CHAPTER 2

# The Operating Room Environment

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## KEY CONCEPTS

1. A pressure of 1000 psig indicates an E-cylinder that is approximately half full and represents 330 L of oxygen.
2. The only reliable way to determine residual volume of nitrous oxide is to weigh the cylinder.
3. To discourage incorrect cylinder attachments, cylinder manufacturers have adopted a pin index safety system.
4. A basic principle of radiation safety is to keep exposure "as low as reasonably practical" (ALARP). The principles of ALARP are protection from radiation exposure by the use of time, distance, and shielding.
5. The magnitude of a leakage current is normally imperceptible to touch (<1 mA, and well below the fibrillation threshold of 100 mA). If the current bypasses the high resistance offered by skin, however, and is applied directly to the heart (microshock), current as low as 100 µA may be fatal. The maximum leakage allowed in operating room equipment is 10 µA.
6. To reduce the chance of two coexisting faults, a line isolation monitor measures the potential for current flow from the isolated power supply to the ground. Basically, the line isolation monitor determines the degree of isolation between the two power wires and the ground and predicts the amount of current that *could* flow if a second short circuit were to develop.
7. Almost all surgical fires can be prevented. Unlike medical complications, fires are a product of simple physical and chemistry properties. Occurrence is guaranteed given the proper combination of factors but can be eliminated almost entirely by understanding the basic principles of fire risk.
8. Likely the most common risk factor for surgical fire relates to the open delivery of oxygen.
9. Administration of oxygen to concentrations of greater than 30% should be guided by clinical presentation of the patient and not solely by protocols or habits.
10. The sequence of stopping gas flow and removal of the endotracheal tube when fire occurs in the airway is not as important as ensuring that both actions are performed quickly.
11. Before beginning laser surgery, the laser device should be in the operating room, warning signs should be posted on the doors, and protective eyewear should be issued. The anesthesia provider should ensure that the warning signs and eyewear match the labeling on the laser device as laser protection is specific to the type of laser.

Anesthesiologists, who spend more time in operating rooms than any other group of physicians, are responsible for protecting patients and operating room personnel from a multitude of dangers during surgery. Some of these threats are unique to the operating room. As a result, the anesthesiologist may be responsible for ensuring proper functioning of the operating room's medical gases, fire prevention and management, environmental factors (eg, temperature, humidity, ventilation, and noise), and electrical safety. The role of the anesthesiologist also may include coordination of or assistance with layout and design of surgical suites, including workflow enhancements. This chapter describes the major operating room features that are of special interest to anesthesiologists and the potential hazards associated with these systems.

## Safety Culture

Patients often think of the operating room as a safe place where the care given is centered around protecting the patient. Medical providers such as anesthesia personnel, surgeons, and nurses are responsible for carrying out several critical tasks at a fast pace. Unless members of the operating room team look out for one another, errors can occur. The best way of preventing serious harm to a patient is by creating a culture of safety. When the safety culture is effectively applied in the operating room, unsafe acts are stopped before harm occurs.

One tool that fosters the safety culture is the use of a surgical safety checklist. Such checklists are used prior to incision on every case and can include components agreed upon by the facility as crucial. Many surgical checklists are derived from the surgical safety checklist published by the World Health Organization (WHO). For checklists to be effective, they must first be used; secondly, all members of the surgical team should be engaged when the checklist is being used. Checklists are most effective when performed in an interactive fashion. An example of a suboptimally executed checklist is one that is read in entirety, after which the surgeon asks whether everyone agrees. This format makes it difficult to identify possible problems. A better method is one that elicits a response after each point; eg, "Does everyone agree this is John Doe?", followed by "Does everyone agree we are performing a removal of the left kidney?", and so forth. Optimal checklists do not attempt to cover every possibility but rather address only key components, allowing them to be completed in less than 90 seconds.

Some practitioners argue that checklists waste too much time; they fail to realize that cutting corners to save time often leads to problems later, resulting in a net loss of time. If safety checklists were followed in every case, significant reductions could be seen in the incidence of surgical complications such as wrong-site surgery, procedures on the wrong patient, retained foreign objects, and other easily prevented mistakes. Anesthesia providers are leaders in patient safety initiatives and should take a proactive role to utilize checklists and other activities that foster the safety culture.

## Medical Gas Systems

The medical gases commonly used in operating rooms are oxygen, nitrous oxide, air, and nitrogen. Although technically not a gas, vacuum exhaust for waste anesthetic gas disposal (WAGD or scavenging) and surgical suction must also be provided and is considered an integral part of the medical gas system. Patients are endangered if medical gas systems, particularly oxygen, are misconfigured or malfunction. The main features of such systems are the sources of the gases and the means of their delivery to the operating room. The anesthesiologist must understand both these elements to prevent and detect medical gas depletion or supply line misconnection. Estimates of a particular hospital's peak demand determine the type of medical gas supply system required. Design and standards follow National Fire Protection Association (NFPA) 99 in the United States and HTM 2022 in the United Kingdom.

### SOURCES OF MEDICAL GASES

#### Oxygen

A reliable supply of oxygen is a critical requirement in any surgical area. Medical grade oxygen (99% or 99.5% pure) is manufactured by fractional distillation of liquefied air. Oxygen is stored as a compressed

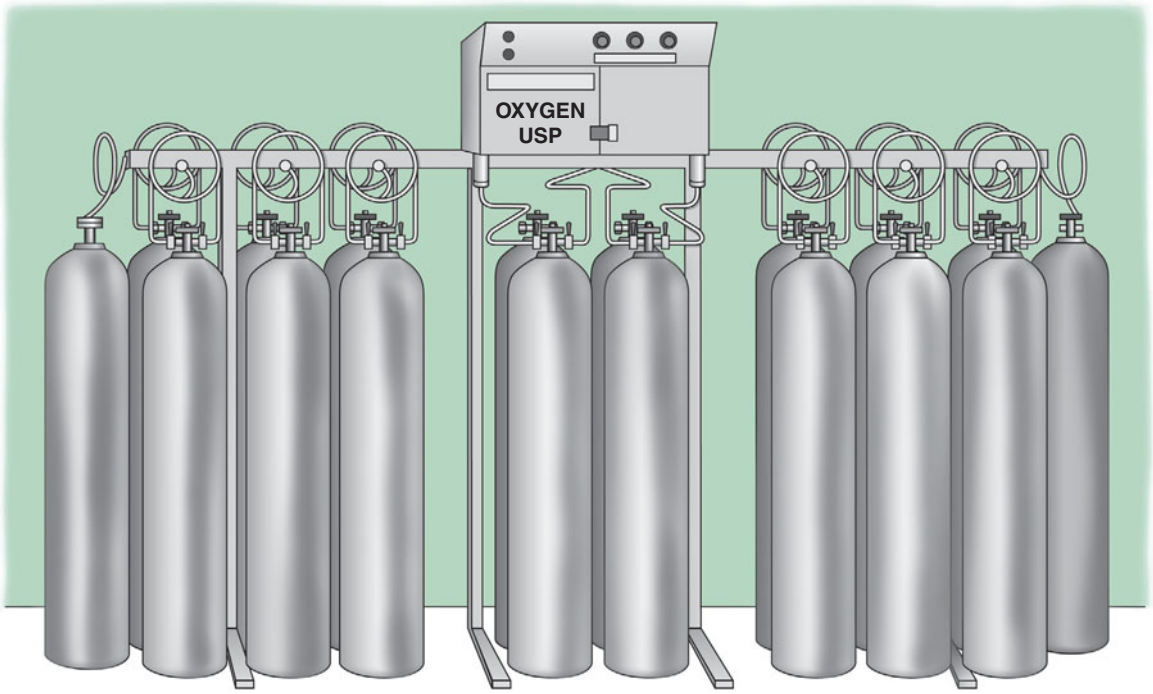


**FIGURE 2–1** A bank of oxygen H-cylinders connected by a manifold.

gas at room temperature or refrigerated as a liquid. Most small hospitals store oxygen in two separate banks of high-pressure cylinders (H-cylinders) connected by a manifold (Figure 2–1). Only one bank is utilized at a time. The number of cylinders in each bank depends on anticipated daily demand. The manifold contains valves that reduce the cylinder pressure (approximately 2000 pounds per square inch [psig]) to line pressure (55 ± 5 psig) and automatically switch banks when one group of cylinders is exhausted.

A liquid oxygen storage system (Figure 2–2) is more economical for large hospitals. Liquid oxygen must be stored well below its critical temperature of –119°C because gases can be liquefied by pressure *only* if stored below their critical temperature. A large hospital may have a smaller liquid oxygen supply or a bank of compressed gas cylinders that can provide one day's oxygen requirements as a reserve. To guard against a hospital gas-system failure, the anesthesiologist must always have an emergency (E-cylinder) supply of oxygen available during anesthesia.

