2 Plumbing Design for Health-Care Facilities

INTRODUCTION

Health-care facilities, nursing homes, medical schools, and medical laboratories require plumbing systems that are more complex than those for most other types of building. The plumbing designer should work closely with the architect and facility staff and be involved in meetings and discussions in order to fully understand the plumbing requirements for any new or special medical equipment. The plumbing design must be coordinated with the civil, architectural, structural, mechanical, and electrical designs to ensure that adequate provisions have been made for utility capacities, for the necessary clearances and space requirements of the piping systems and related plumbing equipment, and for compliance with applicable codes. Health-care facilities may have different requirements or be exempt from some codes and standards, such as water and energy conservation codes and regulations regarding the physically challenged. The plumbing engineer should consult with the administrative authority in order to ensure conformance with local ordinances.

This chapter discusses the provisions that may be encountered by the plumbing professional in the design of a health-care facility, including the following: plumbing fixtures and related equipment, the sanitary drainage system, the water-supply system, laboratory waste and vent systems, pure-water systems, and medical-gas systems.

PLUMBING FIXTURES AND RELATED EQUIPMENT

Selection Process

Meetings of the plumbing engineer with the architect and the facility staff to discuss the general and specific requirements regarding the plumbing fixtures and related equipment are usually held after the architect has prepared the preliminary drawings. At these meetings, the plumbing designer should assist in the selection of plumbing fixtures. Following these sessions, the plumbing designer can prepare the preliminary drawings and coordinate with the architect and facility staff the required piping systems and the plumbing fixture space requirements. In detailing the piping system spaces and plumbing fixture locations, the plumbing engineer should refer to the framing drawings. It is common for the architect to locate the piping shafts and the spaces in direct conflict with the framing; it is the plumbing designer's responsibility to give the architect directions regarding the space requirements, fixture arrangement, and pipe-shaft size and locations.

Following the meetings held with the architect and hospital staff, and with the preliminary drawings available, the plumbing designer should prepare an outline specification for the plumbing fixtures and related equipment. A guide to the required plumbing fixtures and equipment for health-care facilities is provided in Table 2-1 and is discussed later in this section.

A review of applicable code requirements regarding the quality and types of plumbing fixtures

Table 2-1 Recommended Plumbing Fixtures and Related Equipment

Medical-Care Areas

	Elongated Water Closet, FlushValve	Urinal	Handwashing Lavatory	Shower	Drinking Fountain / Water Cooler	Mop Service Basin	Counter Sink, Single Compartment	Counter Sink, Double Compartment	Clinic Sink, Flushing Rim	Scrub-up Sink	Utility Sink	Sink, Triple Compartment	Plaster Sink, Plaster Trap	Cup Sink	Floor Drain	Floor Drain, Flushing Rim	Emergency Shower	Emergency Eyewash	Bathtub / Shower	Sitz Bath	Bedpan Washer	Waste Grinder	Ice Maker	Arm / Leg Bath	Immersion Bath	Glass Washer	Infant Bathtub
Public/Staff Restrooms	●	●	●	●	●	●									●												
Staff Lounge	●	●	●		●		●																●				
Patient Rooms	●		●	●																	●						
Isolation Rooms	●		●	●																	●						
Nurse Stations							●																				
Nursery			●																								●
Formula Room			●				●																			●	
Intensive-Care Room	●		●								●																
Outpatient-Services Area	●		●		●										●												
Emergency Rooms	●		●		●				●		●																
Exam/Treatment Room	●		●				●																				
Labor Room	●		●	●																							
Janitor's Closet			●			●									●												
Clean Linen Holding							●																				
Soiled Linen Holding								●	●																		
Nourishment Station			●				●																●				
Patient Bathing Area	●		●	●											●				●								
Critical-Care Area	●		●			●									●						●						
Pharmacy							●																				
Surgical Scrub-up										●																	
Anesthesia Workroom							●																				
Surgical Supply Services								●																			
Surgical Cleanup Room									●																		
Doctors' Locker Room	●	●	●	●																							
Nurses' Locker Room	●		●	●																							
Recovery Room			●						●												●						
Fracture Room			●										●														
Cleanup/Utility Room			●				●		●												●						
Sub-Sterilizing Room							●																				
Medical Laboratory	●	●	●		●	●	●							●	●		●	●								●	
Physical Therapy Room	●		●				●								●					●				●	●		
Cystoscopic Room	●		●	●					●							●						●					
Autopsy Room	●		●	●		●	●		●							●						●					
Dietary Services	●	●	●			●	●	●				●			●							●	●				
Laundry Facility	●		●								●				●												
Family Waiting Room	●		●		●																						

