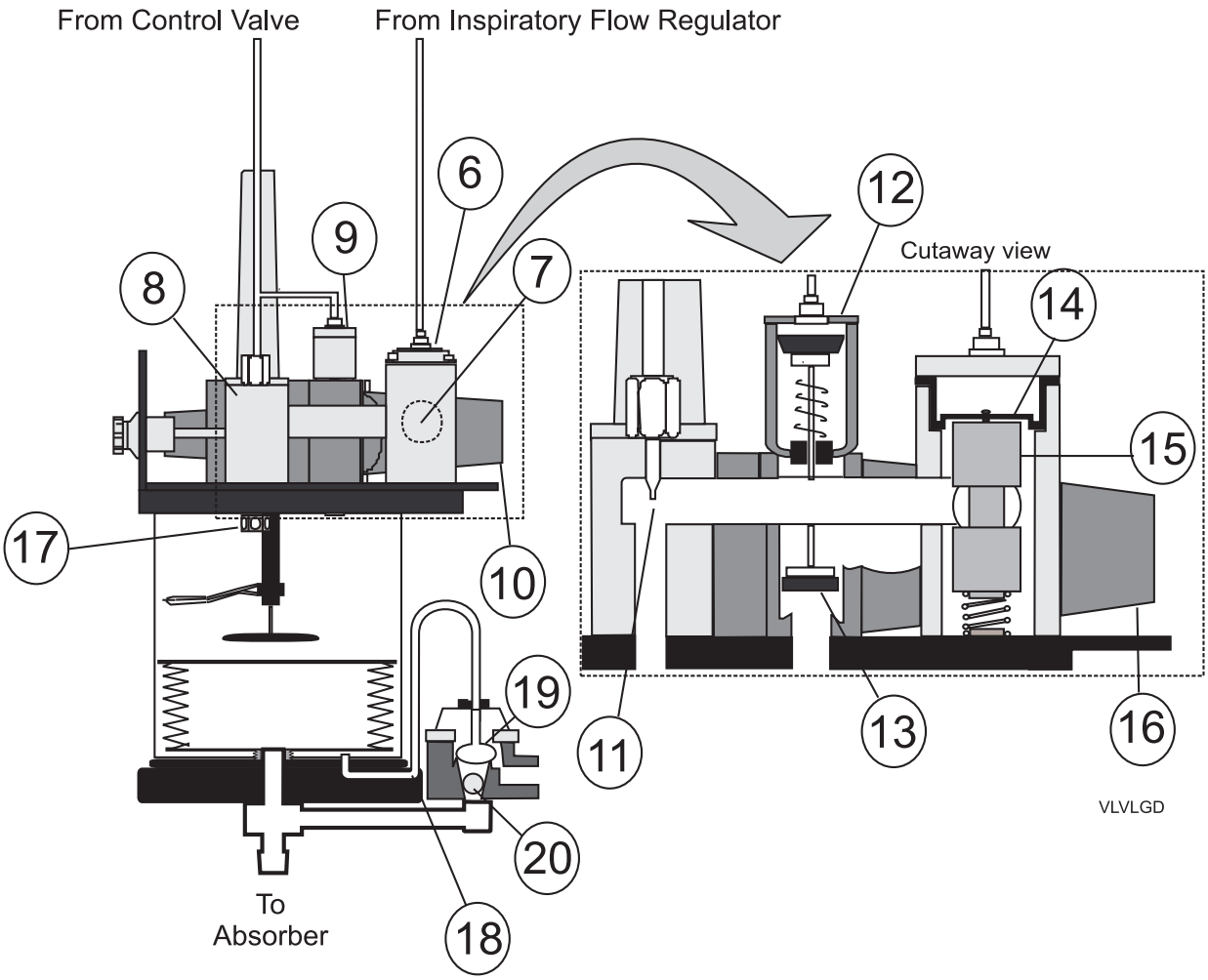


Figure 7-13: AV2+ Bellows valve assembly legend

Legend - Bellows Valve Assembly

6. **Auto-ranging valve (ARV)** - Variable opening to ambient air in response to inspiratory flow setting.

7. **ARV intake (not shown)** - Point at which ambient air enters.

8. **Venturi housing** - See #11 for operation

9. **Pilot actuator** - See #12 for operation

10. **Exhaust port** - Port through which drive gas is exhausted from exhaust valve and PLC

11. **Venturi** - Air injector creating high gas flow/low pressure, through which entrained ambient air mixes with oxygen to create resulting drive gas.

12. **Pilot actuator** - This valve operates in response to pressure applied to the top. When sufficient pressure is applied, the valve moves down against opposing spring tension, when there is no pressure applied, the spring tension moves the valve upward.

13. **Exhaust valve** - Valve connected to the pilot actuator. When pressure is applied to the pilot actuator, it seals an open port to the bellows canister. When there is no pressure applied to the pilot actuator, the valve moves off its seat and the bellows canister is open to the exhaust port.

14. **Diaphragm** - Rolling diaphragm "rolls" open when pressure is applied.

15. **Plunger** - Plunger moves downward when pressure is applied to the diaphragm. This will dictate the opening through which ambient air is entrained.

16. **Exhaust port** - Port through which gas will be exhausted from exhaust valve, PLC, and safety relief valve.

17. **Diffuser** - Creates an even distribution of drive gas in the bellows canister.

18. **Pilot line** - Routes drive gas pressure to the ventilator relief valve diaphragm.

19. **Balloon diaphragm** - Inflates and deflates in response to the drive gas pressure in the bellows canister. When inflated, it prevents gas flow through the ventilator relief valve and on to the scavenger.

20. **Ball** - The weight of this ball dictates that a certain gas pressure must be present to allow gas flow through the ventilator relief valve, even if the balloon diaphragm is deflated.

Inspiratory Flow Time

The inspiratory flow time of the ventilator is the phase in which the fresh gas mixture is delivered to the patient breathing circuit. This phase begins with the downward movement of the bellows and is seen as the upward curve at the beginning of the breathing pressure waveform.

During the inspiratory flow time, the controller energizes the solenoid. When the solenoid is energized, oxygen from the anesthesia system flows through the solenoid and pressurizes the supply valve, causing it to open. When the supply valve opens, the oxygen that has been regulated by the flow regulator can now flow to the bellows valve assembly. Before this oxygen reaches the bellows valve assembly, another small portion is diverted to the pilot actuator. This pressure causes the pilot actuator to move downward, sealing the exhaust valve, which prevents the drive gas from escaping to atmosphere as pressure within the bellows canister begins to rise. A small portion of the regulated oxygen also flows to the auto ranging valve and opens the valve in proportion to the setting of the inspiratory flow regulator. This allows just the right amount of room air to flow to the entrainment port of the venturi.

As the oxygen flows into the bellows valve assembly, it enters the air injector. As the oxygen flows through the air injector it is forced through a narrow aperture, causing a significant increase in the velocity of the oxygen flow. The increased velocity causes a pressure drop as the oxygen enters the entrainment port. This pressure drop allows room air to enter the gas stream at the entrainment port and increase the volume of this gas flow. The combined flow of oxygen and entrained room air constitutes the drive gas that now enters the canister through the diffuser. By combining room air with oxygen to create the drive gas, the demand for oxygen from the anesthesia system is greatly reduced.

As the drive gas enters the canister through the diffuser, it pressurizes the space between the bellows and the canister. The tidal volume, within the bellows, is determined by the height of the adjustment plate. The adjustment plate height is controlled with the tidal volume control knob on the front of the ventilator. As pressure builds within the canister, the drive gas compresses the bellows, forcing the fresh gas mixture to exit through the breathing circuit port and flow into the patient breathing circuit.

The pilot line for the ventilator relief valve connects to a small port on the bottom of the canister assembly and allows drive gas to inflate the balloon valve as the canister is pressurized. The inflated balloon valve seals the port to the scavenger forcing all the fresh gas to flow to the patient breathing circuit.

The pressure in the canister builds until the bellows is completely compressed. This ends the inspiratory flow phase.

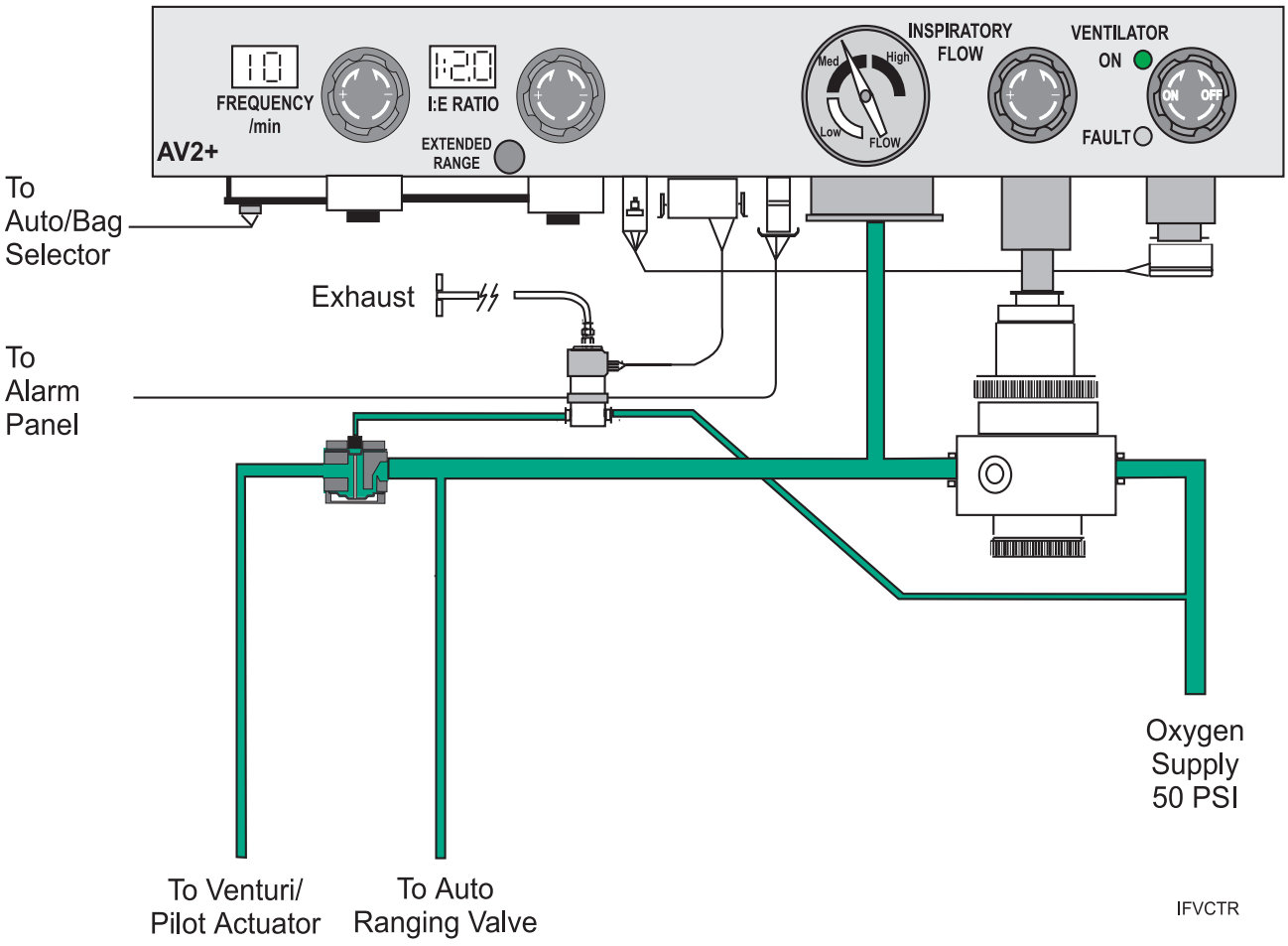


Figure 7-14: AV2+ ventilator controller assembly in the inspiratory flow phase

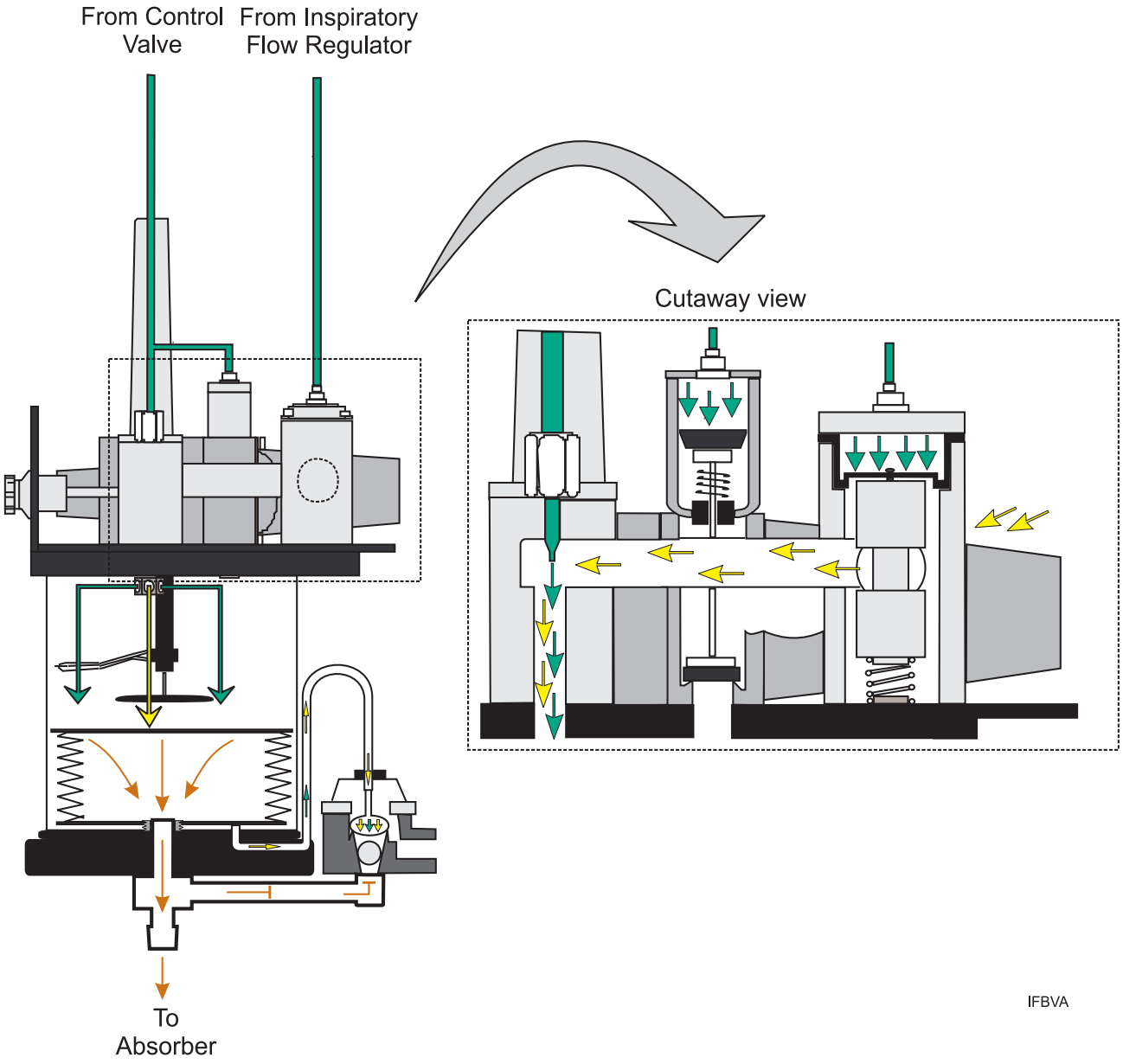


Figure 7-15: AV2+ bellows valve assembly in the inspiratory flow phase

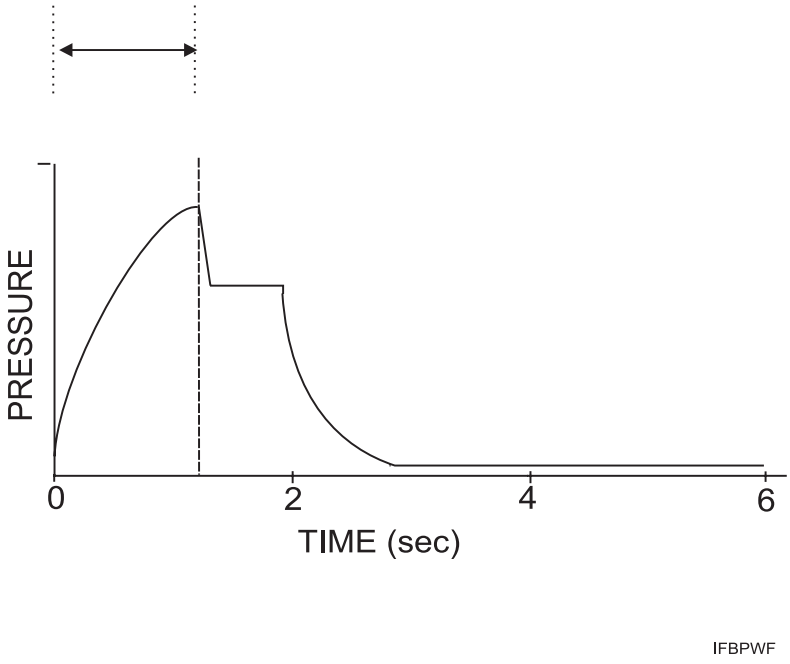


Figure 7-16: Pressure waveform during the inspiratory flow phase.