Most anesthesia machines accommodate E-cylinders of oxygen (Table 2–1). As oxygen is expended, the cylinder's pressure falls in proportion to its content. A pressure of 1000 psig indicates an E-cylinder that is approximately half full and represents 330 L of oxygen at atmospheric pressure and a temperature of 20°C. If the oxygen is exhausted at a rate of 3 L/min, a cylinder that is half full will be empty in 110 min. Oxygen cylinder pressure should be monitored before use and periodically during use. Anesthesia machines usually also accommodate E-cylinders for medical air and nitrous oxide, and may accept cylinders of helium. Compressed medical gases utilize a pin index safety system for these cylinders to prevent inadvertent crossover and connections for different gas types. As a safety feature of oxygen E-cylinders, the yoke has integral components made from Wood's metal. This metallurgic alloy has a low melting point, which allows dissipation of pressure that might otherwise heat the bottle to the point of ballistic explosion. This pressure-relief "valve" is

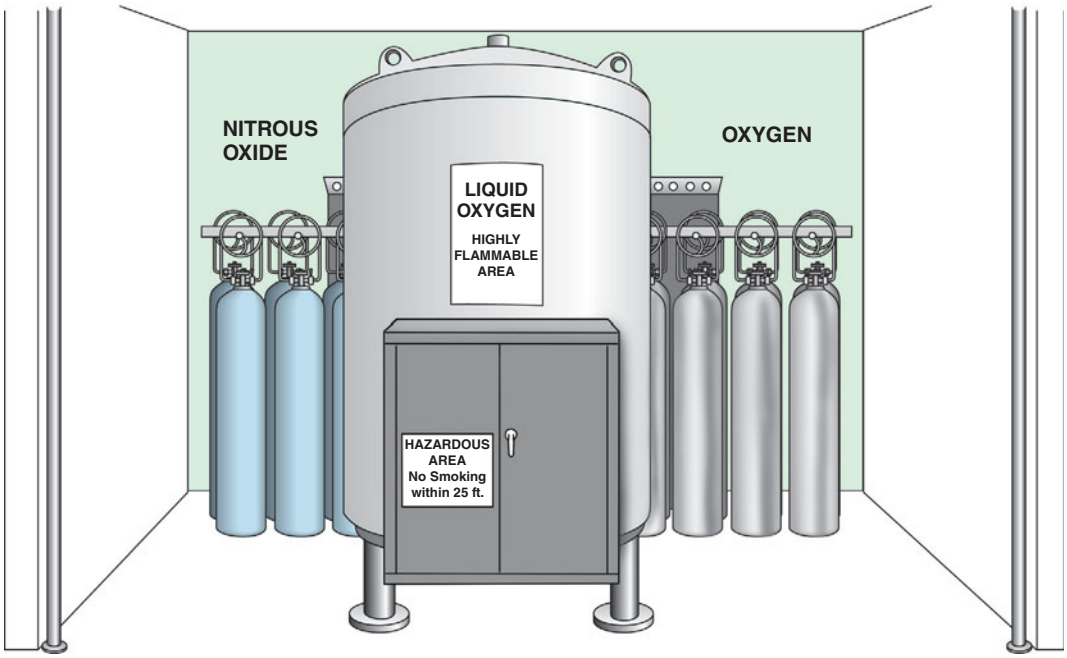


**FIGURE 2–2** A liquid storage tank with reserve oxygen tanks in the background.

designed to rupture at 3300 psig, well below the pressure E-cylinder walls should be able to withstand (more than 5000 psig).

## Nitrous Oxide

Nitrous oxide is manufactured by heating ammonium nitrate (thermal decomposition). It is almost always stored by hospitals in large H-cylinders connected by a manifold with an automatic crossover feature. Bulk liquid storage of nitrous oxide is economical only in very large institutions.

**Because the critical temperature of nitrous oxide (36.5°C) is above room temperature, it can be kept liquefied without an elaborate refrigeration system**. If the liquefied nitrous oxide rises above its critical temperature, it will revert to its gaseous phase. Because nitrous oxide is not an ideal gas and is easily compressible, this transformation into a gaseous phase is not accompanied by a great rise in tank pressure. Nonetheless, as with oxygen cylinders, all nitrous oxide E-cylinders are equipped with a Wood's metal yoke to prevent

**TABLE 2–1 Characteristics of medical gas cylinders.**

| Gas | E-Cylinder Capacity[1] (L) | H-Cylinder Capacity[1] (L) | Pressure[1] (psig at 20°C) | Color (USA) | Color (International) | Form |
|---|---|---|---|---|---|---|
| $O_2$ | 625–700 | 6000–8000 | 1800–2200 | Green | White | Gas |
| Air | 625–700 | 6000–8000 | 1800–2200 | Yellow | White and black | Gas |
| $N_2O$ | 1590 | 15,900 | 745 | Blue | Blue | Liquid |
| $N_2$ | 625–700 | 6000–8000 | 1800–2200 | Black | Black | Gas |

[1]Depending on the manufacturer.

explosion under conditions of unexpectedly high gas pressure (eg, unintentional overfilling), particularly during fires.

Although a disruption in supply is usually not catastrophic, most anesthesia machines have reserve nitrous oxide E-cylinders. Because these smaller cylinders also contain nitrous oxide in its liquid state, the volume remaining in a cylinder is *not* proportional to cylinder pressure. By the time the liquid nitrous oxide is expended and the tank pressure begins to fall, only about 400 L of nitrous oxide remains. **If liquid nitrous oxide is kept at a constant temperature (20°C), it will vaporize at the same rate at which it is consumed and will maintain a constant pressure (745 psig) until the liquid is exhausted**.

2 The only reliable way to determine residual volume of nitrous oxide is to weigh the cylinder. For this reason, the tare weight (TW), or empty weight, of cylinders containing a liquefied compressed gas (eg, nitrous oxide) is often stamped on the shoulder of the cylinder. The pressure gauge of a nitrous oxide cylinder should not exceed 745 psig at 20°C. A higher reading implies gauge malfunction, tank overfill (liquid fill), or a cylinder containing a gas other than nitrous oxide.

Because energy is consumed in the conversion of a liquid to a gas (the latent heat of vaporization), the liquid nitrous oxide cools. The drop in temperature results in a lower vapor pressure and lower cylinder pressure. The cooling is so pronounced at high flow rates that there is often frost on the tank, and pressure regulators may freeze.

### Medical Air

The use of air is becoming more frequent in anesthesiology as the popularity of nitrous oxide and unnecessarily high concentrations of oxygen has declined. Cylinder air is medical grade and is obtained by blending oxygen and nitrogen. Dehumidified but unsterile air is provided to the hospital pipeline system by compression pumps. The inlets of these pumps must be distant from vacuum exhaust vents and machinery to minimize contamination. Because the critical temperature of air is –140.6°C, it exists as a gas in cylinders whose pressures fall in proportion to their content.

### Nitrogen

Although compressed nitrogen is not administered to patients, it may be used to drive some operating room equipment, such as saws, drills, and surgical handpieces. Nitrogen supply systems either incorporate the use of H-cylinders connected by a manifold or a wall system supplied by a compressor driven central supply.

### Vacuum

A central hospital vacuum system usually consists of independent suction pumps, each capable of handling peak requirements. Traps at every user location prevent contamination of the system with foreign matter. The medical-surgical vacuum may be used for waste anesthetic gas disposal (WAGD) providing it does not affect the performance of the system. Medical vacuum receptacles are usually black in color with white lettering. A dedicated WAGD vacuum system is generally required with modern anesthesia machines. The WAGD outlet may incorporate the use of a suction regulator with a float indicator. The float should be maintained between the designated markings. Excess suction may result in inadequate patient ventilation, and insufficient suction levels may result in the failure to evaluate WAGD. WAGD receptacles and tubing are usually lavender in color.

### Carbon Dioxide

Many surgical procedures are performed using laparoscopic or robotic-assisted techniques requiring insufflation of body cavities with carbon dioxide, an odorless, colorless, nonflammable and slightly acidic gas. Large cylinders containing carbon dioxide, such as M-cylinders or LK-cylinders, are frequently found in the operating room; these cylinders share a common size orifice and thread with oxygen cylinders and can be inadvertently interchanged.