is always required. In addition to the local codes, it is necessary for the plumbing engineer to refer to the special hospital code requirements published by the local hospital authorities, the state hospital or health-department authorities, the Joint Commission for the Accreditation of Hospitals Organization (JCAHO), and the US Department of Health and Human Services. The architect may investigate these special requirements; however, the plumbing designer must be familiar with them since they contain many other applicable requirements (in addition to the table indicating the plumbing fixtures necessary for a particular installation).

General Requirements

Plumbing fixtures in health-care facilities should be of dense, impervious materials having smooth surfaces. Plumbing fixtures of vitreous china, enameled cast iron, and stainless steel are commonly used. Fixture brass—including faucets, traps, strainers, escutcheons, stops, and supplies—should be chromium plated in a manner approved by the administrative authority. Die-cast metals should not be used. Faucets should have a laminar flow device (no alternative) of brass, Monel metal, or stainless-steel trim. Each plumbing fixture in health-care facilities should be provided with individual stop valves. Each water-service main, branch main, and riser shall have valves. Access shall be provided at all valves. All submerged inlets, faucets with hose adapters, and flush valves must be equipped with approved vacuum breakers. Backflow-prevention devices shall be installed on hose bibbs, supply nozzles used for the connection of hoses or tubing, and at other locations where the potable water supply must be protected from contamination.

All plumbing fixtures, faucets, piping, solder, and fluxes used in potential drinking-water areas should comply with the latest maximum lead content regulations. Facilities for the physically challenged shall be in compliance with the Americans with Disabilities Act (ADA) accessibility guidelines.

Fixtures for Specific Health-Care Areas

General-use staff and public areas

Water closets Vitreous china, siphon-jet water closet with elongated bowl design with open-front seat, less cover, should be specified. Wall-hung water closets are preferred for easy cleaning; however, floor-set models are also acceptable by most local jurisdictions. All water closets should be operated by water-saver flush valves.

Lavatories and sinks Vitreous china, enameled cast iron or stainless-steel lavatories and sinks should be specified. The most commonly specified size is 20 × 18 × 7½ in. deep (508 × 457.2 × 190.5 mm deep). Hands-free controls (foot or knee controls) are generally employed for staff use and for scrub-up sinks. In public areas, codes should be checked for the requirement of self-closing valves and/or metered valves. Stops should be provided for all supply lines. Aerators are not permitted; use laminar flow devices. Insulated and/or offset p-traps should be used for handicapped fixtures.

Faucets Valves should be operable without hands, i.e., with wrist blades or foot controls or electronically. If wrist blades are used, blade handles used by the medical and nursing staff, patients, and food handlers shall not exceed 4½ in. (11.43 cm) in length. Handles on scrub sinks and clinical sinks shall be at least 6 in. (15.24 cm) long. Water spigots used in lavatories and sinks shall have clearances adequate to avoid contaminating utensils and the contents of carafes, etc.

Urinals Vitreous china wall-hung urinals with flush valves. Flush valves should be equipped with stops and may be of the exposed or concealed design.

Showers The shower enclosures and floor specified by the plumbing engineer may be constructed of masonry and tile or of prefabricated fiberglass. Showers and tubs shall have nonslip walking surfaces. The shower valve should automatically compensate for variations in the water-supply pressure and temperature to deliver the discharge water at a set temperature that will prevent scaldings.

Drinking fountains and water coolers Drinking fountains are available in vitreous china, steel and stainless steel. Units for exterior installations are available in suitable materials. Refrigerated water coolers are available in steel or stainless steel. All of these materials are acceptable by most local administrative authorities. These units may be of the surface-mounted, semi-recessed or fully-recessed design.

Chilled water for drinking purposes should be provided between 45 and 50°F (7.2 and 10.0°C) and obtained by chilling water with a refrigeration compressor. The compressor may be enclosed in a cabinet with the dispenser (water cooler), installed in a wall cavity behind a grill adjacent to the dispenser, or remotely located for single or multiple dispensers. A remotely installed unit for multiple dispensers (central system) should have a recirculation system.