Inspiratory Pause Time

The inspiratory pause time is the phase during which the pressure generated by the drive gas is given time to equalize. This equalization occurs throughout the absorber, the patient breathing circuit, and the patient's lungs. This phase constitutes the time from when the bellows is completely compressed until the bellows begin to rise (for expiration).

During inspiratory pause, the controller continues to energize the solenoid. In turn, the continuous gas pressure on the supply valve causes it to remain open allowing oxygen to continue flowing to the bellows valve assembly. As long as oxygen flows to the bellows valve assembly, the pressure is maintained on the pilot actuator and the exhaust port remains closed. (Figures 7-17 and 7-18)

The oxygen continues to flow through the upper portion of the air injector. Because the bellows is completely compressed and the canister is pressurized, no additional drive gas can enter. Since no additional gas can flow into the canister, entrainment of room air ceases. The flow of oxygen through the upper portion of the air injector maintains the pressure in the canister. Any excess oxygen flows through the entrainment port to atmosphere.

The pressure within the canister remains constant and the pilot line and the balloon valve remain pressurized. The balloon valve remains sealed and the gas from the patient breathing circuit cannot flow to the scavenger. Inspiration, which includes inspiratory flow time and inspiratory pause time, continues until the time base for inspiration, as determined by the controller settings, is completed.

Inspiratory pause time starts when the bellows are completely compressed and ends when the bellows begins to rise at the start of exhalation. This phase is visually represented by a short downswing of the breathing pressure waveform, followed by a level plateau. (Figure 7-19)

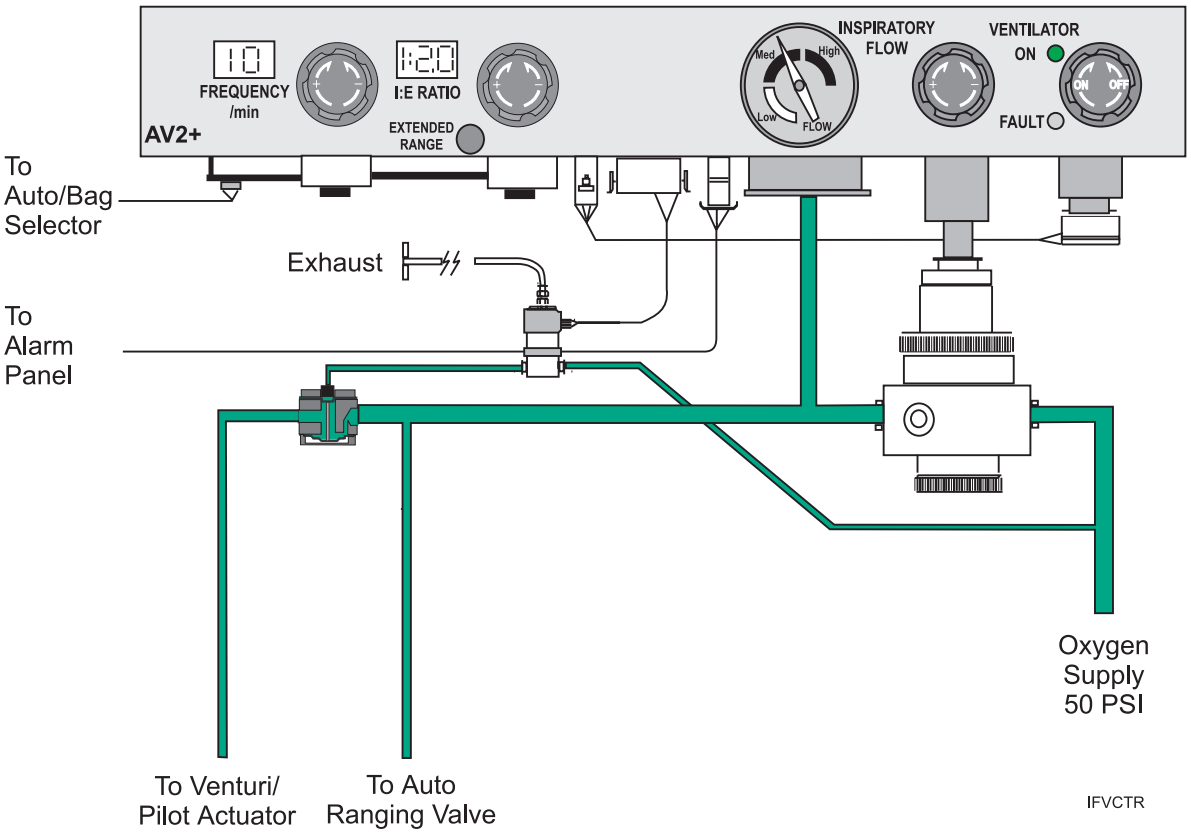


Figure 7-17: AV2+ ventilator controller in the inspiratory pause phase.

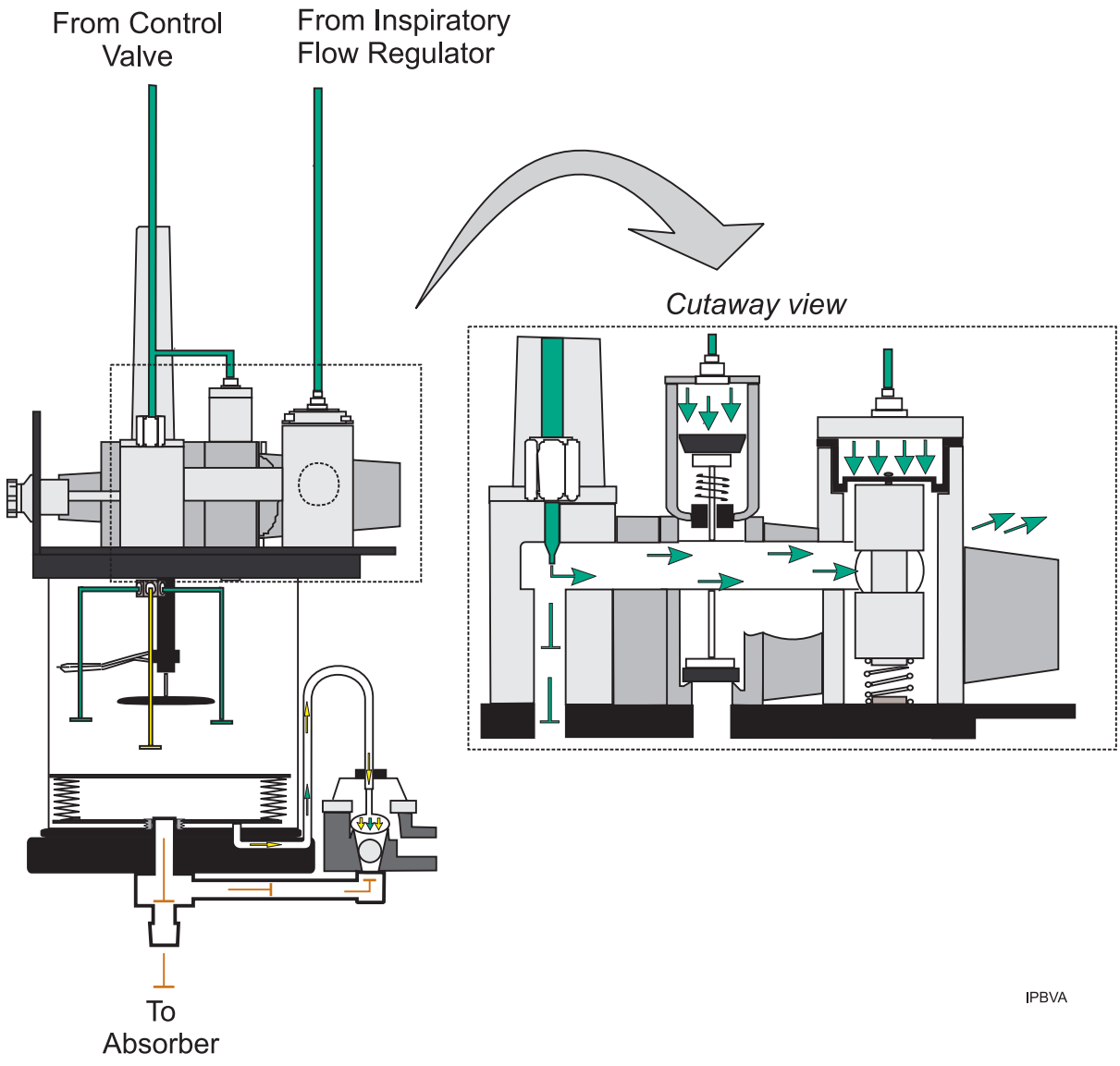


Figure 7-18: AV2+ bellows valve assembly in the inspiratory pause phase.

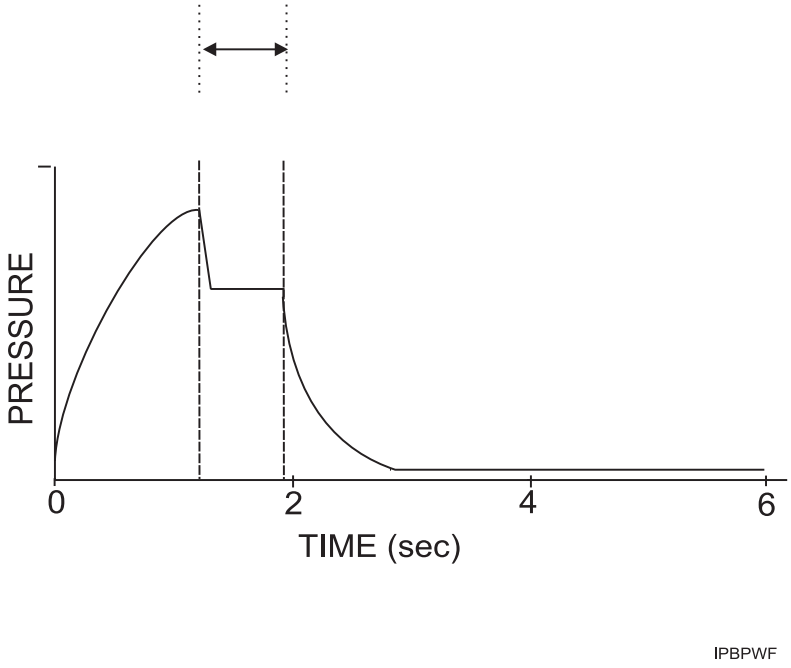


Figure 7-19: Breathing pressure waveform during the inspiratory pause phase.

Effect of Inspiratory Flow Rate on the Breathing Pressure Waveform

Adjusting the inspiratory flow control regulator will influence only the inspiratory portion of the waveform. When the inspiratory flow control is set to the low range, the bellows is compressed slowly, resulting in a longer inspiratory flow time and a shorter inspiratory pause time. If the inspiratory flow control is set in the high range, the bellows is compressed quickly and the result is a shorter inspiratory flow time and a longer inspiratory pause time.

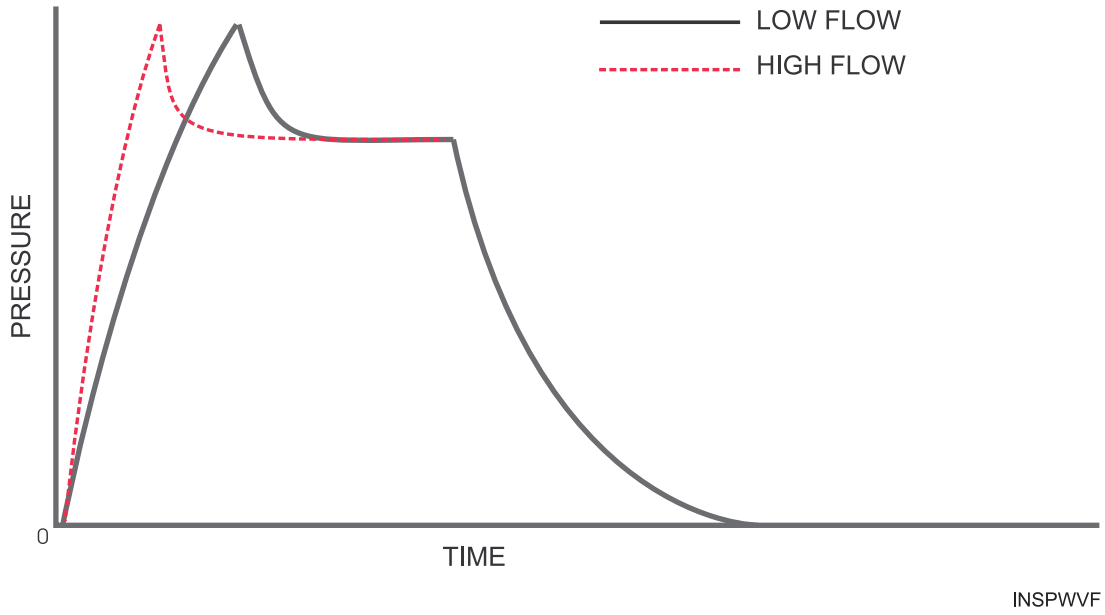


Figure 7-20: Breathing pressure waveform - high vs. low inspiratory flow

Expiratory Flow Time

The expiratory flow time is the phase when the patient exhales the fresh gas mixture back into the anesthesia system. (Figures 7-21 and 7-22)

During expiratory flow time, the controller de-energizes the solenoid, which in turn stops the flow of oxygen through the solenoid. The oxygen pressure in the tubing between the solenoid and the supply valve can now vent to atmosphere via a small tube going from the top of the solenoid to the muffler section of the anesthesia system. Once this oxygen is vented, the supply valve closes and stops the flow of oxygen to the air injector. This also allows the pilot actuator to depressurize. With the pilot actuator depressurized the spring below it forces the exhaust valve upward, opening the exhaust port.

As the patient exhales, the pressure in the bellows exceeds the pressure in the canister, and the bellows starts to rise. The drive gas vents to atmosphere, primarily through the exhaust port, but a smaller portion of the drive gas also escapes through the entrainment port and the auto-ranging valve.

As the pressure within the canister decreases, the pressure within the pilot line for the ventilator relief valve also decreases and the balloon valve deflates. The ball check valve below the balloon valve creates a greater resistance to the flow of exhaled gas than does the bellows, so the exhaled gases will continue to fill the bellows instead of escaping through the ventilator relief valve.

Expiratory flow time starts when the bellows begins to rise and ends when the bellows inflates to the point where it reaches the adjustment plate and stops.