## DELIVERY OF MEDICAL GASES

Medical gases are delivered from their central supply source to the operating room through a piping network. Pipes are sized such that the pressure drop across the whole system never exceeds 5 psig. Gas pipes are usually constructed of seamless copper tubing using a special welding technique. Internal

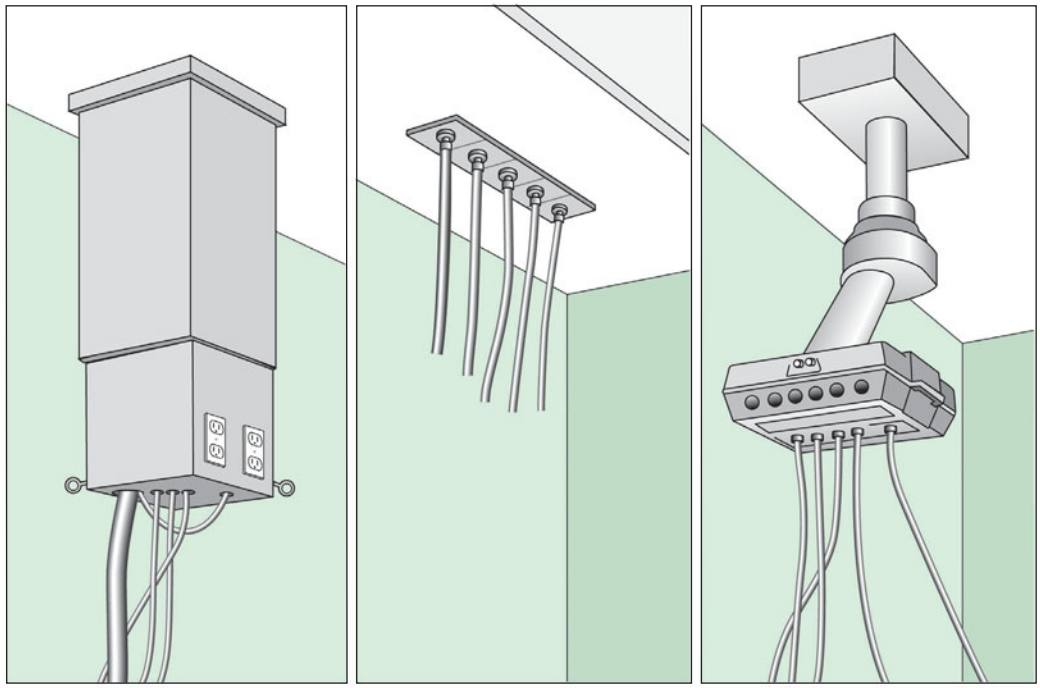


**FIGURE 2–3** Typical examples of (**A**) gas columns, (**B**) ceiling hose drops, and (**C**) articulating arms. One end of a color-coded hose connects to the hospital medical gas supply system by way of a quick-coupler mechanism. The other end connects to the anesthesia machine through the diameter index safety system.

contamination of the pipelines with dust, grease, or water must be avoided. The hospital's gas delivery system appears in the operating room as hose drops, gas columns, or elaborate articulating arms (Figure 2–3). Operating room equipment, including the anesthesia machine, interfaces with these pipeline system outlets by color-coded hoses. Quick-coupler mechanisms, which vary in design with different manufacturers, connect one end of the hose to the appropriate gas outlet. The other end connects to the anesthesia machine through a non-interchangeable diameter index safety system fitting that prevents incorrect hose attachment.

E-cylinders of oxygen, nitrous oxide, and air attach directly to the anesthesia machine. To discourage incorrect cylinder attachments, cylinder manufacturers have adopted a pin index safety system. Each gas cylinder (sizes A–E) has two holes in its cylinder valve that mate with corresponding pins in the yoke of the anesthesia machine (Figure 2–4). The relative positioning of the pins and holes is unique for each gas. Multiple washers placed between the cylinder and yoke, which prevent proper engagement of the pins and holes, have unintentionally defeated this system. The pin index safety system is also ineffective if yoke pins are damaged or the cylinder is filled with the wrong gas.

The functioning of medical gas supply sources and pipeline systems is constantly monitored by central and area alarm systems. Indicator lights and audible signals warn of changeover to secondary gas sources and abnormally high (eg, pressure regulator malfunction) or low (eg, supply depletion) pipeline pressures (Figure 2–5).

Modern anesthesia machines and anesthetic gas analyzers continuously measure the fraction of inspired oxygen ($FiO_2$). Analyzers have a variable threshold setting for the minimal $FiO_2$ but should

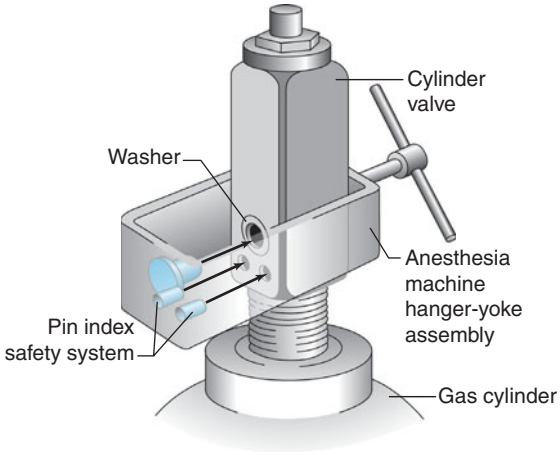


**FIGURE 2–4** Pin index safety system interlink between the anesthesia machine and gas cylinder.

be configured to prevent disabling this alarm. The monitoring of $FiO_2$ does not reflect the oxygen concentration distal to the monitoring port and should not be used to reference the oxygen concentration within devices such as endotracheal tubes or at the distal tip of the tube. Due to gas exchange, flow rates, and shunting a marked difference can exist between the monitored $FiO_2$ and oxygen concentration at the tissue level.

# Environmental Factors in the Operating Room

## TEMPERATURE

The temperature in most operating rooms seems uncomfortably cold to many conscious patients and, at times, to anesthesiologists. However, scrub nurses and surgeons stand in surgical garb for hours under hot operating room lights. As a general principle, the comfort of operating room personnel must be reconciled with patient care. Hypothermia has been associated with an increased incidence of wound infection, greater intraoperative blood loss (impaired coagulation assessed by thromboelastography), and prolonged hospitalization (see Chapter 52).

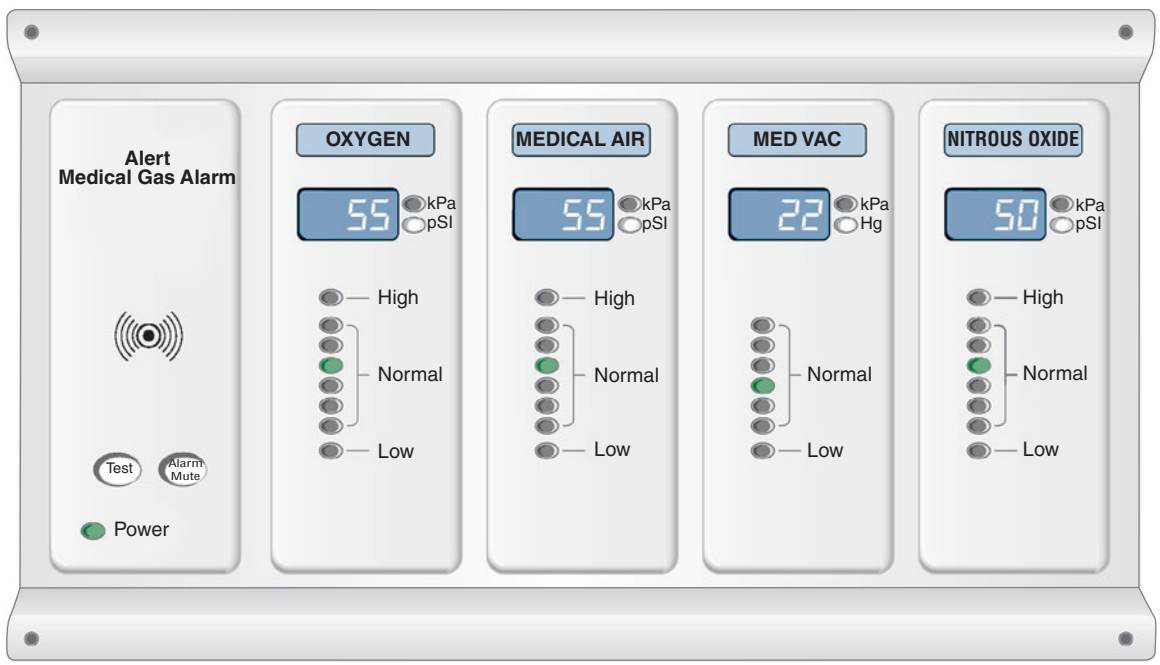


**FIGURE 2–5** An example of a master alarm panel that monitors gasline pressure.

## HUMIDITY

In past decades, static discharges were a feared source of ignition in an operating room filled with flammable anesthetic vapors. Now humidity control is more relevant to infection control practices. Optimally humidity levels in the operating room should be maintained between 50% and 55%. Below this range the dry air facilitates airborne motility of particulate matter, which can be a vector for infection. At high humidity, dampness can affect the integrity of barrier devices such as sterile cloth drapes and pan liners.

## VENTILATION

A high rate of operating room airflow decreases contamination of the surgical site. These flow rates, usually achieved by blending up to 80% recirculated air with fresh air, are engineered in a manner to decrease turbulent flow and be unidirectional. Although recirculation conserves energy costs associated with heating and air conditioning, it is unsuitable for WAGD. Therefore, a separate anesthetic gas scavenging system must always supplement operating room ventilation. The operating room should maintain a slightly positive pressure to drive away gases that escape scavenging and should be designed so fresh air is introduced through or near the ceiling and air return is handled at or near floor level. Ventilation considerations must address air quality and volume changes. The National Fire Protection Agency (NFPA) recommends 25 air volume exchanges per hour to decrease risk of stagnation and bacterial growth. Air quality should be maintained by adequate air filtration using a 90% filter, defined simply as one that filters out 90% of particles presented. High-efficiency particulate filters (HEPA) are frequently used but are not required by engineering or infection control standards.