Mop-service basins Floor-mounted mop-service basins can be obtained in precast or (terazzo) molded-stone units of various sizes. The plumbing engineer should specify the most suitable model. Rim guards are normally provided to protect the rims from damage and wall guards are provided to protect walls from splashing and chemical stains. The water-supply fixture is usually a two-handle mixing faucet mounted on the wall with a wall brace, vacuum breaker, and hose adapter.

Floor drains Floor drains in toilet rooms are optional in most cases; however, there are many instances where the floor drains are required by the applicable codes. The plumbing designer should give consideration to maintaining a trap seal in the floor drain through the use of deep-seal p-traps and/or trap primers. Floor drains shall not be installed in operating and delivery rooms.

Patient rooms These rooms (private or semi-private) usually are provided with a toilet room containing a water closet, a lavatory, and a shower or bathtub. (Some hospitals use common shower and bath facilities for a group of patient rooms.) The plumbing fixtures should conform with the following recommendations:

The water closet should be vitreous china, wall-hung or floor-mounted design, with an elongated bowl. All water closets should be operated by a flush valve. Water closets should have open-front seats, less cover. Bedpan lugs and bedpan washers are often required by the local codes. Bedpan-flushing devices shall be provided in each inpatient toilet room; however, installation is optional in psychiatric and alcohol-abuse units, where patients are ambulatory.

The lavatory should be a minimum of 20 × 18 × 7½ in. (508 × 457.2 × 190.5 mm) deep. Lavatories should be installed at least 34 in. (863.6 mm) above the floor. Mixing faucets should be of the gooseneck-spout design and provided with wrist-blade handles, electronic, or hands-free controls.

The shower is usually constructed of masonry and tile, acrylics, or fiberglass. The shower bases should be nonslip surfaces. The shower valve should automatically compensate for variations in the water-supply pressure and temperature to deliver the discharge water at a set temperature that will prevent scalding. Grab bars, located within the shower enclosure, are usually required by the local codes. The plumbing engineer should always check with the local administrative authority regarding approved designs.

Bathtubs can be constructed of cast iron, fiberglass, acrylics, or steel. Faucets should be as they are for showers. Shower heads may be of the stationary design, but in many locations hand-held showers are required.

A lavatory intended for use by doctors, nurses, and other hospital staff is sometimes required by the local ordinances. This particular lavatory is usually located on the wall near the door with a gooseneck spout and hands-free controls.

A water closet and lavatory, with a fixed or fold-away water closet made of stainless steel, may be considered. This concept, as well as the construction of the unit, must be accepted by the administrative authority.

Ward rooms Ward rooms are infrequently found in health-care facilities, particularly in the private hospital field. These rooms require at least 1 lavatory. This lavatory should be a minimum 20 × 18 in. (508 × 457.2 mm) and made of vitreous china or stainless steel. The faucet should be of the gooseneck-spout design and provided with wrist-blade handles or hands-free controls.

Nurseries The hospital's nursery is usually provided with a minimum size 20 × 18 in. (508 × 457.2 mm) lavatory with hands-free controls and a high gooseneck spout. An infant's bathtub, wall- or counter-mounted with an integral large drainboard and rinsing basin, is provided. Water-supply fittings are filler spouts over the basins with separate hand-valve controls. The spout and the spray are usually supplied and controlled through a thermostatic mixing valve. The ultimate in maintaining a safe water temperature is a separate supply tank.

Intensive-care rooms These rooms usually have utility sinks with hands-free controls with high gooseneck spouts. A water-supply fitting equipped with a gooseneck spout and provision for bedpan washing (either at an immediately adjacent water closet or at a separate bedpan washing station within an enclosure in the room) should be provided. Newer designs have included combination lavatory/water closets for patient use, especially in cardiac-care units.

Emergency (triage) rooms The plumbing fixtures provided in emergency rooms include a utility sink with an integral tray and a water-supply fitting with a gooseneck spout and wrist-blade handles. A vitreous china clinic sink (or a flushing-rim sink), for the disposal of solids, with the water-supply fitting consisting of a flush valve and a separate combination faucet with vacuum breaker mounted on the wall above the plumbing fixture, should also be provided.