Expiratory flow time is visually represented by the sharp downswing of the breathing pressure waveform to the baseline. (Figure 7-23)

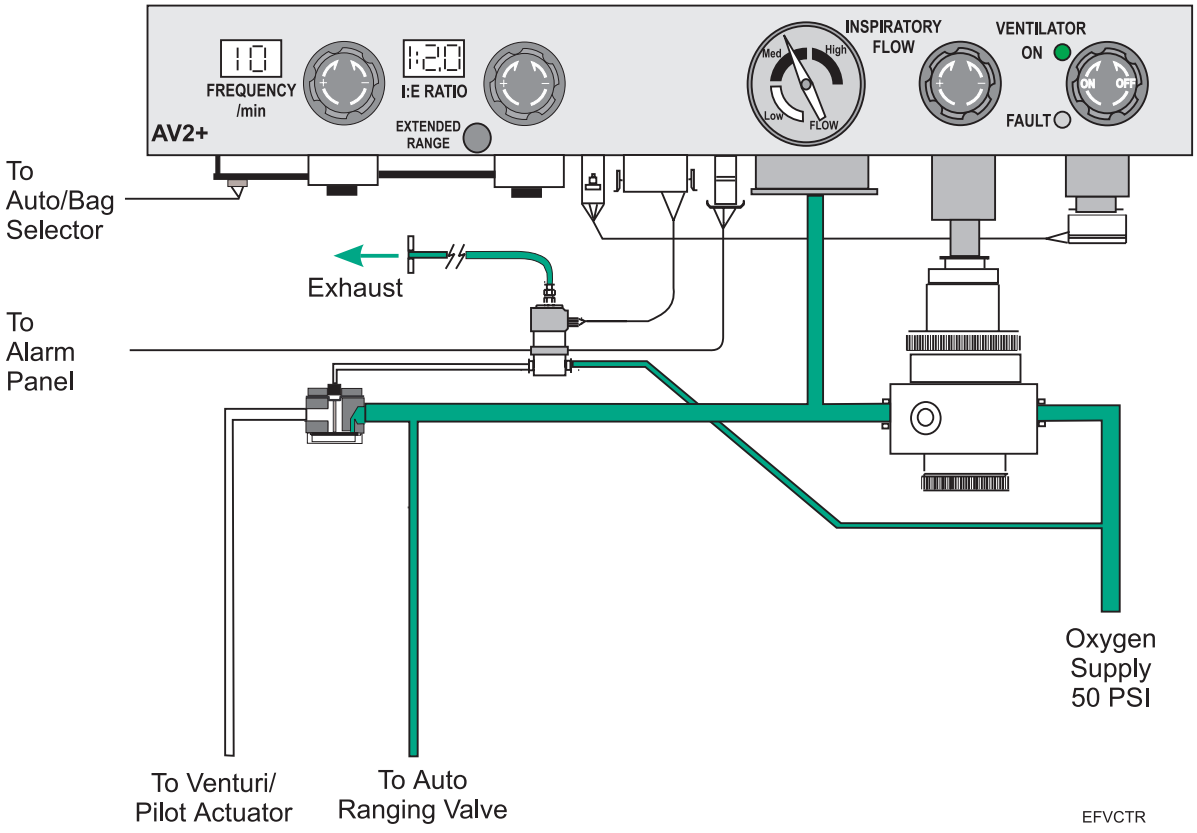


Figure 7-21: AV2+ ventilator controller assembly in the expiratory flow phase.

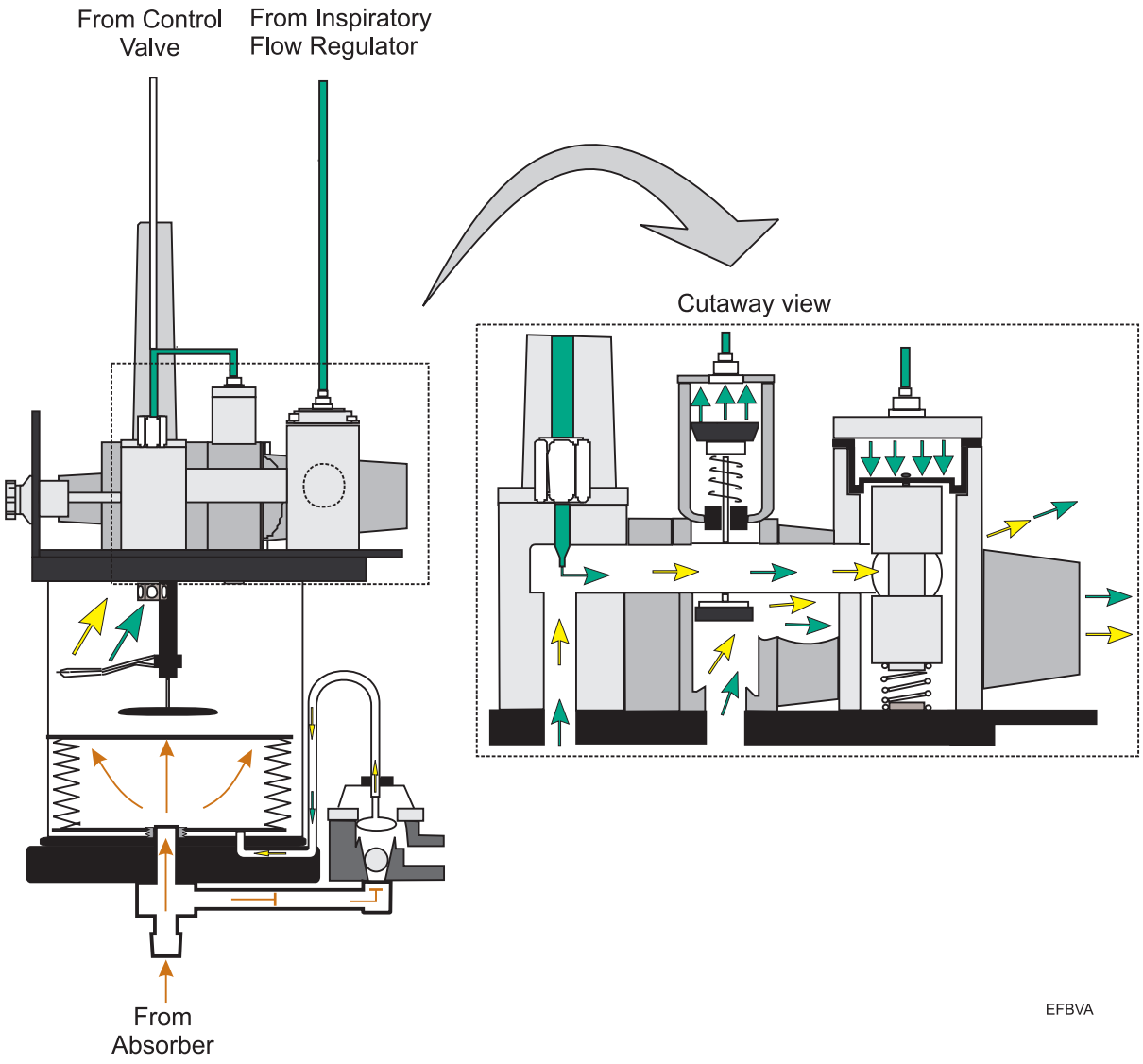


Figure 7-22: AV2+ bellows valve assembly in the expiratory flow phase.

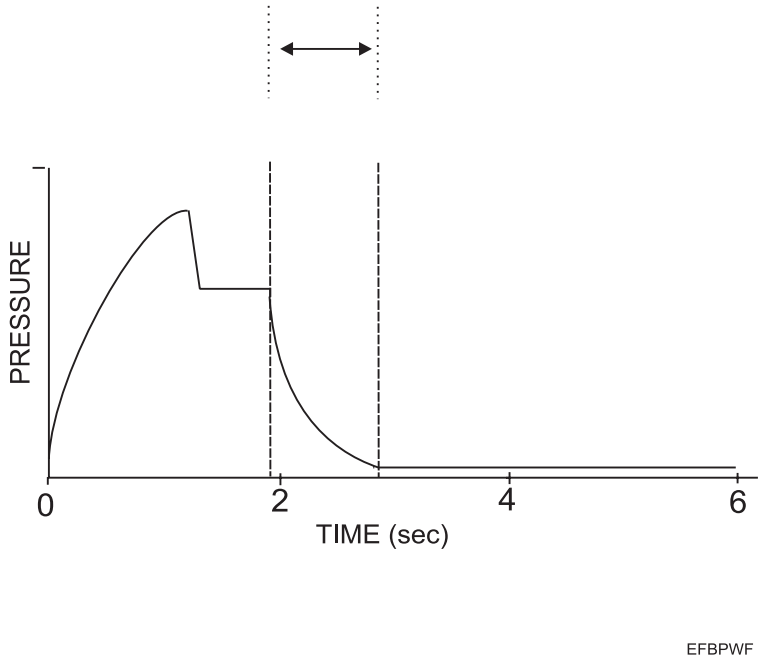


Figure 7-23: Breathing pressure waveform in the expiratory flow phase.

Expiratory Pause Time

The expiratory pause time is the phase in which the bellows remains completely filled and excess exhaled fresh gas from the patient breathing circuit is released to the scavenging system by the ventilator relief valve. Because there is a constant flow of fresh gas into the patient breathing circuit from the anesthesia system, some fresh gas will flow through the ventilator relief valve along with the last portion of the exhaled gas to the scavenger system. (Figures 7-24 and 7-25)

During the expiratory pause phase, the signal from the controller remains the same, the solenoid remains closed, and the supply valve remains closed. Accordingly, the pilot actuator and the exhaust valve remain open.

The pressure within the canister and the pilot line for the ventilator relief valve decreases to atmospheric level. The balloon valve remains deflated and because the bellows has risen as far as possible (against the adjustment plate), it resists the influx of the remaining exhaled fresh gas flowing from the patient breathing circuit. When this flow exceeds the resistance created by the weight of the ball in the ventilator relief valve, the ball is lifted and the excess gas flows to the scavenging system. The weight of the ball along with the positioning of the balloon valve creates a slight positive end-expiratory pressure of approximately 2 cmH_2O on the patient breathing circuit. The position of the balloon valve is adjustable. Adjustment toward the seat of the ventilator relief valve will create a higher positive end expiratory pressure. Adjustment away from the seat will create less positive end expiratory pressure. Expiration, which includes expiratory flow time and expiratory pause time, continues until the time base for expiration, as determined by the controller settings, is exhausted.

Expiratory pause time starts when the bellows reaches the adjustment plate and ends when the bellows begins to move downward at the start of the next inspiratory cycle.

Expiratory pause is visually represented by the waveform as it travels along the baseline. (Figure 7-26)

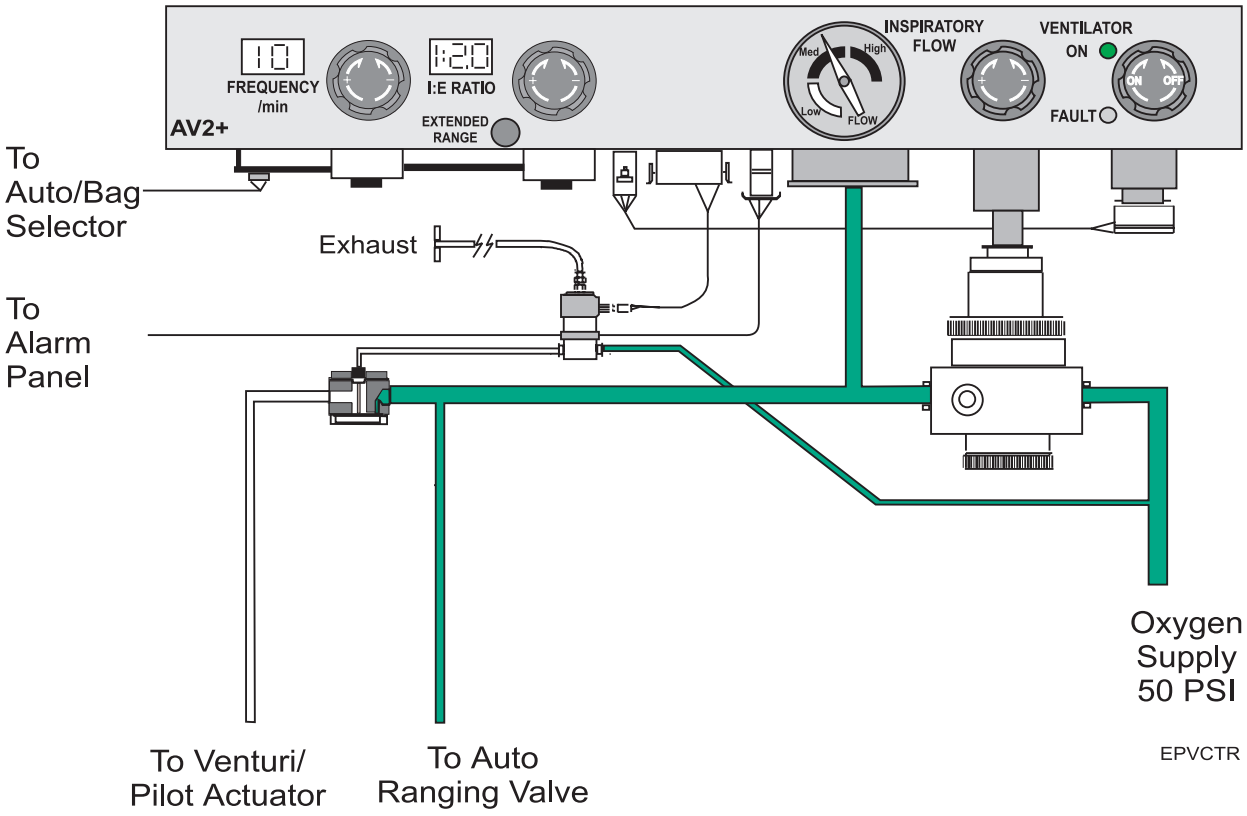


Figure 7-24: AV2+ ventilator controller assembly in the expiratory pause phase.

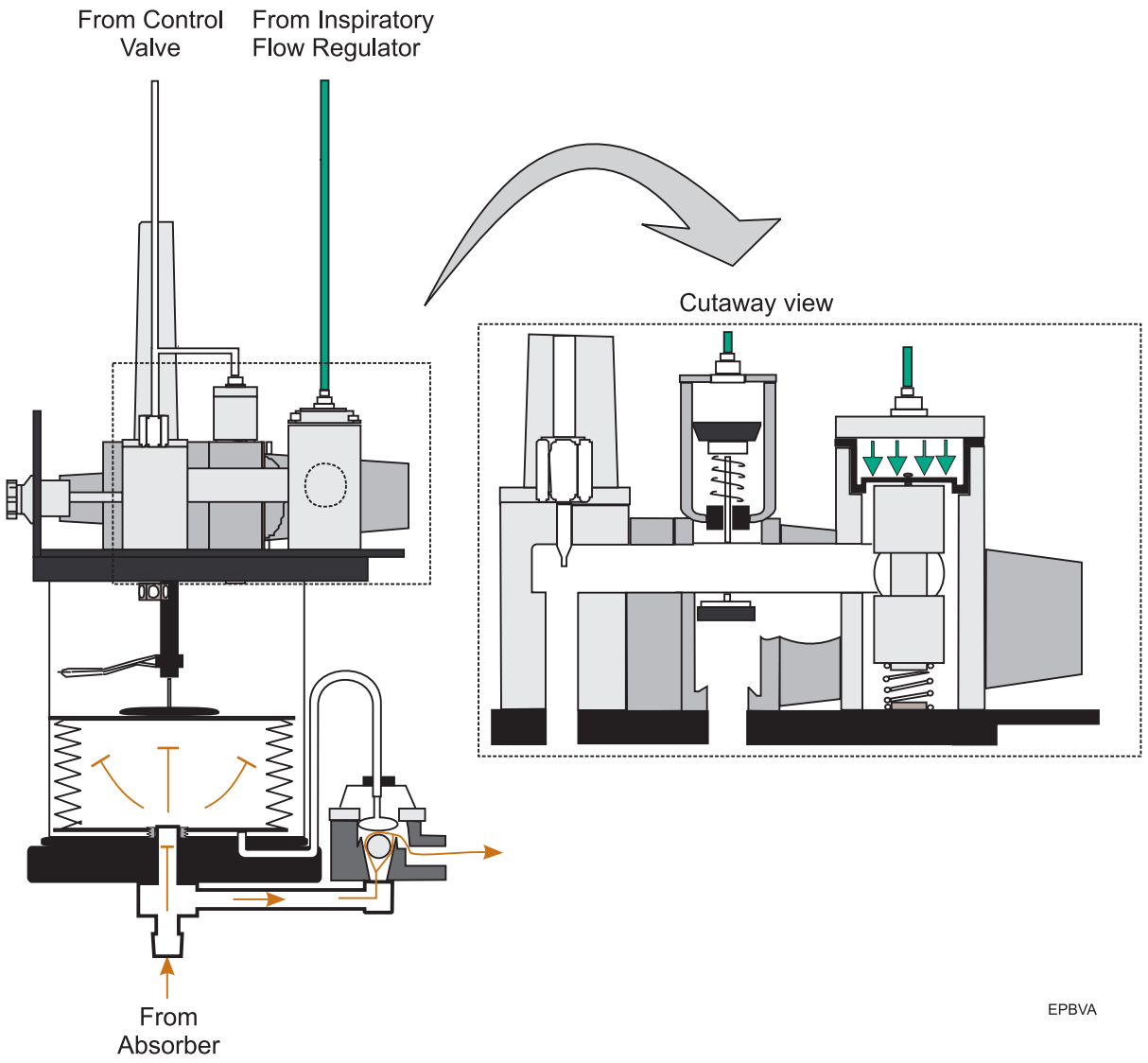


Figure 7-25: AV2+ bellows valve assembly in the expiratory pause phase.