## NOISE

Multiple studies have demonstrated that exposure to noise can have a detrimental effect on multiple human cognitive functions and may result in hearing impairment with prolonged exposure. Operating room noise has been measured at 70–80 decibels (dB) with frequent sound peaks exceeding 80 dB. As a reference, if your speaking voice has to be raised above conversational level, then ambient noise is approximated at 80 dB. Noise levels in the operating room approach the time-weighted average (TWA) for which the Occupational Safety and Health Administration (OSHA) requires hearing protection. Orthopedic air chisels and neurosurgical drills can approach the noise levels of 125 dB, the level at which most human subjects begin to experience pain.

## IONIZING RADIATION

Radiation is an energy form that is found in specific beams. For the anesthesia provider radiation is usually a component of either diagnostic imaging or radiation therapy. Examples include fluoroscopy, linear accelerators, computed tomography, directed beam therapy, proton therapy, and diagnostic radiographs. Human effects of radiation are measured by units of absorbed doses such as the gray (Gy) and rads or equivalent dose units such as the Sievert (Sv) and Roentgen equivalent in man (REM). Radiation-sensitive organs such as eyes, thyroid, and gonads must be protected, as well as blood, bone marrow, and fetus. Radiation levels must be monitored if individuals are exposed to greater than 40 REM. The most common method of measurement is by film badge. Lifetime exposure can be tabulated by a required database of film badge wearers.

4 A basic principle of radiation safety is to keep exposure "as low as reasonably practical" (ALARP). The principles of ALARP are protection from radiation exposure by the use of time, distance, and shielding. The length of time of exposure is usually not an issue for simple radiographs such as chest films but can be significant in fluoroscopic procedures such as those commonly performed during interventional radiology, c-arm use, and in the diagnostic gastroenterology lab. Exposure can be reduced to the provider by increasing the distance between the beam and the provider. Radiation exposure over distance follows the inverse square law. To illustrate, intensity is represented as $1/d^2$

(where $d$ = distance) so that 100 mRADs at 1 inch will be 0.01 mRADs at 100 inches. Shielding is the most reliable form of radiation protection; typical personal shielding is in the form of leaded apron and glasses. Physical shields are usually incorporated into radiological suites and can be as simple as a wall to stand behind or a rolling leaded shield to place between the beam and the provider. Although most modern facilities are designed in a very safe manner, providers can still be exposed to scattered radiation as atomic particles are bounced off shielding. For this reason radiation protection should be donned whenever ionizing radiation is used.

As use of reliable shielding has increased, the incidence of radiation-associated diseases of sensitive organs has decreased, with the exception of radiation-induced cataracts. Because protective eyewear has not been consistently used to the same degree as other types of personal protection, radiation-induced cataracts are increasing among employees working in interventional radiology suites. Anesthesia providers who work in these environments should consider the use of leaded goggles or glasses to decrease the risk of such problems.

# Electrical Safety

## THE RISK OF ELECTROCUTION

The use of electronic medical equipment subjects patients and hospital personnel to the risk of electrocution. Anesthesiologists must have at least a basic understanding of electrical hazards and their prevention.

Body contact with two conductive materials at different voltage potentials may complete a circuit and result in an electrical shock. Usually, one point of exposure is a live 110-V or 240-V conductor, with the circuit completed through a ground contact. For example, a grounded person need contact only one live conductor to complete a circuit and receive a shock. The live conductor could be the frame of a patient monitor that has developed a fault to the hot side of the power line. A circuit is now complete between the power line (which is earth grounded at the utility company's pole-top transformer) through the victim and back to the ground (Figure 2–6). The physiological effect of electrical current depends on the location, duration, frequency, and magnitude (more accurately, current density) of the shock.

**Leakage current** is present in all electrical equipment as a result of capacitive coupling, induction between internal electrical components, or defective insulation. Current can flow as a result of capacitive coupling between two conductive bodies (eg, a circuit board and its casing) even though they are not physically connected. Some monitors are doubly insulated to decrease the effect of capacitive coupling. Other monitors are designed to be connected to a low-impedance ground (the safety ground wire) that should divert the current away from a person touching the instrument's case. 5 The magnitude of such leaks is normally imperceptible to touch (<1 mA, and well below the fibrillation threshold of 100 mA). If the current bypasses the high resistance offered by skin, however, and is applied directly to the heart (**microshock**), current as low as 100 μA may be fatal. The maximum leakage allowed in operating room equipment is 10 μA.

Cardiac pacing wires and invasive monitoring catheters provide a conductive pathway to the myocardium. In fact, blood and normal saline can serve as electrical conductors. The exact amount of current required to produce fibrillation depends on the timing of the shock relative to the vulnerable period of heart repolarization (the T wave on the electrocardiogram). Even small differences in potential between the earth connections of two electrical outlets in the same operating room might place a patient at risk for microelectrocution.

## PROTECTION FROM ELECTRICAL SHOCK

Most patient electrocutions are caused by current flow from the live conductor of a grounded circuit through the body and back to a ground (Figure 2–6). This would be prevented if everything in the operating room were grounded except the patient. Although direct patient grounds should be avoided, complete patient isolation is not feasible

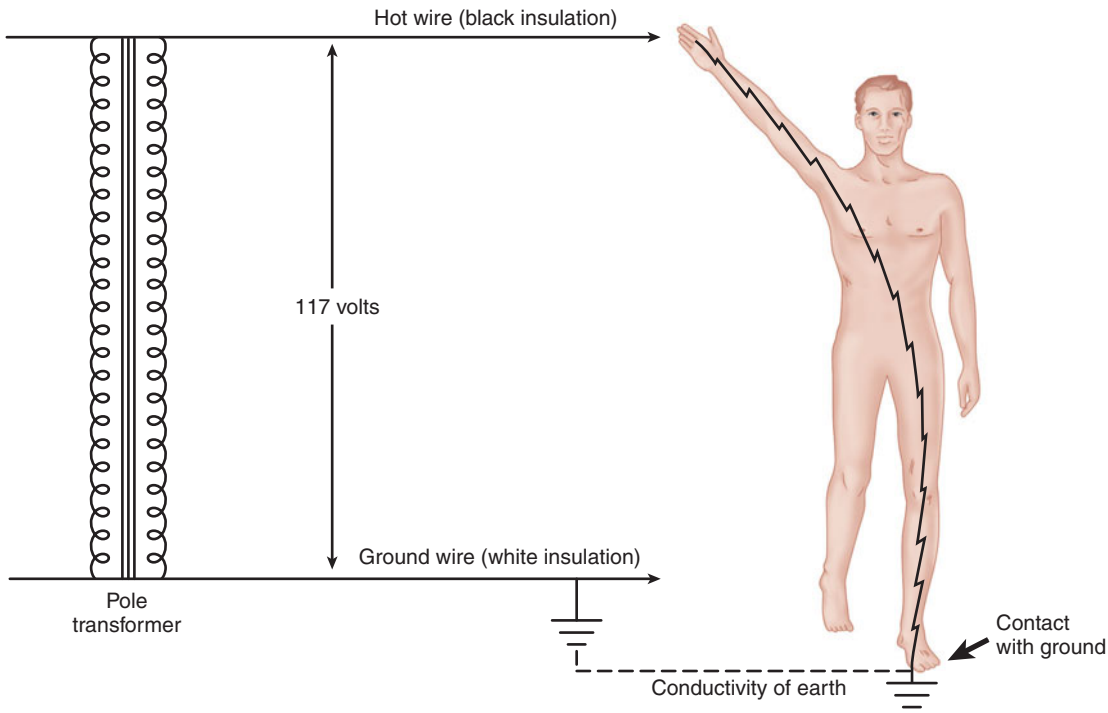


**FIGURE 2–6** The setting for the great majority of electric shocks. An accidentally grounded person simultaneously contacts the hot wire of the electric service, usually via defective equipment that provides a pathway linking the hot wire to an exposed conductive surface. The complete electrical loop originates with the secondary of the pole transformer (the voltage source) and extends through the hot wire, the victim and the victim's contact with a ground, the earth itself, the neutral ground rod at the service entrance, and back to the transformer via the neutral (or ground) wire. (Modified and reproduced, with permission, from Bruner J, Leonard PF: *Electricity, Safety, and the Patient*. Mosby Year Book, 1989.)

during surgery. Instead, the operating room power supply can be isolated from grounds by an **isolation transformer** (Figure 2–7).

Unlike the utility company's pole-top transformer, the secondary wiring of an isolation transformer is not grounded and provides two live ungrounded voltage lines for operating room equipment. Equipment casing—but not the electrical circuits—is grounded through the longest blade of a three-pronged plug (the safety ground). If a live wire is then unintentionally contacted by a grounded patient, current will not flow through the patient since no circuit back to the secondary coil has been completed (Figure 2–8).