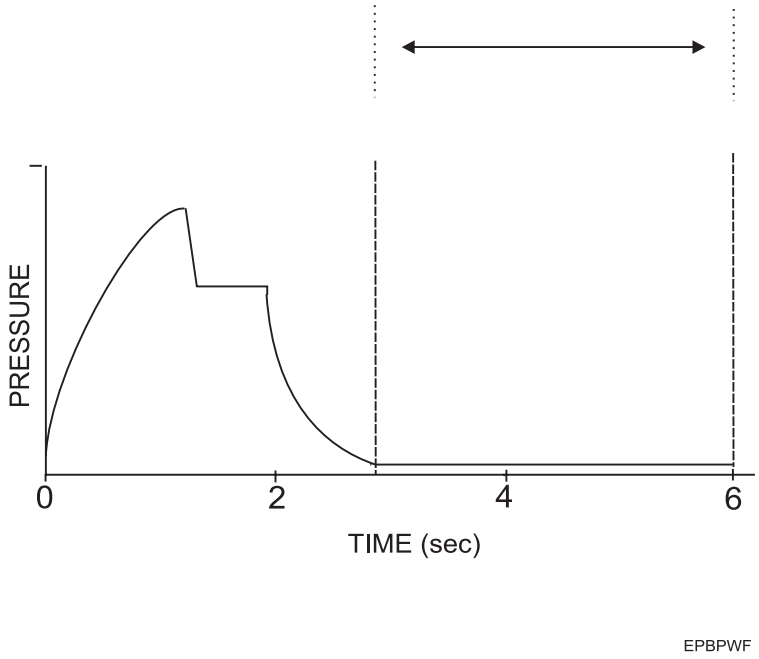


Figure 7-26: Breathing pressure waveform in the expiratory pause phase.

Safety Relief Valve

The safety relief valve is designed to relieve the drive gas pressure to atmosphere if a failure creates excessive drive gas pressure in the canister.

This valve consists of a steel ball in a cup and o-ring seat with an additional spring maintaining pressure on the ball so that it remains on the o-ring seat.

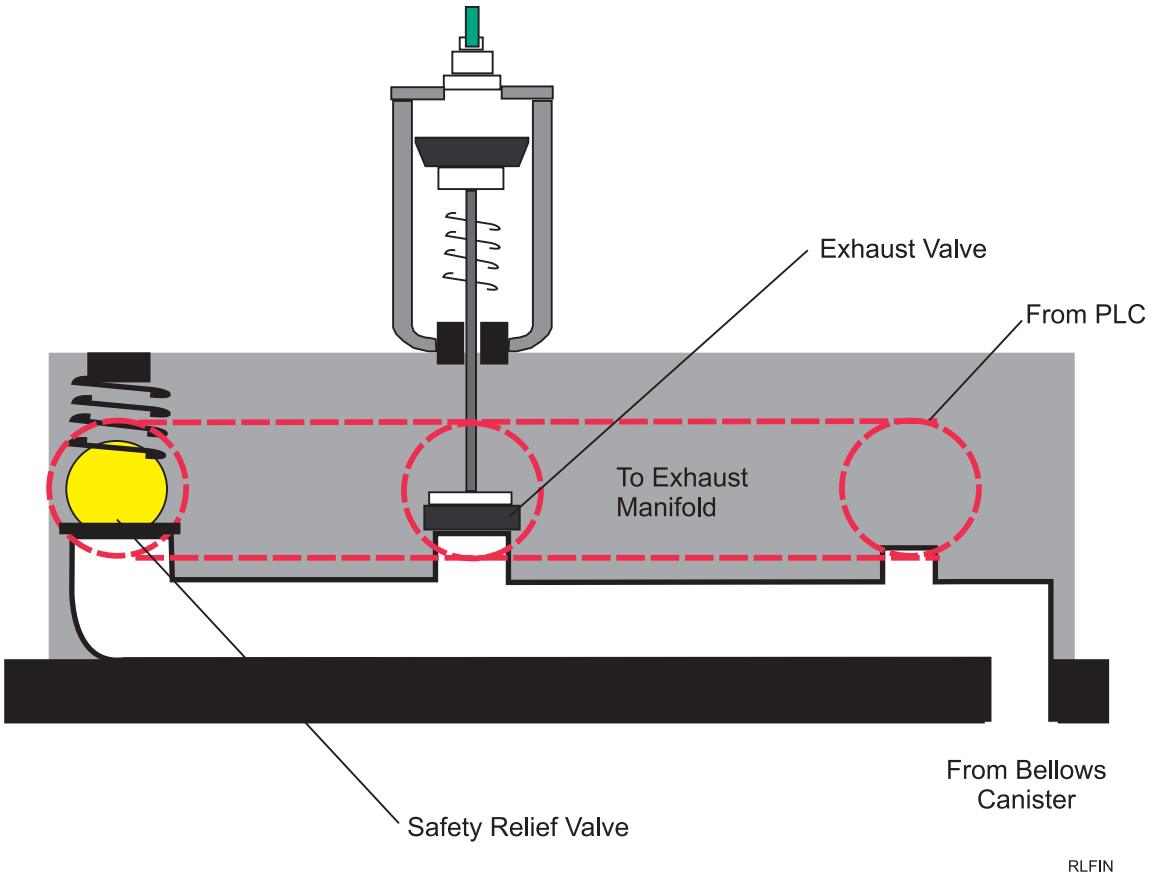


Figure 7-27: Safety relief valve in the inactive state

The safety relief valve is activated only when all other means of escape are denied to the bellows drive gas. In order for this valve to activate, three failures must occur simultaneously; the exhaust valve fails in the closed position, the pressure limiter fails in the closed position, and the auto-ranging valve fails in a closed position. In the event that these three devices all fail concurrently and the drive gas pressure in the bellows canister exceeds 120 cmH_2O, the gas pressure overcomes the weight of the ball and the spring pressure, relieving the drive gas to atmosphere.

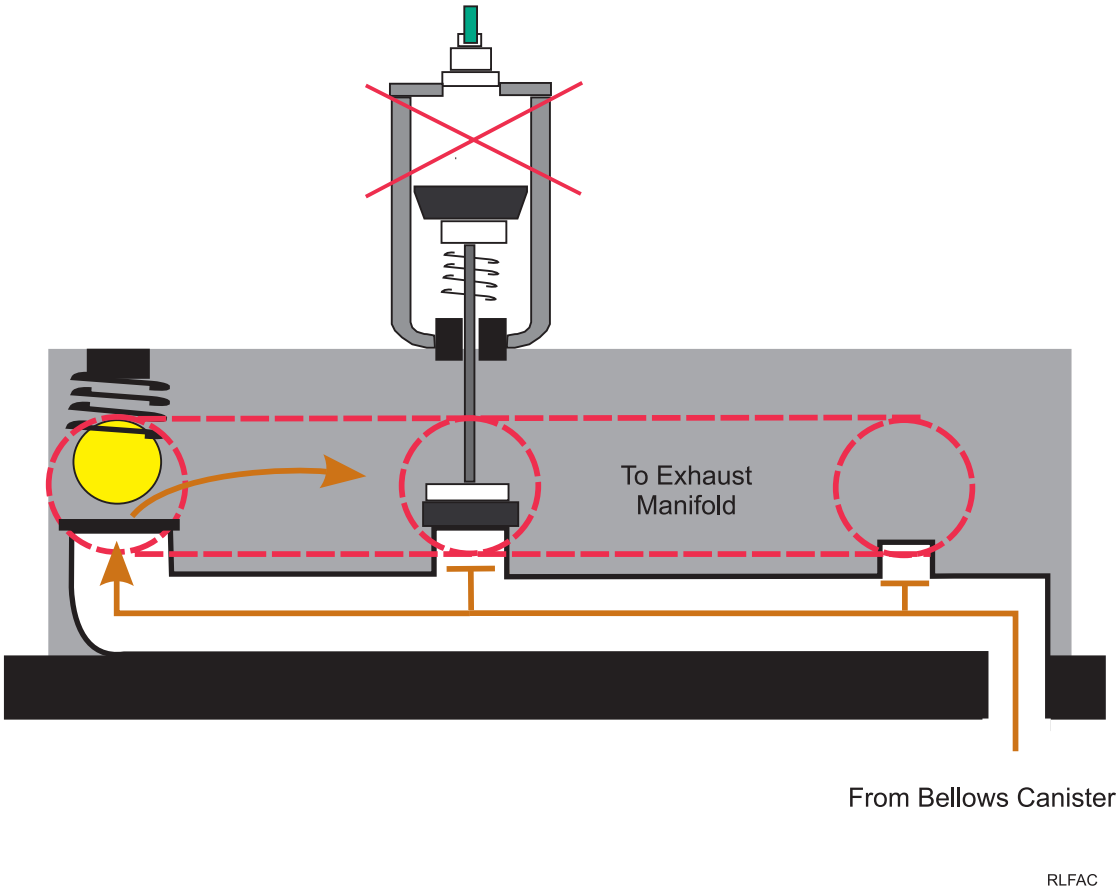


Figure 7-28: Safety relief valve in the active state

8: Monitoring Systems

North American Dräger pioneered the idea of integrating monitors into the anesthesia system and linking all monitors to a central reporting system to structure the various alarm conditions. The idea of using monitors to increase patient vigilance is not new, but the technology required to allow communication between the different technologies used in modern monitoring devices, and the ability to capture the resultant data, is evolving rapidly.

All modern Narkomed anesthesia systems incorporate one to six monitors integral to the anesthesia system. The only differences among the various models is the location of the actual monitors and the layout of the information displaed. In all models, the monitor first acquires a signal external to the anesthesia system. That signal is routed to the interface panel and then enters the electronic circuitry of the anesthesia system. A processor then analyzes the signal and, with the help of computer-based software, generates a display of the information captured by the monitor in a numeric and/or waveform format.

The Oxygen Monitoring System

It is paramount that the oxygen concentration of the inspired fresh gas mixture be constantly monitored to avoid the possibility of delivering a hypoxic gas mixture to the patient.

The oxygen monitoring system (Figure 8-1) monitors the inspired gas through the oxygen sensor located in a housing at the top of the inspiratory valve dome. In this position, the sensor is exposed to the fresh gas as it flows into the patient breathing circuit.

The oxygen sensor capsule located in the sensor housing is a dual galvanic fuel cell. The oxygen sensor capsule contains electrolytic material that reacts to oxygen and generates two electrical signals in proportion to the concentration of oxygen in the fresh gas mixture.

As the fresh gas mixture flows through the inspiratory valve to the patient breathing circuit, a small portion of the fresh gas mixture enters the sensor housing and passes through the diffusion membrane into the electrolytic material of both cells. The oxygen reacts with this electrolytic material, causing a chemical reaction that creates a small voltage differential between the anode and the cathode in each cell. This voltage is conducted to the contacts in the sensor housing, through the cabling, to the machine interface panel, and finally to the processor for analysis. Any changes in the oxygen concentration result in a corresponding change in the voltage conducted to the processor.

The processor analyzes these voltages and generates the proper numerical display. Alarm parameters and trend information can also be displayed on command. If an alarm parameter is violated, an audible and visual message is delivered to the clinician.

The electrolytic material within the oxygen sensor capsule is depleted as it reacts with oxygen. Theoretically, both of the dual cells should deplete at the same rate, but this is not the case. Toward the end of the useful life of the oxygen sensor capsule, one cell always degenerates faster than the other. When the processor detects a significant difference between the signals sent by the two cells, it prompts the operator to replace the oxygen sensor capsule.

The display for the oxygen monitoring system typically shows the oxygen concentration of the fresh gas mixture, the low oxygen alarm limit, and the high oxygen alarm limit. In addition, there is a calibration device that allows the clinician to calibrate the oxygen monitor to 21% oxygen.

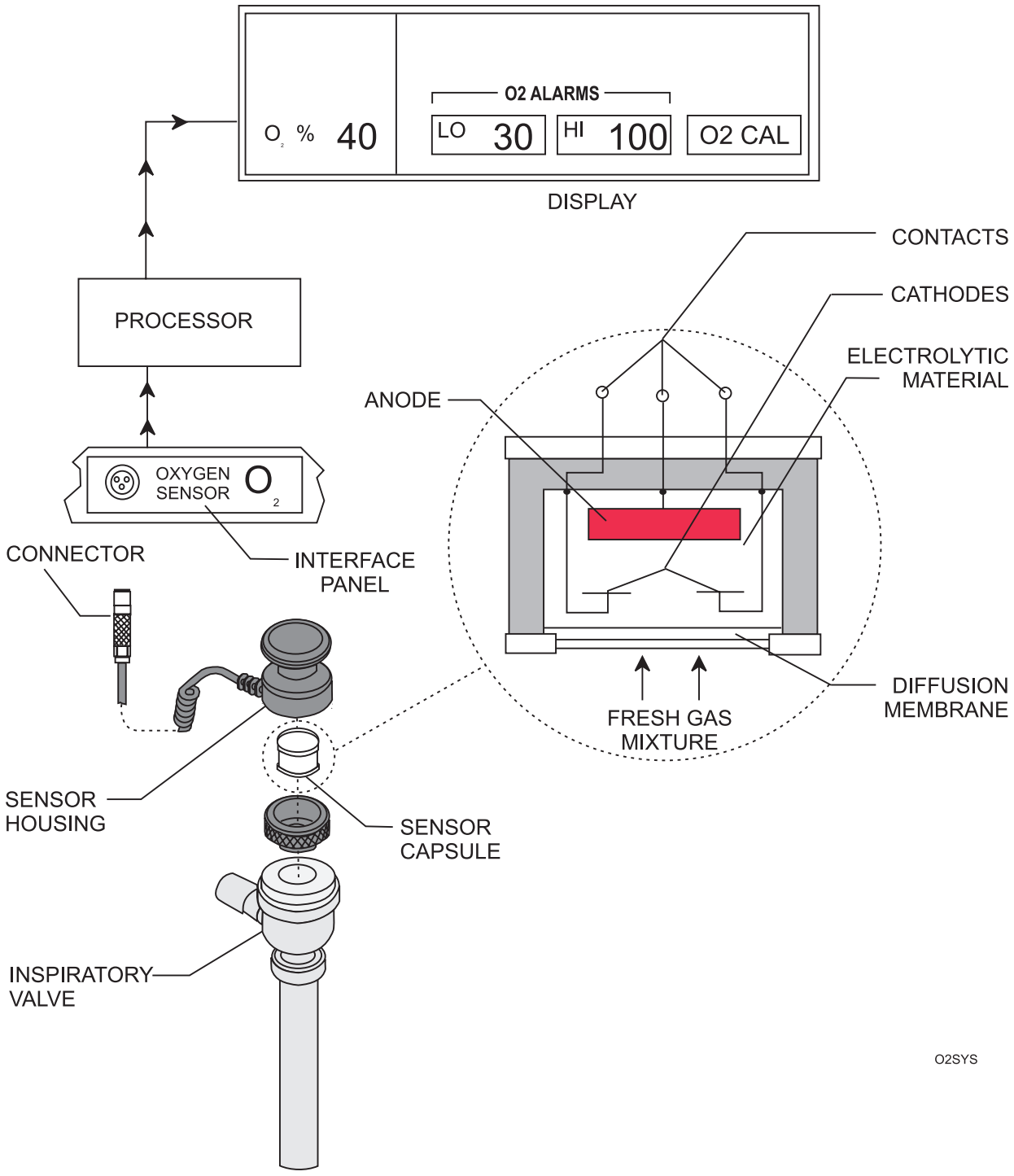


Figure 8-1: Oxygen monitoring system

Breathing Pressure Monitoring System

The breathing pressure monitoring system (Figure 8-2) provides real-time information about the patient breathing circuit airway pressures.