Of course, if both power lines are contacted, a circuit is completed and a shock is possible. In addition, if either power line comes into contact with a ground through a fault, contact with the other power line will complete a circuit through a grounded patient. To reduce the chance of two coexisting faults, a **line isolation monitor** measures the potential for current flow from the isolated power supply to the ground (Figure 2–9). Basically, the line isolation monitor determines the degree of isolation between the two power wires and the ground and predicts the amount of current that *could* flow if a second short circuit were to develop. An alarm is activated if an unacceptably high current flow to the ground becomes possible (usually 2 mA or 5 mA), but power is not interrupted unless a ground-fault circuit interrupter is also activated. The latter, a feature of household bathrooms, is usually not installed in locations such as operating rooms,

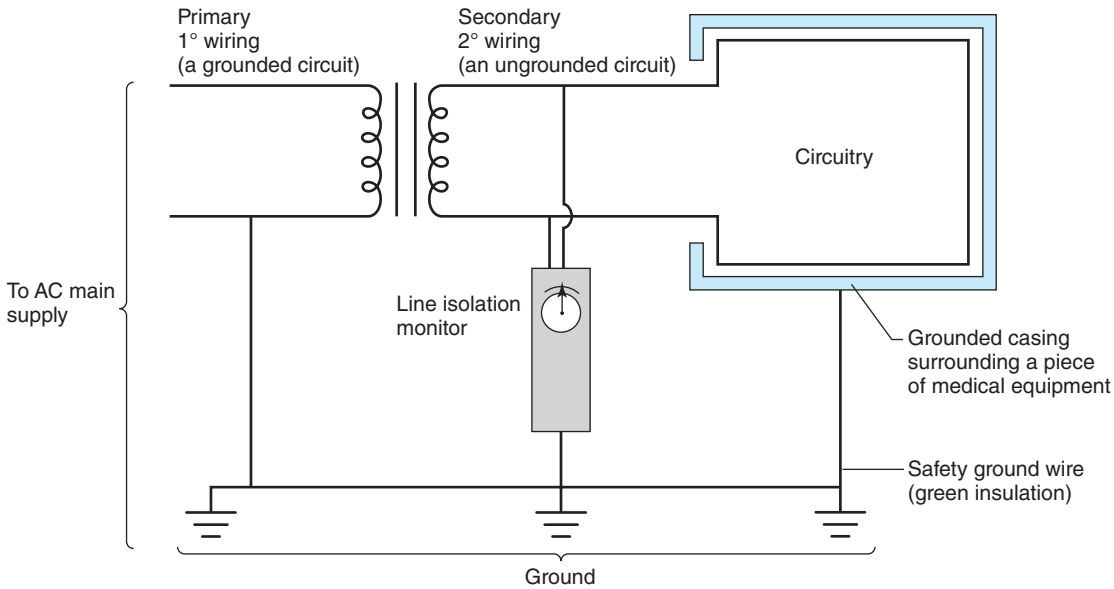


**FIGURE 2–7** A circuit diagram of an isolation transformer and monitor.

where discontinuation of life support systems (eg, cardiopulmonary bypass machine) is more hazardous than the risk of electrical shock. The alarm of the line isolation monitor merely indicates that the power supply has partially reverted to a grounded system. In other words, while the line isolation monitor warns of the existence of a single fault (between a power line and a ground), two faults are required for a shock to occur. Since the line isolation monitor alarms when the sum of leakage current exceeds the set threshold, the last piece of equipment is usually the defective one; however, if this item is life-sustaining, other equipment can be removed from the circuit to evaluate whether the life safety item is truly at fault.

Even isolated power circuits do not provide complete protection from the small currents capable of causing microshock fibrillation. Furthermore, the line isolation monitor cannot detect all faults, such as a broken safety ground wire within a piece of equipment. Despite the overall utility of isolated power systems, they add to construction costs. Their requirement in operating rooms was deleted from the National Electrical Code in 1984, and circuits of newer or remodeled operating rooms may offer less protection from electroshock injury than circuits of a household bathroom.

There are, however, modern equipment designs that decrease the possibility of microelectrocution. These include double insulation of the chassis and casing, ungrounded battery power supplies, and patient isolation from equipment-connected grounds by using optical coupling or transformers.

## SURGICAL DIATHERMY

Electrosurgical units (ESUs) generate an ultrahigh-frequency electrical current that passes from a small active electrode (the cautery tip) through the patient and exits by way of a large plate electrode (the dispersal pad, or return electrode). The high current density at the cautery tip is capable of tissue coagulation or cutting, depending on the electrical waveform. Ventricular fibrillation is prevented by the use of ultrahigh electrical frequencies (0.1–3 MHz) compared with line power (50–60 Hz). The large surface area of the low-impedance return electrode avoids burns at the current's point of exit by providing a low current density (the concept of *exit* is technically incorrect, as the current

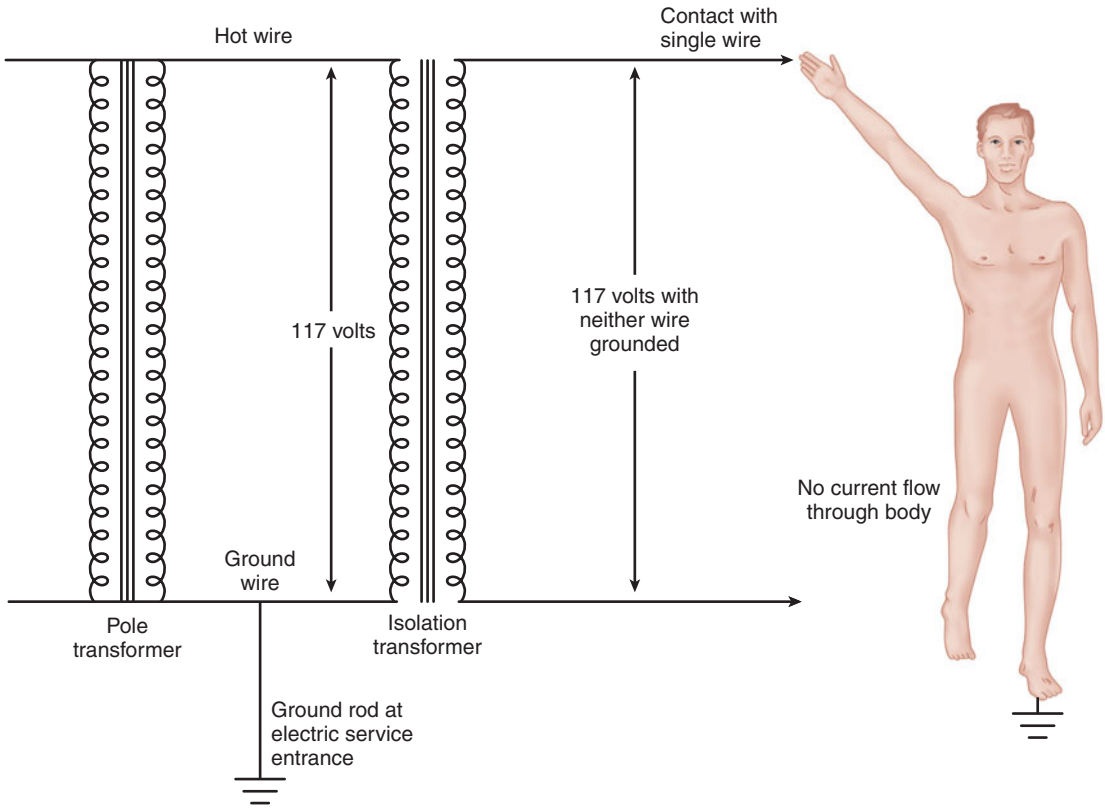


**FIGURE 2–8** Even though a person is grounded, no shock results from contact with one wire of an isolated circuit. The individual is in simultaneous contact with two separate voltage sources but does not close a loop including either source. (Modified and reproduced, with permission, from Bruner J, Leonard PF: *Electricity, Safety, and the Patient*. Mosby Year Book, 1989.)

is alternating rather than direct). The high power levels of ESUs (up to 400 W) can cause inductive coupling with monitor cables, leading to electrical interference.

Malfunction of the dispersal pad may result from disconnection from the ESU, inadequate patient contact, or insufficient conductive gel. In these situations, the current will find another place to exit (eg, electrocardiogram pads or metal parts of the operating table), which may result in a burn (**Figure 2–10**). Precautions to prevent diathermy burns include proper return electrode placement, avoiding prostheses and bony protuberances, and elimination of patient-to-ground contacts. Current flow through the heart may lead to dysfunction of an implanted cardiac rhythm management device (CRMD). This can be minimized by placing the return electrode as close to the surgical field and as far from the CRMD as practical.