At any given moment, the pressure within the absorber assembly reflects the pressure within the patient breathing circuit. Pressure changes within the patient breathing circuit are immediately observable on the absorber pressure gauge and the breathing pressure monitor display.

Connected to the top of the absorber assembly is a clear plastic tube called the breathing pressure pilot line, which serves as a pneumatic link between the patient breathing circuit and the machine interface panel. Internally, a similar tube completes the pathway from the interface panel to the pressure transducer. The pressure transducer converts the pneumatic pressure into an electronic signal. This electronic signal is then routed to a processor where it is analyzed. The data derived from this analysis is then displayed on the monitor for the clinician.

Displayed information includes peak and mean breathing pressures, PEEP, and breathing pressure waveforms. All of the displayed information represents the pressure in the patient breathing circuit in real time. The breathing pressure monitoring system also has alarms to warn the clinician of subatmospheric pressure, high pressure, continuing pressure, and apnea conditions in the patient breathing circuit.

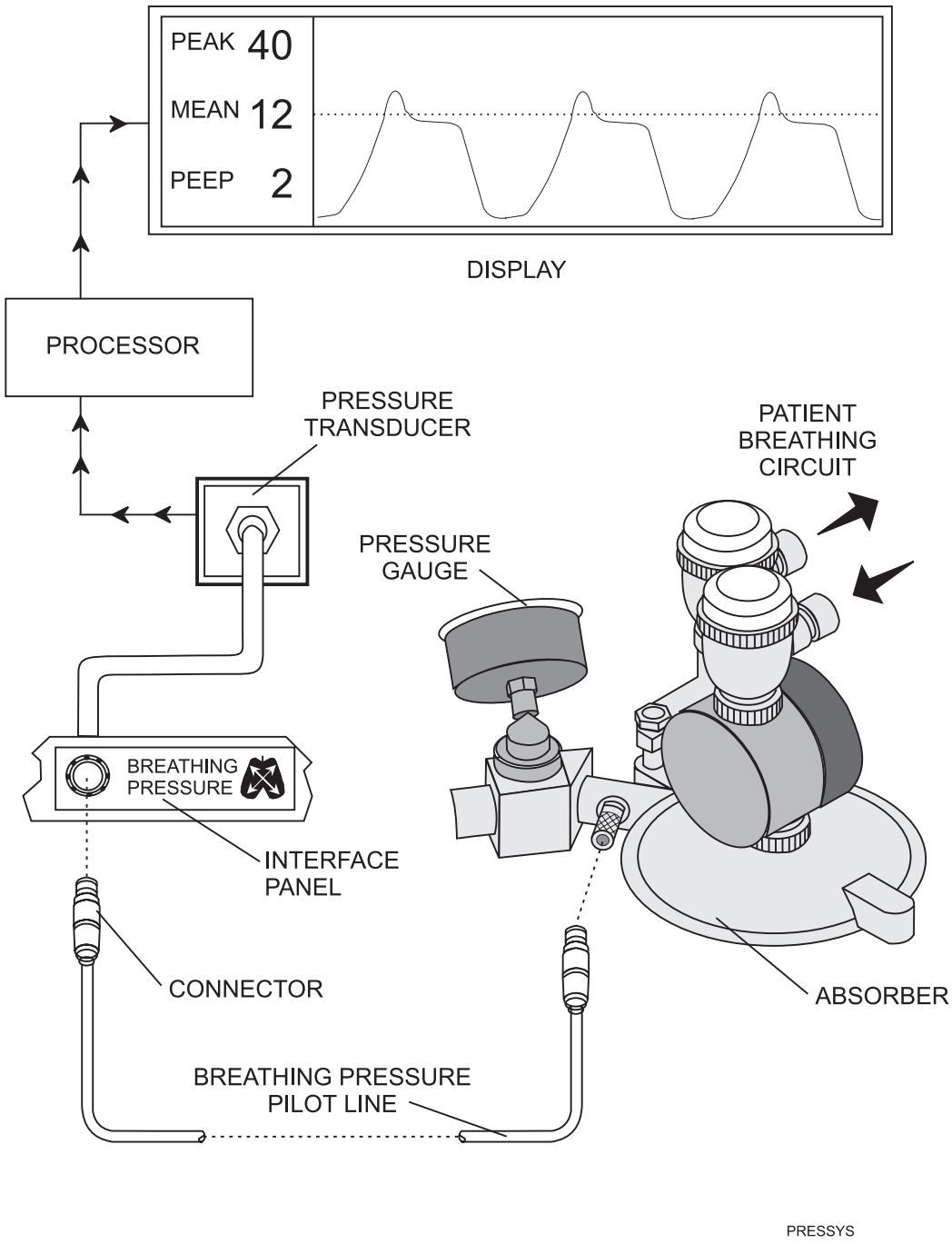


Figure 8-2: Breathing pressure monitoring system

Respiratory Volume Monitoring System

Regardless of whether a patient is being ventilated manually or automatically, there must be a means of measuring the tidal volume, the minute volume, and the rate of respiration of the patient. The respiratory volume monitoring system (Figure 8-3) accomplishes these tasks and senses gas flow direction as well. On machines equipped with the necessary means of display, the respiratory volume monitoring system also produces a visual exhalation waveform.

During each exhalation, exhaled gas from the patient flows through the patient breathing circuit, through the exhalation valve, and down into the Spiromed respiratory volume sensor. As the exhaled gas flows through the sensor, it forces a pair of peanut-shaped rotors to counter-rotate. That is, one rotor spins counterclockwise and the other rotor spins clockwise. The gas then flows out of the sensor and into the absorber assembly.

Attached to the axle of one of the rotors is a four-pronged armature, which houses a small magnet at the tip of each prong. As exhaled gas flows through the sensor, the rotor and armature spin in unison. Located at approximately 12 and 7 o'clock in relation to the rotation of the armature, are a pair of Hall effect transistors. The Hall effect transistors are semiconductors that turn on in the presence of a magnetic field and turn off in the absence of a magnetic field. As the armature carrying the magnets rotates, a magnet passes the first Hall effect transistor (A), turning it on and creating an electronic pulse. As the armature continues to rotate, the magnet opposing the first one will pass the second Hall effect transistor (B), turning it on and creating a second electrical pulse that is slightly out of phase with the first pulse. These pulse pairs are transmitted through the sensor cable to the interface panel. The pulse pairs are then routed from the interface panel to the processor for interpretation so the appropriate information can be displayed.

The number of pulse pairs is directly related to the volume of gas that passes through the sensor with each exhalation. The processor counts each pulse pair as approximately 10cc of gas flow. The total number of pulse pairs counted during each exhalation determines the displayed numeric tidal volume.

In a similar manner, the minute volume display can be calculated after the pulse pairs are generated for at least 60 continuous seconds. After data is collected for 60 seconds, the minute volume is calculated and displayed. The minute volume is then recalculated after each exhalation to produce the current minute volume.

Sixty seconds of continuous data is also required for the initial display of the respiratory rate and the displayed reading is recalculated after each exhalation. The processor counts exhalations for the respiratory rate differently than it does for respiratory volume. For an exhalation to be counted as a "valid breath", the processor must count at least 5 pulse pairs, or 50cc. If the processor counts less than 5 pulse pairs, the exhalation is deemed invalid and is not included in the calculations for the respiratory rate. Any volume of exhaled gas greater than 50cc is counted as a valid breath and the processor resets the count to zero at the end of each exhalation. All exhaled gas volumes, regardless of size, are counted and included in the calculation of the minute volume displayed.

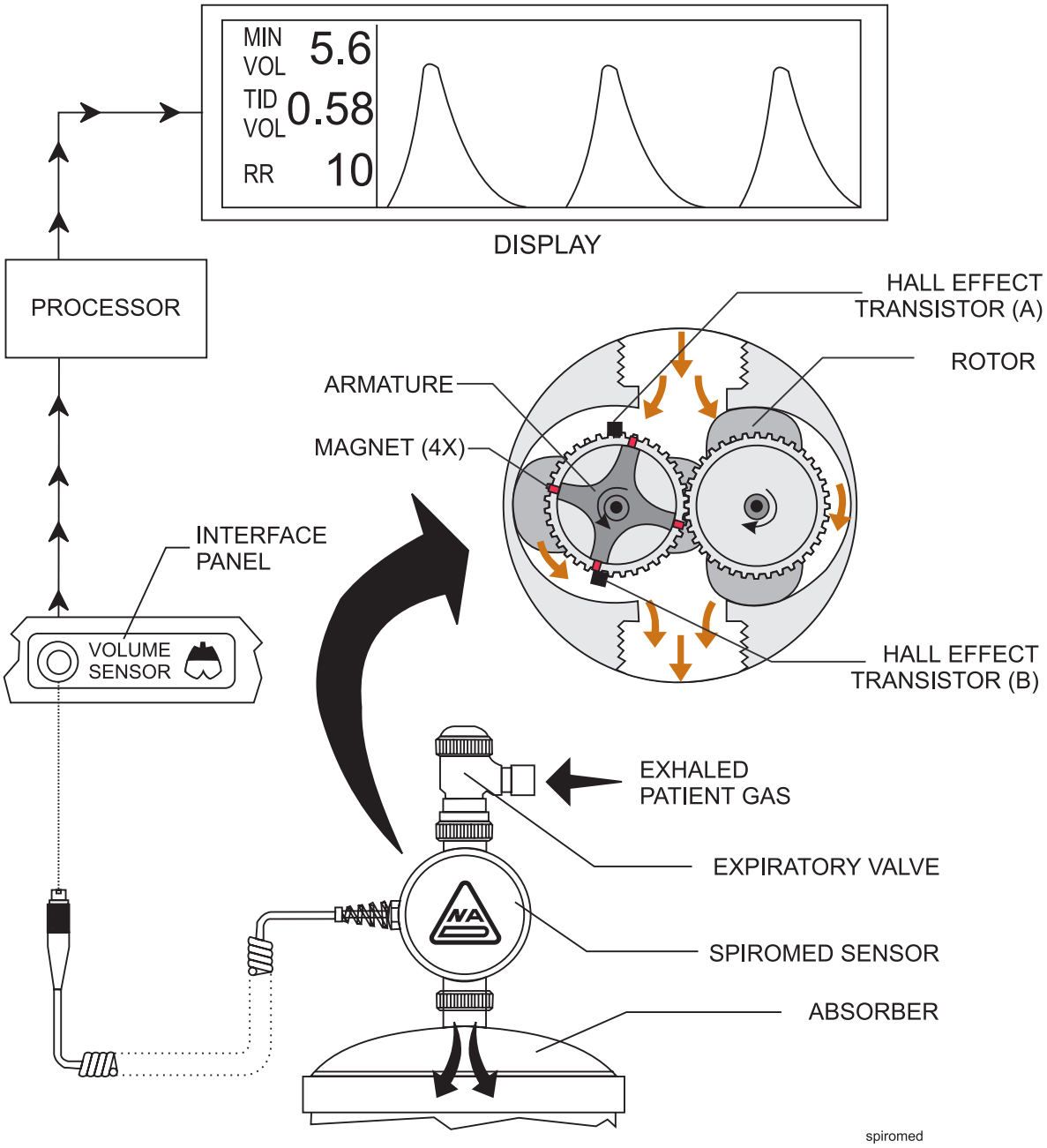


Figure 8-3: Respiratory volume monitoring system

Direction of Gas Flow

The sensor recognizes the direction of gas flow by monitoring the phase relationship between the pulses in each pulse pair. When the gas flows "forward" during exhalation, the pulse from Hall effect transistor B leads the pulse from Hall effect transistor A because of the their position in relation to the rotation of the armature (Figure 8-4). This is the normal sequence for pulse pairs.

However, if the gas flows in the wrong direction through the sensor during exhalation, the processor recognizes this as reverse flow. This can occur when a substantial leak develops in the breathing system somewhere between the inlet for the sensor and the inlet for the exhalation valve. In this instance, the rotation of the armature is reversed and the pulse generated by Hall effect transistor A leads the pulse generated by Hall effect transistor B (Figure 8-5). If two consecutive pulse pairs representing 20cc of gas flow occur in this manner, a reverse flow alarm is generated. If the condition persists, the alarm is sounded at each occurrence.

Volume Waveform

The displayed exhalation waveform reflects the changing gas velocity as each phase of exhalation occurs. The speed at which the gas flows through the sensor determines the duration of each pulse pair. At the beginning of exhalation, the rapid gas flow causes the rotors and armature to spin rapidly, producing pulse pairs of a shorter duration. As exhalation ends, the rotors slow to a stop. As the rotors and armature are slowing down, the transistors remain activated longer, because the magnetic fields pass them at a slower rate and the resulting pulse pairs are longer. The processor analyzes the pulse lengths and formulates the corresponding fluctuations in the waveform.

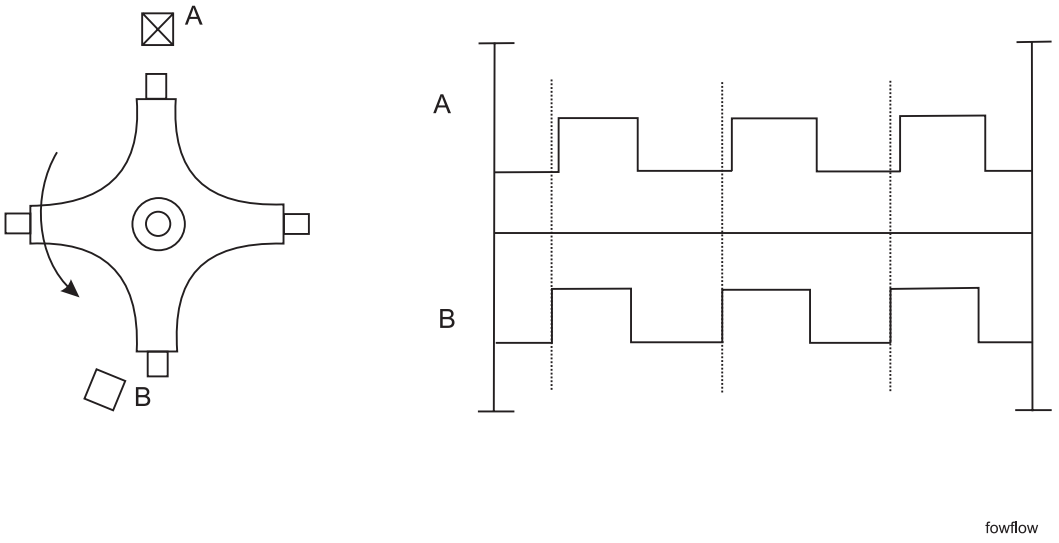


Figure 8-4: Pulse pairs generated by the sensor during forward gas flow.

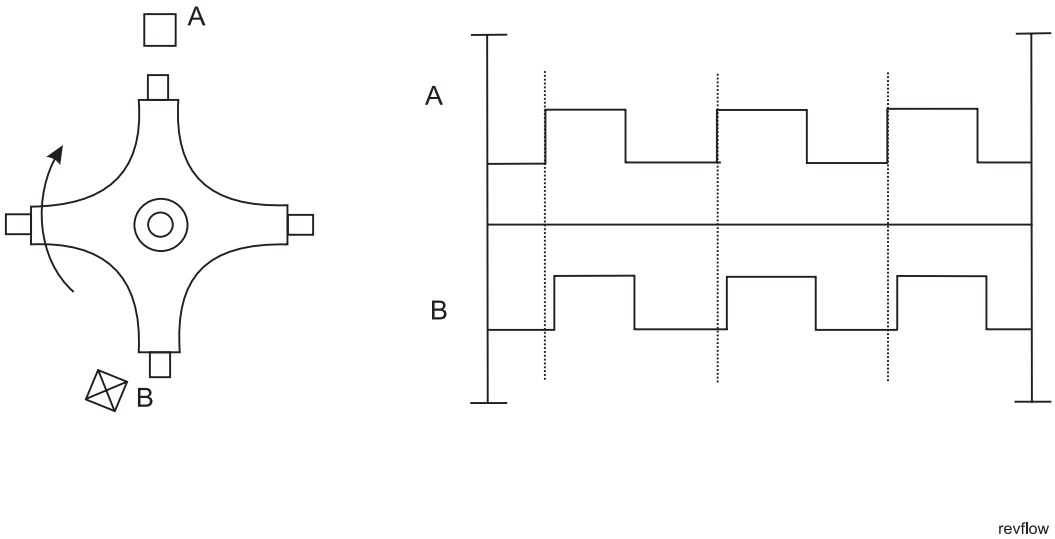


Figure 8-5: Pulse pairs generated by the sensor during reverse flow conditions.

The Gas Analysis Monitoring System

The gas analyzer system and its associated alarms are based on infrared technology. The gas analyzer system used in Narkomed anesthesia systems is the side-stream type. The gas analyzer system is capable of monitoring either the expired patient gas or a sample of fresh gas taken from the fresh gas outlet.

The gas analysis monitoring system (Figure 8-6) consists of a sample line that pulls a gas sample from the patient breathing circuit (typically connected to the y-piece) through a water trap, to the IR (infrared) bench. The IR bench analyzes the gas sample and sends a signal to the processor. The processor receives the signal, processes the information and generates the numerical/waveform information shown on the display panel(s) and, when necessary, the associated visual and audible alarms.

The heart of the gas analysis system is the IR bench. The IR bench contains an infrared light source that produces a known quantity of infrared light. Between the infrared light source and the sample cell is a filter wheel. By passing different filters between the infrared light source and the sample cell, the infrared beam can be modified to allow for the detection of more than one gas. The filter wheel has a section to allow for referencing the infrared light source, as well as sections for the detection of of CO_2, halogenated agent, and N_2O. As the gas sample from the patient flows through the sample cell, the modified infrared light beam passes through the gas. The infrared light is absorbed in varying amounts by the gas sample and the remainder is absorbed by an IR (infrared) detector. The infrared detector then sends a signal to the processor. This signal is coordinated with information concerning which segment of the filter wheel is modifying the infrared light source, and the processor generates the signals required to display the correct waveforms and numerical information.

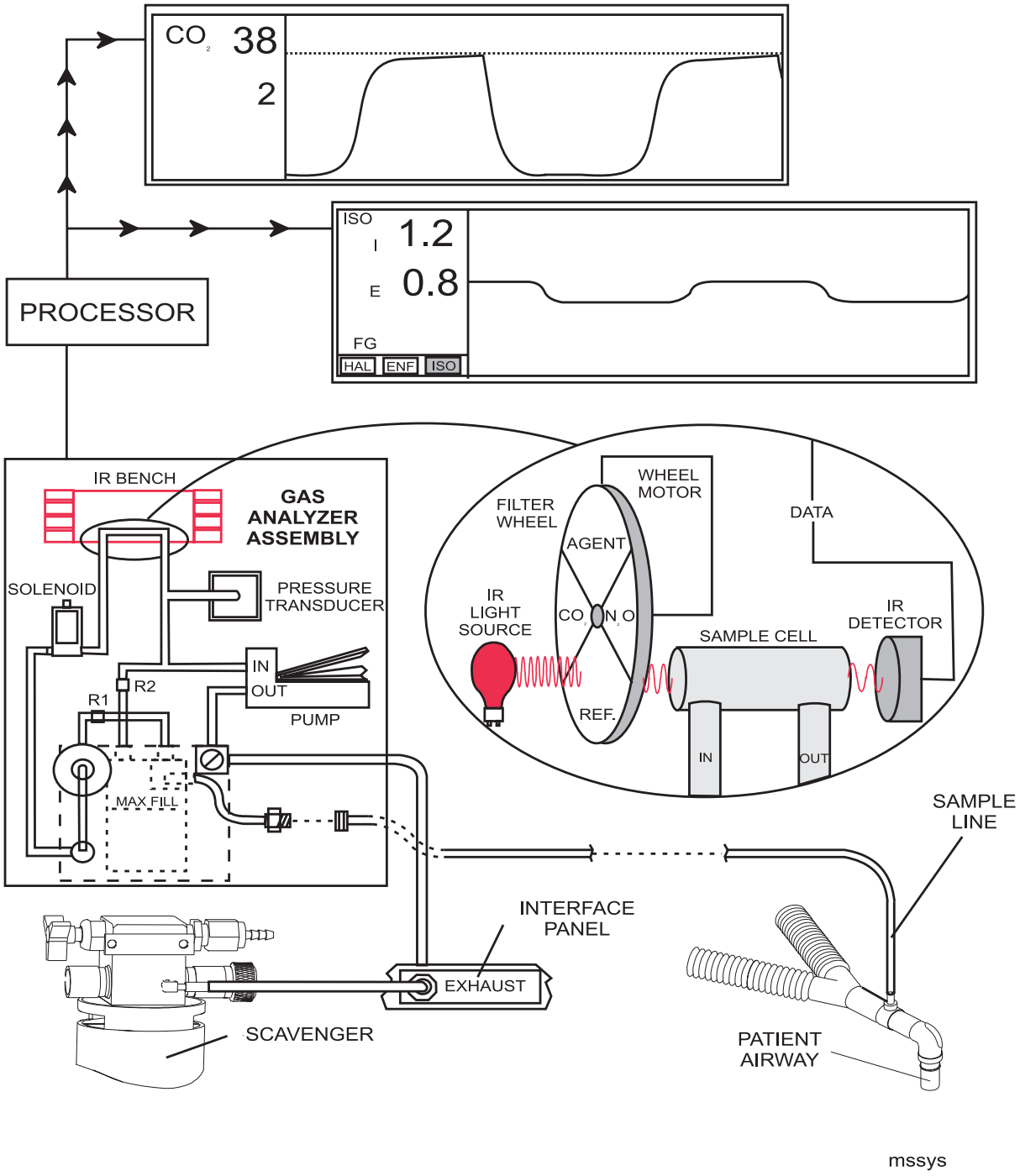


Figure 8-6: Gas analysis monitoring system

The Noninvasive Blood Pressure Monitoring System

The noninvasive blood pressure (NIBP) monitoring system automatically takes and records the patient's blood pressure in a time based format. The noninvasive blood pressure monitoring system (Figure 8-7) consists of a standard blood pressure cuff, typically attached to the patient's arm, which conducts air pressure, through the interface panel, to the NIBP subassembly. The NIBP subassembly contains a pump and a pressure transducer that generates and interprets pressure readings. The NIBP subassembly generates a signal and sends it to the processor. The processor converts the signal to a usable format that is displayed on a screen and generates audible and visual warnings when appropriate.

The NIBP subassembly used in all Narkomed anesthesia systems operates on the oscillometric principle. It literally means that it detects the patient's blood pressure through oscillations in the air pressure of the system. After the blood pressure cuff is placed over the brachial artery, the pump generates air pressure in the cuff, the cuff expands and compresses the tissue until blood no longer flows through the artery. When maximum inflation pressure is reached, the NIBP subassembly allows the air pressure to slowly bleed out of the cuff. As the air pressure in the cuff decreases and the tissue expands, blood begins to force its way through the artery again. As the blood begins to pulse through the artery, it produces fluctuations in the air pressure in the cuff. The pressure transducer senses these air pressure fluctuations and a signal representing the systolic reading is generated. As more air pressure is released from the cuff and the tissue continues to expand, eventually the force of the blood pulsing through the artery no longer produces fluctuations in the air pressure and a signal representing the diastolic reading is generated. The signals are sent to the processor and the processor converts them into the visual display. The processor also extrapolates and displays the mean arterial blood pressure and pulse of the patient.

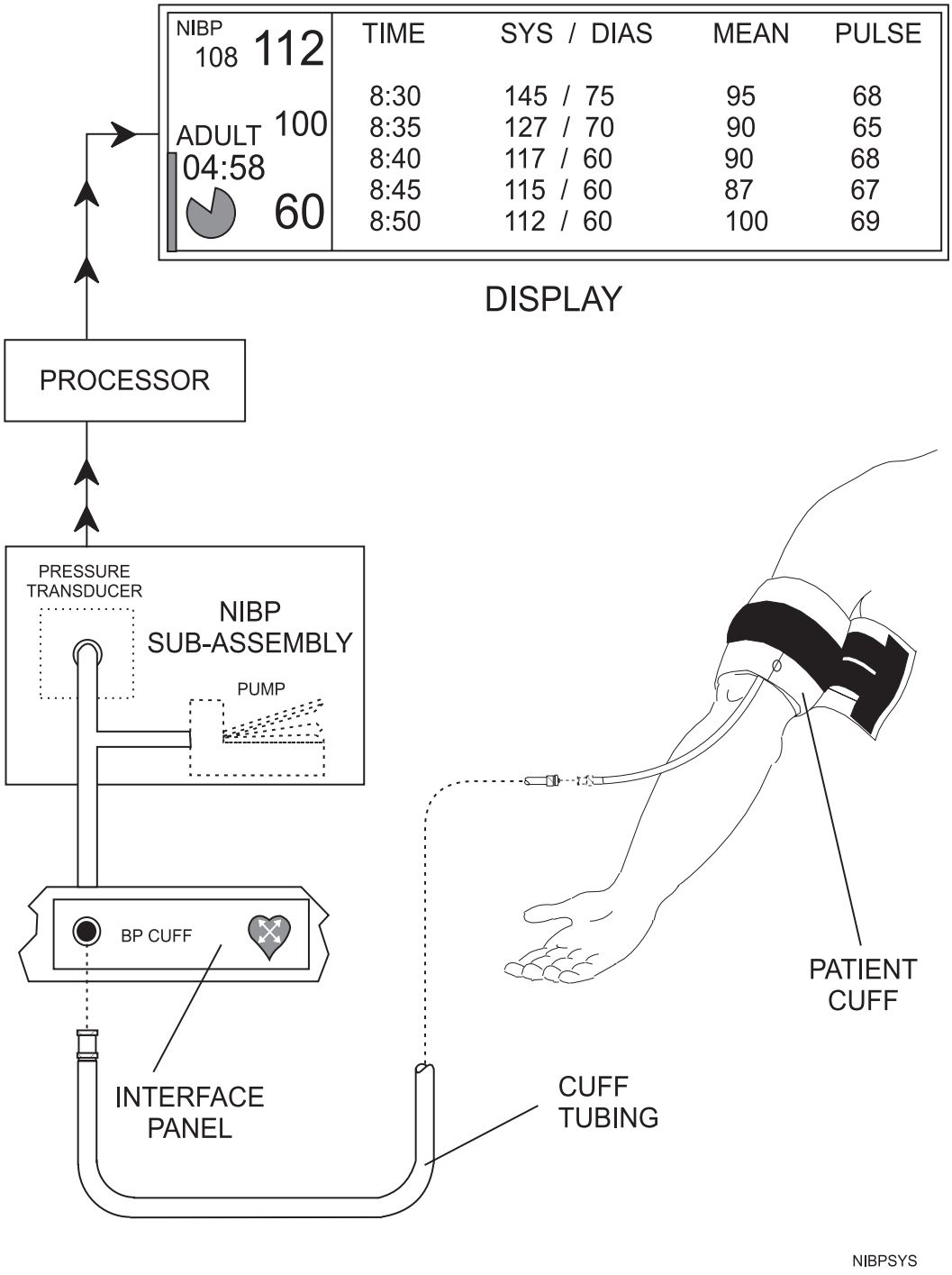


Figure 8-7: Noninvasive blood pressure monitoring system

Pulse Oximetry Monitoring System

The pulse oximetry monitoring system constantly monitors the patient's pulse rate and the amount of oxygen that is getting to the tissues. Components of the Nellcor pulse oximeter are used in all Narkomed anesthesia systems in conjunction with processor boards designed specifically for each Narkomed. The pulse oximetry monitoring system is based on infrared technology and depends on the absorption of infrared light of varying wavelengths. The components of the pulse oximetry system (Figure 8-8) include a sensor that connects to a patient module, which in turn plugs into the interface panel. The signal from the sensor is transmitted to the pulse oximeter subassembly which in turn transmits a signal to the processor. The processor receives the signal and generates a visual display, as well as visual and audible alarms when appropriate, for the clinician.

The pulse oximetry monitoring system monitors the amount of oxygen reaching the tissues through a sensor that is typically attached to the patient's finger. The sensor produces two wavelengths of infrared light, transmits that light through the tissue, and receives all nonabsorbed infrared light. As the shorter wavelength (660 nanometers) passes through the tissue, it is absorbed by the reduced hemoglobin in the blood. As the longer wavelength (930 nanometers) passes through the tissue, it is absorbed by the total hemoglobin. By knowing the amount of infrared light that was transmitted and subtracting the amount of infrared light that was received, the monitor calculates the amount of infrared light absorbed by the tissue. Comparing the absorption of infrared light in total hemoglobin against the absorption of infrared light in reduced hemoglobin allows the monitor to extrapolate the amount of oxygen delivered to the tissues.

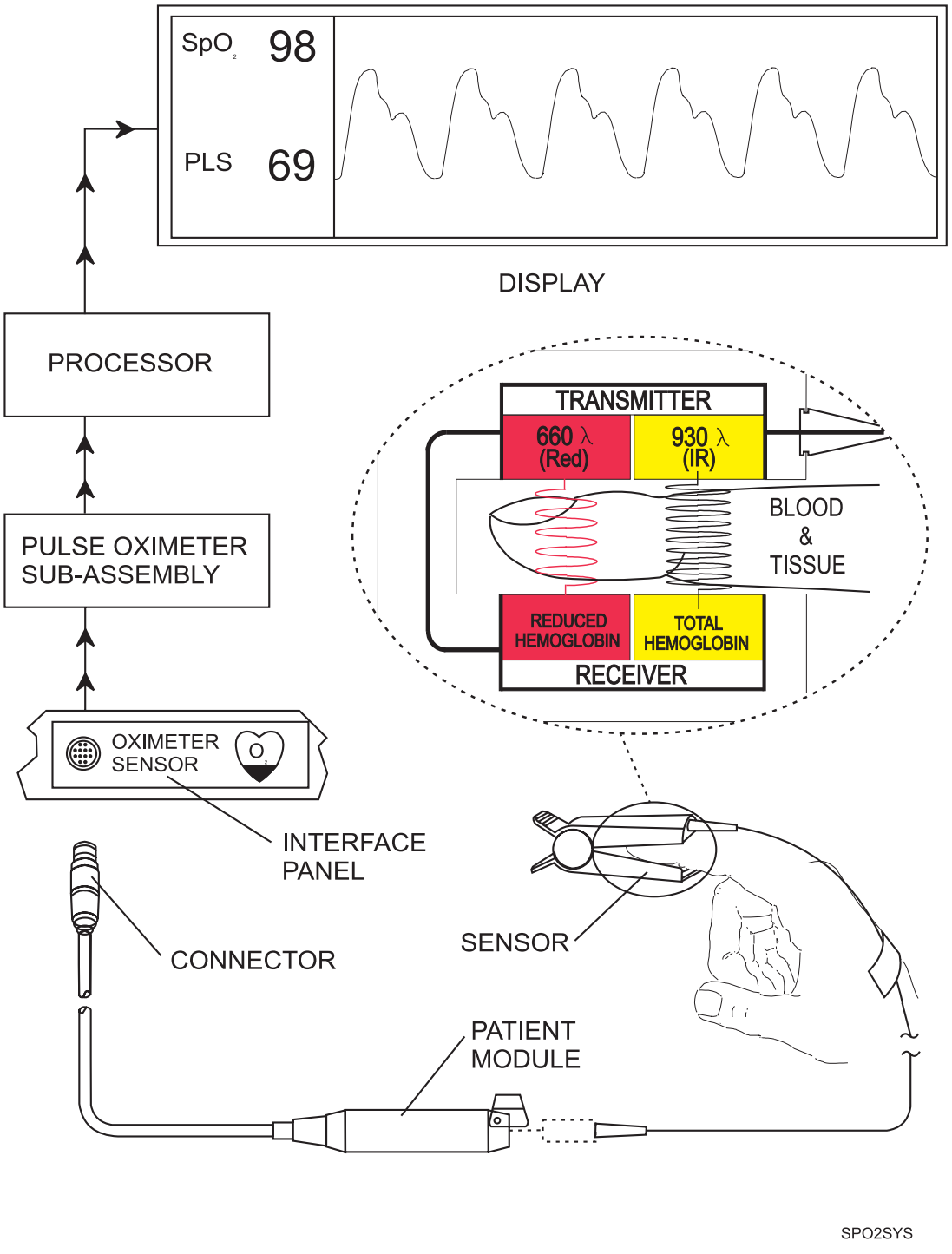


Figure 8-8: Pulse oximetry monitoring system

Similarly, by comparing constant absorption against pulsatile absorption (Figure 8-9), the monitor directly reads the pulse of the patient.