Newer ESUs are isolated from grounds using the same principles as the isolated power supply (isolated output versus ground-referenced units). Because this second layer of protection provides ESUs with their own isolated power supply, the operating room's line isolation monitor may not detect an electrical fault. Although some ESUs are capable of detecting poor contact between the return electrode and the patient by monitoring impedance, many older units trigger the alarm only if the return electrode is unplugged from the machine. Bipolar

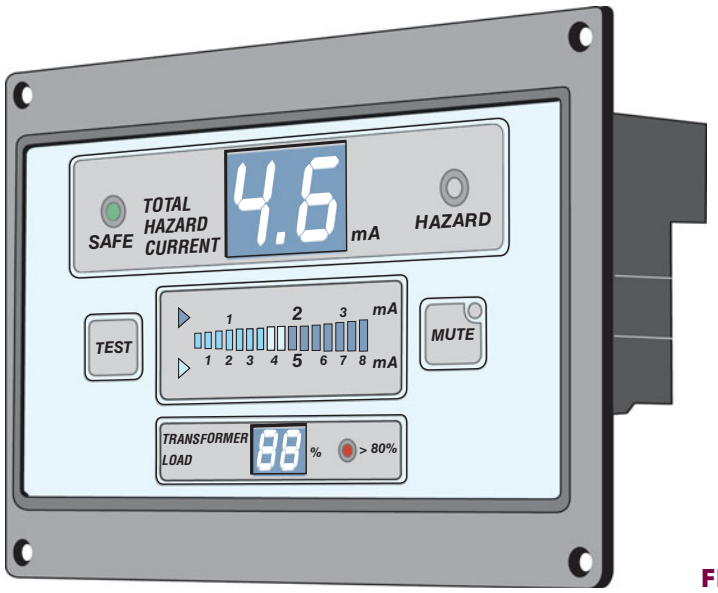


**FIGURE 2–9** A line isolation monitor.

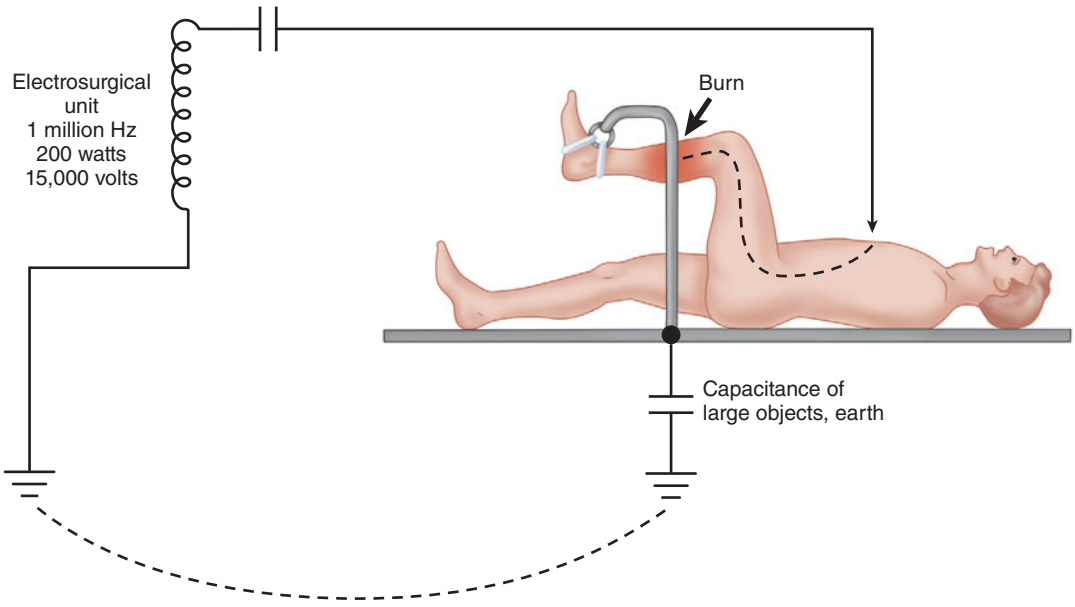


**FIGURE 2–10** Electrosurgical burn. If the intended path is compromised, the circuit may be completed through other routes. Because the current is of high frequency, recognized conductors are not essential; capacitances can complete gaps in the circuit. Current passing through the patient to a contact of small area may produce a burn. (A leg drape would not offer protection in the situation depicted.) The isolated output electrosurgical unit (ESU) is much less likely than the ground-referenced ESU to provoke burns at ectopic sites. *Ground-referenced* in this context applies to the ESU output and has nothing to do with isolated versus grounded power systems. (Modified and reproduced, with permission, from Bruner J, Leonard PF: *Electricity, Safety, and the Patient*. Mosby Year Book, 1989.)

electrodes confine current propagation to a few millimeters, eliminating the need for a return electrode. Because pacemaker and electrocardiogram interference is possible, pulse or heart sounds should be closely monitored when any ESU is used. Automatic implanted cardioversion and defibrillator devices may need to be suspended if monopolar ESU is used and any implanted CRMD should be interrogated after use of a monopolar ESU.

# Surgical Fires & Thermal Injury

## FIRE PREVENTION & PREPARATION

Surgical fires are relatively rare, with an incidence of about 1:87,000 cases, which is close to the incidence rate of other events such as retained foreign objects after surgery and wrong-site surgery. 7 Almost all surgical fires can be prevented. Unlike medical complications, fires are a product of simple physical and chemical properties. Occurrence is guaranteed given the proper combination of factors but can be eliminated almost entirely by understanding the basic principles of fire risk. 8 Likely the most common risk factor for surgical fire relates to the open delivery of oxygen.

Situations classified as carrying a high risk for a surgical fire are those that involve an ignition source used in close proximity to an oxidizer. The simple chemical combination required for any fire is commonly referred to as the fire triad or fire triangle. The triad is composed of fuel, oxidizer, and ignition source (heat). Table 2–2 lists potential contributors to fires and explosions in the operating room. Surgical fires can be managed and possibly avoided completely by incorporating education, fire drills, preparation, prevention, and response into educational programs provided to operating room personnel.

For anesthesia providers, fire prevention education should place a heavy emphasis on the risk relating to the open delivery of oxygen. The Anesthesia Patient Safety Foundation has developed an educational video and online teaching module that provides fire safety education from the perspective of the anesthesia provider.

**TABLE 2–2 Potential contributors to operating room fires and explosions.**

| |
|---|
| Flammable agents (fuels) |
| Solutions, aerosols, and ointments |
| Alcohol |
| Chlorhexidine |
| Benzoin |
| Mastisol |
| Acetone |
| Petroleum products |
| Surgical drapes (paper and cloth) |
| Surgical gowns |
| Surgical sponges and packs |
| Surgical sutures and mesh |
| Plastic/polyvinyl chloride/latex products |
| Endotracheal tubes |
| Masks |
| Cannulas |
| Tubing |
| Intestinal gases |
| Hair |
| Gases supporting combustion (oxidizers) |
| Oxygen |
| Nitrous oxide |
| Ignition sources (heat) |
| Lasers |
| Electrosurgical units |
| Fiberoptic light sources (distal tip) |
| Drills and burrs |
| External defibrillators |

Operating room fire drills increase awareness of the fire hazards associated with surgical procedures. In contrast to the typical institutional fire drill, these drills should be specific to the operating room and should place a greater emphasis on the particular risks associated with that setting. For example, consideration should be given to both vertical and horizontal evacuation of surgical patients, movement of patients requiring ventilatory assistance, and unique situations such as prone or lateral positioning and movement of patients who may be fixed in neurosurgical pins.

Preparation for surgical fires can be incorporated into the time-out process of the universal protocol. Team members should be introduced and specific roles agreed upon should a fire erupt. Items needed to properly manage a fire can be assembled

or identified beforehand (eg, ensuring the proper endotracheal tube for patients undergoing laser surgery; having water or saline ready on the surgical field; identifying the location of fire extinguishers, gas cutoff valves, and escape routes). A poster or flowsheet to standardize the preparation may be of benefit.

Preventing catastrophic fires in the operating room begins with a strong level of communication among all members of the surgical team. Different aspects of the fire triad are typically under the domain of particular surgical team members. Fuels such as alcohol-based solutions, adhesive removers, and surgical drapes and towels are typically controlled by the circulating nurse. Ignition sources such as electrocautery, lasers, drills, burrs, and light sources for headlamps and laparoscopes are usually controlled by the surgeon. The anesthesia provider maintains control of the oxidizer concentration of oxygen and nitrous oxide. Communication between personnel is evident when a surgeon enters the airway and verifies the concentration of oxygen before using cautery, or when an anesthesiologist asks the circulator to configure drapes to prevent the accumulation of oxygen in a surgical case that involves sedation and use of a nasal cannula.

**9** Administration of oxygen in concentrations of greater than 30% should be guided by clinical presentation of the patient and not solely by protocols or habits. If oxygen is being delivered via nasal cannula or face mask, and if increased oxygen levels are needed, then the airway should be secured by either endotracheal tube or supraglottic device. This is of prime importance when the surgical site is above the level of the xiphoid.

When the surgical site is in or near the airway and a flammable tube is present, the oxygen concentration should be reduced for a sufficient period of time before use of an ignition device (eg, laser or cautery) to allow reduction of oxygen concentration at the site. Laser airway surgery should incorporate either jet ventilation without an endotracheal tube or the appropriate protective tube specific for the wavelength of the laser. Precautions for laser cases are outlined below.

Alcohol-based skin preparations are extremely flammable and require an adequate drying time. Pooling of solutions must be avoided. Large prefilled swabs of alcohol-based solution should be used with caution on the head or neck to avoid both oversaturation of the product and excess flammable waste. Product inserts are a good source of information about these preparations. Surgical gauze and sponges should be moistened with sterile water or saline if used in close proximity to an ignition source.

Should a fire occur in the operating room it is important to determine whether the fire is located *on the patient, in the airway,* or *elsewhere in the operating room*. For fires occurring in the airway, the delivery of fresh gases to the patient must be stopped. Effective means of stopping fresh gases to the patient can be accomplished by turning off flowmeters, disconnecting the circuit from the machine, or disconnecting the circuit from the endotracheal tube. The endotracheal tube should be removed and either sterile water or saline should be poured into the airway to extinguish any burning embers. The sequence of stopping gas flow and removal of the endotracheal tube when fire occurs in the airway is not as important as ensuring that both actions are performed quickly. Often the two tasks can be accomplished at the same time and even by the same individual. If carried out by different team members, the personnel should act without waiting for a predetermined sequence of events. After these actions are carried out, ventilation may be resumed, preferably using room air and avoiding oxygen or nitrous oxide–enriched gases. The tube should be examined for missing pieces. The airway should be reestablished and, if indicated, examined with a bronchoscope. Treatment for smoke inhalation and possible transfer to a burn center should also be considered.

**10**

For fires on the patient, the flow of oxidizing gases should be stopped, the surgical drapes removed, and the fire extinguished by water or smothering. The patient should be assessed for injury. If the fire is not immediately extinguished by first attempts, then a carbon dioxide ($CO_2$) fire extinguisher may be used. Further actions may include evacuation of the patient and activation of the nearest pull station. As noted previously, prior to an actual emergency, the location of fire extinguishers, emergency exits,

and fresh gas cutoff valves should be established by the anesthesia provider.

Fires that result in injuries requiring medical treatment or death must be reported to the fire marshal, who retains jurisdiction over the facility. Providers should gain basic familiarity with local reporting standards, which can vary according to location.

Cases in which supplemental delivery of oxygen is used and the surgical site is above the xiphoid constitute the most commonly reported scenario for surgical fires. Frequently the face or airway is involved, resulting in life-threatening injuries and the potential for severe facial disfigurement. For the most part, these fires can be avoided by the elimination of the open delivery of oxygen, by use of an oxygen blender, or by securing the airway.

## FIRE EXTINGUISHERS

For fires not suppressed by initial attempts or those in which evacuation may be hindered by the location or intensity of the fire, the use of a portable fire extinguisher is warranted. A $CO_2$ extinguisher should be safe during external and internal exposure for fires on the patient in the operating room. $CO_2$ readily dissipates, is not toxic, and as used in an actual fire is not likely to result in thermal injury. FE-36, manufactured by DuPont, also can be used to extinguish fires but is expensive. Both choices are equally effective and acceptable agents as reflected by manufacturers' product information.

"A"-rated extinguishers contain water, which makes their use in the operating room problematic because of the presence of so much electrical equipment. A water mist "AC"-rated extinguisher is excellent but requires time and an adequate volume of mist over multiple attempts to extinguish the fire. Furthermore, these devices are large and difficult to maneuver. Both can be made cheaply in a nonferromagnetic extinguisher, making them the best choice for fires involving magnetic resonance imagers. Halon extinguishers, although very effective, are being phased out because of concerns about depletion of the ozone layer, as well as the hypoxic atmosphere that results for rescuers. Halotrons are "greener" halon-type extinguishers that may have fewer effects on the ozone layer.

## LASER SAFETY

Lasers are commonly used in operating rooms and procedure areas. When lasers are used for airway surgeries or for procedures involving the neck and face, the case should be considered as high risk for surgical fire and managed as previously discussed. The type of laser ($CO_2$, neodymium yttrium aluminum garnet [NG:YAG], or potassium titanyl phosphate [KTP]), wavelength, and focal length are all important considerations for the safe operation of medical lasers. Without this vital information, operating room personnel cannot adequately protect themselves or the patient from harm. Before beginning laser surgery, the laser device should be in the operating room, warning signs should be posted on the doors, and protective eyewear should be issued. The anesthesia provider should ensure that the warning signs and eyewear match the labeling on the device as protection is specific to the type of laser. The American National Standards Institute (ANSI) standards specify that eyewear and laser devices must be labeled for the wavelength emitted or protection offered. Some ophthalmologic lasers and vascular mapping lasers have such a short focal length that protective eyewear is not needed. For other devices, protective goggles should be worn by personnel at all times during laser use, and eye protection in the form of either goggles or protective eye patches should be used on the patient.

Laser endotracheal tube selection should be based on laser type and wavelength. The product insert and labeling for each type of tube should be compared to the type of laser used. Certain technical limitations are present when selecting laser tubes. For instance, tubes less than 4.0 mm in diameter are not compatible with the ND:YAG or argon laser nor are ND:YAG-compatible tubes available in half sizes. Attempts to wrap conventional endotracheal tubes with foil should be avoided. This archaic method is not approved by either manufacturers or the U.S. Food and Drug Administration, is prone to breaking or unraveling, and does not confer protection against laser penetration. Alternatively, jet

ventilation without an endotracheal tube can offer a reduced risk of airway fire.

## CREW RESOURCE MANAGEMENT: CREATING A CULTURE OF SAFETY IN THE OPERATING ROOM

Crew resource management (CRM) was developed in the aviation industry to allow personnel to intervene or call for investigation of any situation thought to be unsafe. Comprising seven principles, its goal is to avoid errors caused by human actions. In the airline model CRM gives any crew member the authority to question situations that fall outside the range of normal practice. Before the implementation of CRM, crew members other that the captain had little or no input on aircraft operations. After CRM was instituted, anyone identifying a safety issue could take steps to ensure adequate resolution of the situation. The benefit of this method in the operating room is clear, given the potential for a deadly mistake to be made.

The seven principles of CRM are (1) adaptability/flexibility, (2) assertiveness, (3) communication, (4) decision making, (5) leadership, (6) analysis, and (7) situational awareness. *Adaptability/flexibility* refers to the ability to alter a course of action when new information becomes available. For example, if a major blood vessel is unintentionally cut in a routine procedure, the anesthesiologist must recognize that the anesthetic plan has changed and volume resuscitation must be made even in presence of medical conditions that typically contraindicate large-volume fluid administration.

*Assertiveness* is the willingness and readiness to actively participate, state, and maintain a position until convinced by the facts that other options are better; this requires the initiative and the courage to act. For instance, if a senior and well-respected surgeon tells the anesthesiologist that the patient's aortic stenosis is not a problem because it is a chronic condition and the procedure will be relatively quick, the anesthesiologist should respond by voicing concerns about the management of the patient and should not proceed until a safe anesthetic and surgical plan have been agreed upon.

*Communication* is defined simply as the clear and accurate sending and receiving of information, instructions, or commands, and providing useful feedback. Communication is a two-way process and should continue in a loop fashion.

*Decision making* is the ability to use logical and sound judgment to make decisions based on available information. Decision-making processes are involved when a less experienced clinician seeks out the advice of a more experienced clinician or when a person defers important clinical decisions because of fatigue. Good decision making is based on realization of personal limitations.

*Leadership* is the ability to direct and coordinate the activities of other crew members and to encourage the crew to work together as a team. *Analysis* refers to the ability to develop short-term, long-term, and contingency plans, as well as to coordinate, allocate, and monitor crew and operating room resources.

The last and most important principle is *situational awareness*; that is, the accuracy with which a person's perception of the current environment mirrors reality. In the operating room, lack of situational awareness can cost precious minutes, as when readings from a monitor (eg, capnograph or arterial line) suddenly change and the operator focuses on the monitor rather than on the patient, who may have had an embolism. One must decide whether the monitor is correct and the patient is critically ill or the monitor is incorrect and the patient is fine. The problem-solving method utilized should consider both possibilities but quickly eliminate one. In this scenario, tunnel vision can result in catastrophic mistakes. Furthermore, if the sampling line has come loose and the capnograph indicates low end-tidal $CO_2$, this finding does not exclude the possibility that at the same time or even a bit later, the patient could have a pulmonary embolus resulting in decreased end-tidal $CO_2$.

If all members of the operating room team apply these seven principles, problems arising from human factors can almost entirely be eliminated. A culture of safety must also exist if the operating room is to be made a safer place. These seven principles serve no purpose when applied in a suppressive surgical environment. Anyone with a concern must be able speak up without fear of repercussion.

Chapter 58 provides further discussion of these and other issues relating to patient safety.