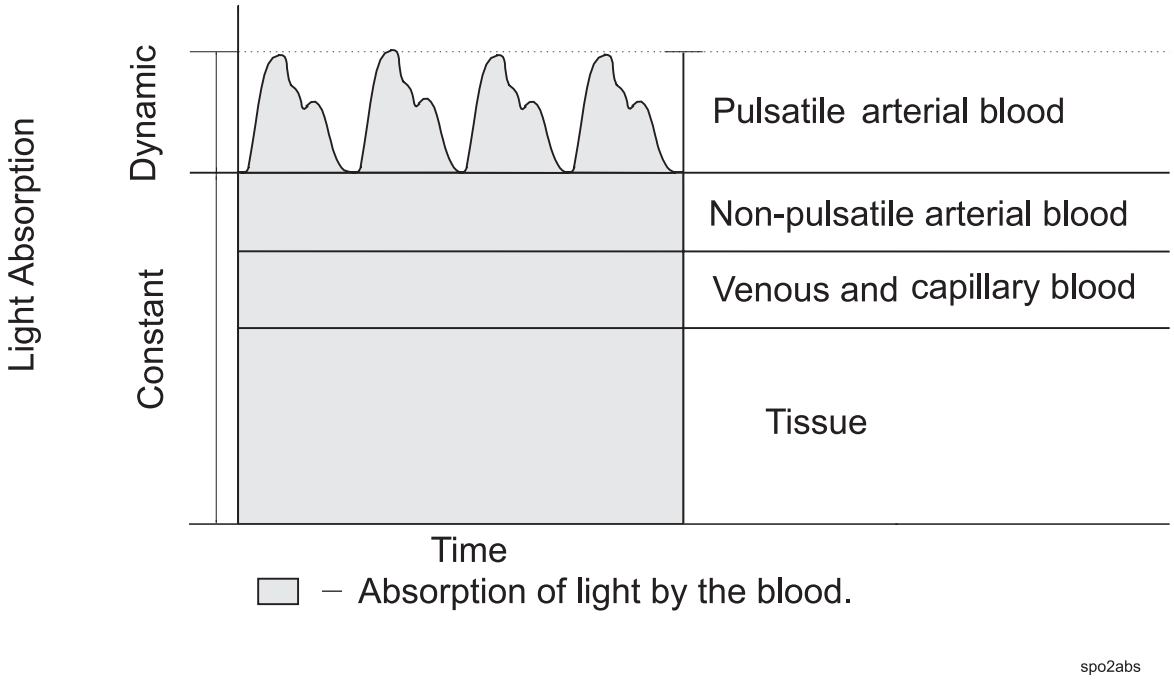


Figure 8-9: The different kinds of infrared light absorption.

Appendix A

Safety Precautions:

*Remove contents of shelves before moving machine.

*When moving the anesthesia machine, always use the handles provided and pull the machine while walking backwards.

*Always disconnect pressure hoses and electric cords, securing them before moving the anesthesia machine.

*Always turn the E cylinders off and bleed all gas pressure from the anesthesia machine before moving.

*Always turn all flow valves, vaporizers, external monitors, and the system power switch to OFF when the anesthesia machine is not in use.

*Always activate the oxygen flush button for several seconds after the anesthesia machine has been shut down.

*Always remove the oxygen sensor from the inspiratory valve dome, and install the plug in the inspiratory valve dome when the oxygen monitor is not in use.

*Always clean your hands thoroughly before servicing anesthesia equipment.

*Always use barrier precautions when handling or servicing an anesthesia machine that may be contaminated.

*Use only lubricants specified by NAD on your Narkomed anesthesia system.

*Service the anesthesia equipment only in a well ventilated area; avoid inhaling gases or vapors.

*Do not repair high pressure cylinder regulators. When malfunctioning, replace with a new regulator.

*Do not attempt to disassemble, repair, or recalibrate vaporizers. Any vaporizer requiring service should be drained of residual fluid, dried, and returned to NAD.

*Do not operate the anesthesia machine unless the electrical power cord is plugged into an appropriate, live AC receptacle.

Appendix B: Formulas and Conversions

Bernoulli's Theorem

At any point in a tube through which liquid is flowing, the sum of the pressure energy, potential energy, and kinetic energy is constant.

$$p + hdg + 1/2dv^2 = k$$

p = pressure; ***h*** = height above a reference plane; ***d*** = density of the liquid; ***g*** = gravitational pull at the earth's surface; ***v*** = velocity of flow; ***k*** = constant

Boyle's Law for Gases

At a constant temperature, the volume of a quantity of gas varies inversely to the pressure.

$$pv = p^1v^1$$

p = pressure; ***v*** = volume

Dalton's Law of Partial Pressures

The pressure exerted by a mixture of gases is equal to the sum of the separate pressures exerted by each gas within the mixture.

$$PV = V_1p_1 + V_2p_2 + V_3p_3, \text{ etc.}$$

P = total pressure; ***V*** = total volume; $\boldsymbol{V_n p_n}$ = volume of a constituent gas multiplied by the pressure of that gas.

Ohm's Law

A current is equal to electromotive force (voltage) divided by resistance.

$$I = E/R$$

I = current in amperes; ***E*** = electromotive force in volts; ***R*** = resistance in ohms

Power developed by a direct current

The following are equal terms:

power in watts developed by an electric current flowing in a conductor
product of the difference of potential at its terminals and the current
product of the current's resistance and the square of the current

$$P = EI = I^2R$$

P = power in watts; ***E*** = difference of terminal potentials in volts;
I = current in amperes; ***R*** = resistance in ohms

Percent Oxygen (FiO_2)

The percent oxygen equals the volume of delivered oxygen (in air and pure oxygen) divided by the total volume of delivered gas.

$$\frac{(l/min\ of\ air \times 0.21) + (l/min\ of\ oxygen \times 1.00)}{l/min\ total\ gas\ flow} = \%\ oxygen\ (FiO_2)$$

Common Oxygen Concentrations

The following table shows the required volumes of oxygen and air required to achieve a specified percent volume concentration of oxygen.

Common oxygen concentrations		
% oxygen	l/min oxygen	L/min air
25%	0.5	10.0
35%	2.0	10.0
40%	1.0	3.0
50%	2.8	5.0
60%	1.0	1.0
80%	3.0	1.0

Conversion Factors

1 atm = 1033 cmH_2O = 760 mmHg = 760 torr = 1013 mb = 14.7 psi = 101.08 kPa

1 psi = 70.3 cmH_2O = 51.7 mmHg = 68.9 mb = 6.9 kPa

1 mmHg = 1.36 cmH_2O = 1.33 mb

1 cmH_2O = 0.736 mmHg = 0.981 mb

Pressure Unit Conversion Constants

	psi	kpa	mb	cmH_2O	mmHg
psi	1.0	6.89	68.9	70.3	51.7
kPa	0.145	1.0	10.0	10.2	7.5
mb	0.015	0.1	1.0	1.02	0.75
cmH_2O	0.014	0.098	0.98	1.0	0.736
mmHg	0.019	1.33	1.33	1.36	1.0

Appendix C: Glossary

a **-** used in medicine as an abbreviation for "arterial".

A **-** used in medicine as an abbreviation for "alveolar".

a-A gradient- arterial-to-alveolar gradient; commonly refers to pressure difference of carbon dioxide or oxygen.

AAMI **-** Association for the Advancement of Medical Instrumentation

AANA **-** American Association of Nurse Anesthetists

AARC **-** American Association for Respiratory Care

ABG **-** arterial blood gas - the measurement of partial pressure of oxygen and carbon dioxide within arterial blood.

absorbent (barium hydroxide lime) **-** a chemical substance that removes carbon dioxide from the breathing circuit by a chemical neutralization process which produces carbonates, water and heat; (capacity = 27.1 liters of carbon dioxide per 100 grams of absorbent).

absorbent (soda lime) **-** a chemical substance that removes carbon dioxide from the breathing circuit by a chemical neutralization process which produces carbonates, water and heat; capacity = (25.1 liters of carbon dioxide per 100 grams of absorbent).

absorber **-** the component of a rebreathing system designed to remove carbon dioxide from delivered patient gas.

absorption **-** the process by which water and/or dissolved substances enter into cells of the body.

AIDS **-** acquired immunodeficiency syndrome

airway **-** 1. the pathway for air traveling between the atmosphere and the alveoli 2. in anesthesia or resuscitation, a mechanical device used to keep the passages of the upper respiratory tract open for the passage of air.

alveolar membrane **-** a thin layer of tissue which serves as a partition between the air in the alveoli and the capillary blood.

alveolar pressure (PA) **-** the air pressure in the pulmonary alveoli.

alveoli (alveolus, singular) **-** microscopic air sacs located at the very end of the bronchial tree, where the actual exchange of gases with the blood takes place. Normal human lungs contain approximately 300,000,000 alveoli.

AMA **-** American Medical Association

ampere **-** a unit of electrical current equivalent to a steady current produced by one volt applied across a resistance of one ohm.

analgesia **-** loss of pain, absence of sensitivity to pain.

anesthesia **-** partial or complete loss of sensation with or without loss of consciousness induced by an anesthetic agent.

anesthesia agent vapor **-** a gaseous form of an anesthetic agent, normally a liquid at standard temperature and pressure.

anesthesia machine **-** equipment intended for the delivery of anesthetic gases into a breathing system.

anesthesia system **-** an anesthesia machine, used in conjunction with any combination of monitoring devices that enhance the delivery of an anesthetic.

anesthetic agent **-** a drug that induces anesthesia.

anesthetic agent vapor concentration **-** the percentage of anesthetic agent vapor in the total anesthetic gas mixture delivered to the patient.

anesthetizing location **-** any area of a facility that has been designated to be used for the administration of inhalation anesthetic agents in the course of examination or treatment.

anode **-** the positive electrode of an electrolytic cell by which an electrical current enters a conductive material on its way to an opposing pole.

AOA **-** American Osteopathic Association

APL (adjustable pressure limiter) valve **-** the valve located downstream of the PEEP valve on the absorber mounting block that releases excess gas to the scavenger system while in the manual (bag) mode of ventilation.

apnea **-** cessation of respiration.

ARDS **-** adult respiratory distress syndrome

arterial blood gas **-** the measurement of partial pressure of oxygen and carbon dioxide within arterial blood.

arterial pressure (Pa) **-** the pressure within the arteries

ASA **-** American Society of Anesthesiologists

ASATT **-** American Society of Anesthesia Technicians and Technologists.

auto-ranging valve (ARV) **-** a valve in the ventilator that will vary the amount of ambient air that is available for entrainment in the venturi in relation to the inspiratory flow setting.

auxiliary oxygen flowmeter **-** a flowmeter used to deliver Oxygen to a patient via nasal cannula. This flowmeter can be used without turning on the anesthesia machine.

AVE **-** electronic anesthesia ventilator (North American Dräger).

AV2 **-** an advanced design of the electronic anesthesia ventilator that replaced the AVE.

AV2+ **-** the latest advance in electronic anesthesia ventilator design that has replaced the AV2.

bain circuit **-** a breathing circuit composed of two tubes, with one tube situated inside the other. In a Bain circuit, fresh gas continually flows toward the patient through the inner tube; during exhalation, the respired gas flows away from the patient through the outer tube. This breathing circuit is popular for use with children.

barometric pressure **-** the pressure of air registered on a barometer; standard barometric pressure at sea level is 760 mmHg (29.92 in Hg).

barotrauma **-** a rupture of, or physical injury to, the lungs as a result of exposure to excessively high pressure.

bourdon gauge **-** gauge used to measure gases at high pressure.

BPM or bpm **-** breaths per minute.

breathing circuit **-** a system that delivers anesthetic gases from the machine to the patient and also transfers exhaled patient gas to the scavenging system

breathing system (closed) **-** a breathing circuit designed to allow the removal of CO_2 from the exhaled gas and, with the addition of a minimal amount of fresh gas, all exhaled gas can be rebreathed by the patient.

breathing system (semi-closed) **-** a breathing circuit designed to allow some of the exhaled gas to be scavenged while the CO_2 is removed from the remaining exhaled gas which is then mixed with fresh gas before being rebreathed by the patient.

c **-** capillary

calibrate **-** the act of verifying and adjusting, when necessary, the graduation of an instrument that delivers quantitative measurements.

calibrated vaporizer **-** any vaporizer that is calibrated to deliver one specific anesthetic agent to the fresh gas stream of an anesthesia system.

capillaries **-** minute blood vessels that form the connection between small arteries (arterioles) and veins. It is at the capillary level that exchange takes place between the blood and cells, or the blood and the alveoli.

carboxyhemoglobin **-** hemoglobin which has combined with carbon monoxide.

cardiac output **-** the volume of blood pumped by the heart per minute. In anesthesia, cardiac output is usually monitored by a Swan-Ganz catheter as blood passes from the right ventricle into the pulmonary system.

carrier gas **-** the gas mixture that exits the flowmeters and enters the vaporizer.

cathode **-** the negative electrode of an electrolytic cell by which an electrical current leaves a conductive material on its way to an opposing pole.

cc **-** cubic centimeter

CDC **-** Centers for Disease Control

central breathing system **-** a closed or semi-closed breathing system in which the CO_2 absorber forms a part of a continuous loop in which gas flow is unidirectional.

central venous pressure (CVP) **-** the pressure of blood in the right atrium of the heart.

check valve **-** allows gas to flow in one direction only.

cmH_2O **-** centimeters of water pressure.

CO **-** carbon monoxide

CO_2 **-** carbon dioxide

compliance **-** a measure of the distensibility of the chest and/or lung; expressed as the ratio of volume change to pressure change (l/cmH_2O).

compressed air **-** air at any pressure above atmospheric pressure.

continuous positive airway pressure (CPAP) **-** a method of delivering medical gas to a patient in order to hold open alveoli that would normally close at the end of expiration and thereby increase oxygenation and reduce the work of breathing.

convenience outlet **-** receptacle on the Narkomed anesthesia system that provides electrical AC power.