# FUTURE DESIGN OF OPERATING ROOMS

## Safety Interlock Technology

Despite heightened awareness of safety factors and increased educational efforts among operating room personnel, harm to patients still occurs at a rate that most industries and the public deem unacceptably high. Similarly, despite threats of payment withholding, public scoring of medical personnel and hospital systems, provider rating web sites, and punitive legal consequences, the human factors resulting in medical errors have not been completely eliminated. In future, safety-engineered designs may assist in the reduction of medical errors. One developing area is the use of interlock devices in the operating room. An interlock device is simply a device that cannot be operated until a defined sequence of events occurs. Anesthesia personnel use interlock technology with anesthesia vaporizers that prevent the use of more than one vaporizer at a time. Expansion of this technology might prevent release of a drug from an automated dispensing device until a barcode is scanned from a patient's hospital armband or, at a minimum, the patient's drug allergies have been entered into the machine's database. Other applications might include an electrosurgical device or laser that could not be used when the $FiO_2$ content was higher than 30%, thus eliminating the risk of fire. Likewise, computers, monitors, and other devices could be designed to be inoperable until patient identification was confirmed.

## Workflow Design

Coordinating the activities of surgical personnel, anesthesia providers, and operating room nurses is essential to the day-to-day running of a surgical suite. Clinical directors in facilities ranging from one- or two-room suites to multiroom centers must accommodate surgical procedures of varying durations, requiring varying degrees of surgical skill and efficiency, while allowing for sudden, unplanned, or emergency operations. The need to monitor workflow and analyze data for optimizing scheduling and staffing prompted the development of software systems that anticipate and record the timing of surgical events; these systems are constantly being refined.

Surgical suites are also being designed to augment workflow by incorporating separate induction areas to decrease nonsurgical time spent in operating rooms. Several models exist for induction room design and staffing. Although uncommon in the United States, induction rooms have long been employed in the United Kingdom.

One induction room model uses rotating anesthesia teams. One team is assigned to the first patient of the day; a second team induces anesthesia for the next patient in an adjacent area while the operating room is being turned over. The second team continues caring for that patient after transfer to the operating room, leaving the first team available to induce anesthesia in the third patient as the operating room is being turned over. The advantage of this model is continuity of care; the disadvantage is the need for two anesthesia teams for every operating room.

Another model uses separate induction and anesthesia teams. The induction team induces anesthesia for all patients on a given day and then transfers care to the anesthesia team, which is assigned to an individual operating room. The advantage of this model is the reduction in anesthesia personnel to staff induction rooms; disadvantages include failure to maintain continuity of care and staffing problems that occur when several patients must undergo induction concurrently. This model can utilize either a separate induction room adjacent to each operating room or one common induction room that services several operating rooms.

The final model uses several staffed operating rooms, one of which is kept open. After the first patient of the day is transferred to the initial room, subsequent patients always proceed to the open room, thus eliminating the wait for room turnover and readiness of personnel. All of these models assume that the increased overhead cost of maintaining additional anesthesia personnel can be justified by the increased surgical productivity.

## Radio Frequency Identification (RFID)

Radio frequency identification (RFID) technology utilizes a chip with a small transmitter whose

signal is read by a reader; each chip yields a unique signal. The technology has many potential applications in the modern operating room. Using RFID in employee identification (ID) badges could enable surgical control rooms to keep track of nursing, surgical faculty, and anesthesia personnel, obviating the need for paging systems and telephony to establish the location of key personnel. Incorporating the technology in patient ID bands and hospital gurneys could allow a patient's flow to be tracked through an entire facility. The ability to project an identifying signal to hospital systems would offer an additional degree of safety for patients unable to communicate with hospital personnel. Finally, RFID could be incorporated into surgical instruments and sponges, allowing surgical counts to be performed by identification of the objects as they are passed on and off the surgical field. In the event that counts are mismatched, a wand could then be placed over the patient to screen for retained objects.

## CASE DISCUSSION

### Monitored Anesthesia Care with Oxygen Supplementation

**You are asked to provide monitored anesthesia care for a patient undergoing simple removal of a lesion on the cheek. The patient is morbidly obese and has a history of sleep apnea. He states, "It bothers me when people are working on my face," and indicates that he does not want to remember anything about the surgery. The surgeon assures you the procedure will not last more than 5 minutes. The patient's wife mentions that they are from out of town and have made flight arrangements to return home soon after the procedure.**

***What features of this case indicate a high risk for surgical fire?***

Patients with a clinical history of obstructive sleep apnea usually have a sensitivity to sedating medications, especially opioid narcotics. Typically administration of even small doses of narcotics obstructs the upper airways, resulting in hypoventilation and hypercapnia. In the obese patient, this response combined with decreased functional reserve capacity results in rapid oxygen desaturation. Most anesthesia providers respond by increasing the amount of oxygen supplementation delivered via face mask or nasal cannula. Open delivery of oxygen in concentrations greater than 30% is one of the elements of the fire triad. Another consideration is the anatomical location of the procedure. A location above the xiphoid process in this patient would place an ignition source (if used) in close proximity to the open delivery of an oxidizer.

***What is the safest manner in which to proceed?***

There are three strategies that can be implemented to improve safety in this scenario: avoid oxygen supplementation, secure the airway with an endotracheal tube or supraglottic device, or avoid use of an ignition source.

***Are there any concerns relating to airway management or selection of the delivery device?***

As previously noted, the patient is likely to manifest airway changes associated with obstructive sleep apnea and obesity. Selection of a delivery device should take into consideration the need to prevent the open delivery of oxygen.

***How would the length of the procedure affect the management of anesthesia?***

Practically speaking, if the patient requires a lengthy procedure, local anesthetics may wear off; the cumulative dose of narcotics provided may exacerbate the patient's obstructive sleep apnea and increase recovery time. Additionally, more complex surgical excision may result in bleeding requiring the use of cautery.

***Does the patient's expectation of discharge soon after the procedure affect your anesthesia plans?***

The expectation of an accelerated recovery period may not be feasible if the patient requires general anesthesia or significant amounts of opioid narcotics. The American Society of Anesthesiologists (ASA) has published a practice advisory providing direction for the safe postoperative assessment and discharge of patients with obstructive sleep apnea. See www.asahq.org.

***What if the surgeon thinks your plans are "overkill"?***

The first and most effective means for conflict resolution is to communicate your specific concerns to the surgeon. If this fails, the procedure must not be allowed to proceed as long as any team member has a legitimate safety concern. Many ASA safety-related guidelines and advisories are also endorsed by professional societies such as the American College of Surgeons (ACS) and other organizations. The anesthesiologist should also gain familiarity with a facility's methods of dispute resolution before an event occurs.

## SUGGESTED READING

Dorsch JA, Dorsch SE: *Understanding Anesthesia Equipment*, 5th ed. Williams & Wilkins, 2008. A detailed discussion of compressed gases and medical gas delivery systems.

Macdonald MR, Wong A, Walker P, Crysdale WS: Electrocautery-induced ignition of tonsillar packing. J Otolaryngol 1994;23:426. An examination of factors that can decrease the risk of airway fire including lower oxygen concentration (using a cuffed tracheal tube), completely soaked tonsil packs, and avoidance of contact between electrocautery and bismuth subgallate.

National Fire Protection Association (NFPA): *Standard for Health Care Facilities*. NFPA, 2002. An updated version of NFPA 99 standards.

## WEB SITES

http://www.ansi.org
The American National Standards Institute is the reference source for laser standards and many other protective engineering standards.

http://www.apsf.org
The Anesthesia Patient Safety Foundation provides resources and a newsletter that discusses important safety issues in anesthesia. The web site also contains a link to view or request the video *Prevention and Management of Operating Room Fires*, which is an excellent resource to gain information concerning the risks and prevention of surgical fires.

http://www.asahq.org
The American Society of Anesthesiologists (ASA) web site contains the ASA practice parameters and advisories. Many are oriented around patient safety issues and all can be printed for review.

http://www.cganet.com
The Compressed Gas Association and its web site are dedicated to the development and promotion of safety standards and safe practices in the industrial gas industry.

http://www.ecri.org
The ECRI (formerly the Emergency Care Research Institute) is an independent nonprofit health services research agency that focuses on health care technology, health care risk and quality management, and health care environmental management.

http://www.fda.org
The U.S. Food and Drug Administration (FDA) has an extensive web site covering many broad categories. Two major divisions address patient safety: the Center for Devices and Radiological Health (CDRH), which regulates and evaluates medical devices, and the Center for Drug Evaluation and Research (CDER), which regulates and evaluates drugs.

http://www.nfpa.org
The National Fire Protection Association (NPFA) has a web site with a catalog of publications on fire, electrical, and building safety issues. Some areas require a subscription to access.

http://patientsafetyauthority.org
The Patient Safety Authority maintains data collected from the mandatory reporting of incidents of harm or near harm in the Commonwealth of Pennsylvania. Some data such as surgical fires data can be extrapolated to determine the likely incidence for the entire United States.

http://vam.anest.ufl.edu/
The Virtual Anesthesia Machine web site has extensive interactive modules to facilitate understanding of many processes and equipment. The site, which contains high-quality graphic illustrations and animation, requires free registration.