CVP **-** central venous pressure - the pressure of blood in the right atrium of the heart.

cyanosis **-** a bluish discoloration of the skin, mucous membranes, and nail beds as a result of an oxygen deficiency.

cylinder manifold system **-** a system consisting of two banks of cylinders connected by two pressure regulators and a control that switches from an empty bank of cylinders to a full bank of cylinders when the pressure drops below a predetermined setting.

cylinder (medical gas) **-** cylindrical shaped metal tanks, ranging in size from B (smallest) to H (largest), that are color-coded and pin indexed, or CGA valve specified, and are used to contain specified medical gases under pressure.

cylinder pressure gauge **-** a gauge capable of measuring high pressure gas used to monitor the pressure of gas within a cylinder.

dead space, (alveoli) **-** the portions of the respiratory tract that are ventilated but not perfused by pulmonary circulation.

dead space, (anatomical) **-** the area in the trachea, bronchi, and air passages containing air that does not reach the alveoli during respiration.

dead space, (physiological) **-** the area in the respiratory system that includes the anatomical dead space together with the space in the alveoli occupied by air that does not contribute to the oxygen-carbon dioxide exchange.

diameter index safety system (DISS) **-** an indexed connector system that reduces the risk of delivering the wrong gas to the patient by preventing incorrect connection of medical gas pipes. DISS fittings are used on medical devices that administer medical gases from a supply source of 200 psi or less.

diaphragm, (anatomical) **-** the main respiratory muscle separating the abdominal and thoracic cavities. By moving downward, the diaphragm creates suction (negative pressure) to draw in air and expand the lungs.

diaphragm, (mechanical) **-** a flexible material that fluctuates with pressure differences.

diastolic blood pressure **-** the lowest blood pressure during a cardiac cycle; it occurs between cardiac contractions, when the heart chambers or ventricles are relaxed and filling with blood.

diffusion **-** movement of a substance (usually a gas or liquid) from an area of higher concentration to an area of lower concentration.

ECMO **-** extracorporeal membrane oxygenation

electrocardiogram (ECG or EKG) **-** a waveform representation of the heart's actions derived by amplification of minute impulses generated by the heart.

electroencephalogram (EEG) **-** a waveform representation of the amplified biopotentials produced by the brain; detected by electrodes placed on the scalp.

electrolyte **-** a substance that, in solution, dissociates into ions and can conduct an electrical current, but is decomposed by that same current.

electrostatic discharge (ESD) **-** an event that occurs when a static charge is accumulated on one body and is conducted to another body of a different potential, often causing severe internal damage to electronic components.

endotracheal tube **-** tube inserted into the patient's trachea for ventilation purposes.

$EtCO_2$ **-** end-tidal carbon dioxide.

ethylene oxide (EtO) **-** a gas used to sterilize equipment and medical instruments that kills bacteria, fungi, viruses and spores.

exclusion system **-** a mechanical device that prohibits the use of more than one vaporizer at a time.

expiration **-** the act of expelling gas from the lungs.

expiratory reserve volume **-** the volume of air that can be exhaled by active contraction of the expiratory muscles at the end of a normal expiration.

external respiration **-** gas exchange between the lungs and the pulmonary circulation.

FDA **-** Food and Drug Administration

FiO_2 **-** fraction of inspired concentration of oxygen (For example, 0.4 FiO_2 = 40% oxygen).

flow control valve **-** a valve, usually a needle valve, that precisely controls the flow of gas.

flowmeter **-** a device used for measuring volumetric flow rates of gases or liquids.

flowmeter bank **-** the grouping of all flowmeters into one container or location.

fluorinated (halogenated) hydocarbons **-** the class name for stable, nonflammable inhalation anesthetic agents (introduced during the 1950's) characterized by different halogen atoms being added to a short chain of carbon atoms. Fluorine is typically added to the mix and can be found in halothane, methoxyflurane, isoflurane, desflurane, and sevoflurane.

flush button **-** a valve in the anesthesia system that delivers approximately 55 l/min of oxygen to the breathing circuit. Typically, the flush button is located on the front left corner of the anesthesia machine.

forced vital capacity (FVC) **-** the volume of gas that can be forcibly exhaled from a maximum inhalation..

fresh gas **-** the mixture of anesthetic gases and vapors intended for delivery to the patient.

functional residual capacity (FRC) **-** the volume of gas remaining in the lung following a normal tidal expiration.

general anesthesia **-** a state of unconsciousness in which there is an absence of pain sensation throughout the patient's entire body.

Good Manufacturing Practice (GMP) **-** a subsection of the FDA regulations that pertains specifically to manufacture of medical devices and delineates the methods by which manufacturers must ensure the uniform quality of their products.

Hall effect transistor **-** an electronic semiconductor that switches on in the presence of a magnetic field.

hemoglobin (Hgb) **-** the component of red blood cells that combines with oxygen for delivery to the tissues in the body.

hertz (Hz) **-** a unit of measure for frequency; 1 Hz = 1 cycle per second.

HEV **-** hospital equipment vigilance.

HIV **-** human immunodeficiency virus; pathological cause of AIDS.

HR **-** heart rate.

humidifier **-** a device used for adding water vapor to inspired gas.

hyperbaric oxygenation **-** exposure to oxygen greater than 1 atm (760 mmHg).

hypoxia **-** a condition of insufficient oxygen supply in the body's tissues.

hypoxic gas mixture **-** a gas mixture containing less than 21% oxygen.

IBP **-** invasive blood pressure - an intravascular measurement of blood pressure obtained by means of a catheter inserted into an artery.

I:E **-** ratio of inspiratory time to expiratory time.

inspiration **-** the act of breathing in, or drawing gas into the lungs.

inspiratory capacity **-** the maximum volume that can be inhaled from a resting exhalation; tidal volume (TV) + inspiratory reserve volume (IRV).

inspiratory reserve volume (IRV) **-** the volume of gas that can be forcibly inhaled following a normal tidal inspiration.

interlock (NIBP/SpO_2) **-** Electronic circuitry that, when enabled, silences the pulse oximeter alarms when the noninvasive blood pressure module is obtaining a blood pressure sample. This option is used when the cuff and sensor are attached to the same limb.

internal respiration **-** gas exchange between the body's circulatory system and the individual body cells.

invasive blood pressure (IBP) **-** an intravascular measurement of blood pressure obtained by means of a catheter inserted into an artery.

inverse I:E ratio **-** a mode of ventilation in which the time allowed for inspiration is longer than the time allowed for expiration.

IRDS **-**infant respiratory distress syndrome.

JCAHO **-** Joint Commission on the Accreditation of Healthcare Organizations.

key index safety system (K.I.S.S.) **-** an indexed key system that prevents a vaporizer from being filled with the wrong anesthetic agent. The vaporizer's fill and drain port have pins ("keys") that correspond to a keyed bottle adapter for that vaporizer's agent.

kilopascals (kPa) **-** unit of measure for pressure; commonly used in medical instrumentation.

LD50 **-** the dose of a drug that is lethal in 50% of the population.

MAC **-** 1. minimum alveolar concentration of an agent needed to produce an anesthetizing effect in 50% of the population 2. monitored anesthesia care.

magnetic resonance imaging (M.R.I.) **-** a technology that uses powerful magnets to produce two dimensional images of the internal soft tissues of the human anatomy, allowing the physician greater diagnostic power without employing invasive procedures.

malignant hyperthermia syndrome **-** a genetic disease indicated by unexplained tachycardia or elevated exhaled concentrations of carbon dioxide (early signs) or elevated body temperature (later sign). The disease is more common in children than adults.

manual/automatic selector valve **-** the valve that routes gas to the appropriate circuit for manual or mechanical ventilation.

medical gas pipeline supply **-** a system that consists of a central supply system (a manifold, bulk, or compressors), control equipment, piping that extends to points in the facility where nonflammable medical gases are required, and station outlet valves at each point of use.

minimum oxygen flow - a small continuous flow of oxygen to the patient circuit.

minute volume **-** the volume of gas inhaled and exhaled in one minute.

mmHg **-** millimeters of mercury; unit of measure for pressure.

MPL switch **-** micropneumatic logic pressure switch consisting of an internal diaphragm and electrical contact. When the switch is pressurized to a set point, the diaphragm causes the electrical contacts to open or close and produce a specific logic output.

NAD - North American Dräger - manufacturer of anesthesia systems located in Telford, Pennsylvania, USA.

Narkomed - product name for the North American Dräger line of anesthesia systems. A combination of two German words which translates to "medical sleep."

nasal cannula - a device consisting of two short tubes that are inserted into the nostrils for administering oxygen or other therapeutic gases.

neonatal period - the interval from birth to 28 days of age. The neonatal period is the time of greatest risk to an infant.

nitrous oxide - a colorless, odorless gas used as an anesthetic.

noninvasive blood pressure (NIBP) - an indirect measurement of blood pressure obtained by using a cuff occlusion and a stethoscopic or oscillometric interpretation of the pulse.

ohm - a unit of measure used to denote electrical resistance in a conductor in which one volt produces one ampere.

O-ring - "O"-shaped device that creates a seal between two adjoining surfaces.

oscillometric blood pressure device - a device which uses pulsatile (vibrations) fluctuations in gas pressure to determine arterial blood pressures.

oxygen failure protection device (OFPD) - a mechanical device that proportionately restricts the flow of all gas supplies other than oxygen in the event of a partial or complete loss of oxygen.

oxygen ratio controller (ORC) - a mechanical device that inhibits the delivery of a hypoxic gas mixture to the patient by controlling the ratio of nitrous oxide to oxygen. Range 25% (±3%).

oxygen ratio monitor (ORM) - an electro-mechanical device that monitors changes in the oxygen and nitrous oxide flow rates and activates an alarm when the oxygen percentage drops below 28% (±3%).

oxygen ratio monitor controller (ORMC) - device that monitors changes in the oxygen and nitrous oxide flow rates and inhibits the delivery of a hypoxic gas mixture to the patient by controlling the ratio of nitrous oxide to oxygen, activating an alarm if the oxygen concentration is less than 25% (±4%).

oxygen sensor - a device that uses an electrolytic material to convert the concentration of oxygen in a gas mixture to a proportional pair of electronic signals.

oxyhemoglobin - hemoglobin which has combined with oxygen.

P - partial pressure of a gas.

PA - (see alveolar pressure).

Pa **-** (see arterial pressure).

$PACO_2$ **-** partial pressure of carbon dioxide in the alveolar spaces.

$PaCO_2$ **-** partial pressure of carbon dioxide in the arterial blood.

PAO_2 **-** partial pressure of oxygen in the alveolar spaces.

PaO_2 **-** partial pressure of oxygen in the arterial blood.

partial pressure **-** the pressure exerted by one gas in a mixture of gases. The sum of partial pressures for all gases in the mixture makes up the total pressure of the mixture.

patient wye **-** a plastic or metal hose fitting that merges the two branches of the breathing circuit into one at the patient connection .

PEEP (positive end-expiratory pressure) valve **-** a valve that elevates the baseline pressure above atmospheric pressure at the end of exhalation.

perfusion **-** the supplying of a tissue with fresh blood, which allows oxygen to diffuse into the tissue.

Pethick test **-** a test for checking the proper function of a bain anesthesia breathing system. The test consists of closing the APL valve, filling the reservoir bag, and pushing the flush button. As a result, the reservoir bag should collapse.

pH **-** a measure of the concentration of hydrogen ions in a substance or solution, which denotes the degree to which the substance is acidic or alkaline (basic). The pH scale runs from 0 to 14. A pH of 7 is neutral; pHs below 7 are acidic, and pHs above 7 are alkaline.

pilot actuator **-** a pneumatic switch, which turns on, or off a gas flow or pressure.

pin index safety system (P.I.S.S.) **-** the safety system used on small gas cylinders (size E or smaller) with pressures of 200 psi or greater. The cylinder valves are bored with two pin holes whose locations are specific to the cylinder contents and correspond to pins on the cylinder yokes.

pipeline check valve **-** a one way valve which prevents gas flow out of the D.I.S.S. inlet.

PMS **-** periodic manufacturers service.

PO_2 **-** partial pressure of oxygen.

pressure gauge **-** a device used to measure pressure.

pressure limit control (PLC) **-** mechanical device that limits the peak inspiratory pressure produced by the ventilator without affecting the preset time base (I:E ratio).

pressure reducing regulator - a device which reduces pressure (e.g.. from cylinder pressure 2000 psi - to a system pressure of approximately 45 psi).

pressure relief valve - a device (e.g. APL valve) designed to automatically relieve pressure within a specified system; may be fixed or adjustable.

pressure transducer - a device that translates a quantity of pressure into an electrical signal.

processor - the software-driven component, circuit board, or circuitry of a system that performs high-speed arithmetic, memory, timing, and control functions; essentially, a microcomputer.

psi - pounds per square inch; unit of measure for pressure.

pulse oximeter - instrument used to monitor the oxygen saturation of arterial blood by measuring the wavelength of infrared light passing through the artery.

pulse oximetry - a noninvasive method of measuring arterial oxygen saturation and pulse rate.

pulse rate - number of heartbeats per minute.

PvO_2 - partial pressure of oxygen in venous blood.

regulator - a device used to automatically reduce the pressure of a gas or gas mixture to a safe working pressure.

residual volume (RV) - the volume of air that is left within the lung even after a forced exhalation; portion of gas that cannot be exhaled.

resistance (airway) - the driving pressure necessary to move a specified volume of gas in a specified period of time; expressed in pressure change per unit of volume per time change ($cmH_2O/l/sec$).

resistance (electrical) - the tendency of a material to impede the flow of electric current through it. The ohm is the unit of measurement of resistance.

respiratory cycle - the time interval from the beginning of inspiration to the end of expiration.

respiratory rate - the number of inspiratory-expiratory cycles per minute.

restrictor - a device which will reduce gas flow through a component.

SaO_2 - oxygen saturation of arterial blood as determined by a blood oximeter.

scavenging system - a system that safely removes waste gases from the breathing system; system can be classified as active, semi-active or passive.

shunt **-** a diversion from one side to another, bypassing some structure. For example, a right-to-left shunt is the passage of blood from the right side of the heart to the left side of the heart that bypasses the gas exchange process. This can happen when blood moves through an abnormal opening (hole in the heart) instead of through the normal pulmonary route, or when blood moves through the normal pulmonary route but is not oxygenated.

solenoid **-** a component that controls pneumatic flow by means of an electronic signal.

spiromed sensor **-** the component of the volume monitoring system that converts the volume of exhaled patient gas to an electronic signal.

SpO_2 **-** oxygen saturation of arterial blood as determined by a pulse oximeter.

spontaneous ventilation **-** respiration without mechanical assistance - the patient determines respiratory rate and breathing volume.

SvO_2 **-** saturation of venous blood with oxygen.

systolic blood pressure **-** the highest blood pressure reached during a cardiac cycle; it occurs when the heart's ventricles contract, forcing blood out of the heart.

test lung **-** any device capable of simulating the compliance and resistance in a patient's lung and is normally used for testing the functions of a ventilator.

thermostability **-** a condition characterized by a constant temperature in a given situation. The constancy of temperature is a major factor in vaporizer design required for producing and maintaining an accurate output.

tidal volume (TV) **-** the amount of gas that passes in or out of the lungs during inhalation or expiration.

total lung capacity (TLC) **-** the volume of gas within the lungs following a maximum inspiration, including the residual volume.

trace gas analysis **-** a test that determines minute levels of various gases (for example, nitrous oxide, ethylene oxide, formaldehyde) by means of a spectrophotometer.

unidirectional valves **-** any valve that allows gases to flow in only one direction (i.e., inhalation or exhalation valves).

vacuum **-** a space absolutely devoid of air.

vacuum system **-** a system consisting of vacuum-producing equipment with pressure and operating controls, shutoff valves, alarm warning systems, gauges, and a network of piping extending to and terminating with station inlets at locations where patient suction is required.

valid breath **-** is counted by the spiromed sensor when the volume of exhaled patient gas exceeds an arbitrary volume of patient gas.

vaporization **-** the change of a liquid or solid into a gaseous state, generally through the application of heat.

vaporizer **-** a device that converts a liquid anesthetic agent into a gas, or "vapor".

vaporizer exclusion system **-** NAD's safety system which allows only one vaporizer to be turned on at a time.

ventilation **-** movement of gas into and out of the lungs.

ventilator **-** mechanical device that provides artificial ventilation.

ventilator relief valve **-** a component of the ventilator that allows waste gases to escape during mechanical ventilation.

venturi **-** a tubelike device with a constricted nozzle at one end.

watt **-** a unit of measure for electricity equal to 1 joule per second; the power of a current of 1 ampere flowing across a potential difference of 1 volt.

wick **-** a device used to increase surface area to aid in the evaporation process.

yoke **-** a device used to mount and interface a medical gas cylinder with an anesthesia system.

yoke check valve **-** a valve located in the yoke which allows gas to flow in one direction only.