Examination and treatment rooms These rooms are usually provided with vitreous china or stainless-steel lavatories. The water-supply fitting should be a hands-free valve equipped with a high, rigid, gooseneck spout. For a particular examination room or a group of patient rooms, an adjacent toilet room is provided containing a specimen-type water closet for inserting a specimen-collecting bedpan. The toilet room also requires a lavatory and a water supply with wrist-blade handles or hands-free controls and with a gooseneck spout.

Physical-therapy treatment rooms The plumbing fixtures and related equipment for these rooms usually include hydrotherapy immersion baths and leg, hip, and arm baths. These units are generally furnished with electric-motor-driven whirlpool equipment. The water is introduced into the stainless-steel tank enclosure by means of a thermostatic control valve to prevent scalding, usually wall mounted adjacent to the bath for operation by a hospital attendant. The water supply should be sized to minimize tub fill time. The immersion baths are usually provided with overhead hoists and canvas slings for facilitating the lifting in and out of the bath of a completely immobile patient. A hydrotherapy shower is sometimes required. These showers usually consist of multiple shower heads, sometimes as many as 12 to 16, vertically mounted in order to direct the streams of water at a standing patient by means of a sophisticated control console operated by a hospital attendant.

Cystoscopic rooms Among the various plumbing fixtures required in cystoscopic rooms are the following: wall-mounted clinic sinks equipped with flush valves and bedpan washer and combination faucets; lavatories provided with water-supply fittings and gooseneck spouts; and, in a separate adjacent room, specimen water closet and a lavatory. If a floor drain is installed in cystoscopy, it shall contain a nonsplash, horizontal-flow flushing bowl beneath the drain plate.

Autopsy room The autopsy room table is usually provided with cold and hot-water supplies, with a vacuum breaker or backflow preventer, and a waste line. It is necessary that the plumbing designer consult with the table manufacturer and the administrative authority regarding the requirements of the autopsy room table. Drain systems for autopsy tables shall be designed to positively avoid splatter or overflow onto floors or back siphonage and for easy cleaning and trap flushing. The autopsy room is also usually equipped with a stainless steel or vitreous china sink with hands-free fittings, a clinic sink and a "blood" type floor drain. Adjacent to the autopsy room a water closet and a shower room are usually provided. Many autopsy rooms are equipped with waste-disposal units integral with the sink.

Nourishment stations These stations are usually provided on each patient room floor near the nurse station for serving nourishment between regularly scheduled meals. A sink, equipped for hand washing with hands-free controls, an icemaker, and a hot-water dispenser (optional) to provide for the patient's service and treatment should be provided.

Pharmacy and drug rooms The plumbing fixtures for these rooms include medicine and solution sinks. These units can be counter-type or made of stainless steel or vitreous china with a mixing faucet and a swing spout. A solids interceptor should be considered for compounding areas.

Operating-room areas No plumbing fixtures or floor drains are required in the hospital's operating room. However, the scrubbing station located adjacent to the operating room should have at least two scrub sinks, usually made of vitreous china or stainless steel, furnished with hands-free water-supply fittings, and equipped with gooseneck spouts. These sinks should be large

and deep enough to allow scrubbing of hands and arms to the elbow. A soiled workroom, designed for the exclusive use of the hospital's surgical staff, should be located near the operating room area. This workroom should contain a vitreous china, flushing-rim clinical sink, for the disposal of solids, with the water-supply fittings consisting of a flush-valve bedpan washer and a separate faucet mounted on the wall above the fixture and handwashing facilities consisting of a vitreous china or stainless-steel lavatory with a gooseneck spout and equipped with wrist-blade handles. Substerile rooms should be equipped with an instrument sterilizer and general-purpose sink. The plumbing designer should consult with the instrument sterilizer manufacturer for any special requirements for the equipment. The general-purpose sink can be countertop-mounted and equipped with a hands-free water-supply fitting with a gooseneck spout.

Recovery rooms The rooms for the post-anesthesia recovery of surgical patients should include a hand-washing facility, such as a vitreous china or stainless-steel lavatory equipped with a gooseneck spout and wrist-blade handles; and a vitreous china, flushing-rim, clinical sink for the disposal of solids, with the water-supply fitting consisting of a flush valve and a separate faucet mounted on the wall above the fixture with a vacuum breaker. A bedpan washer should also be installed next to the clinical sink. The type of bedpan washer will depend upon the hospital's method of washing and sterilizing bedpans.

Birthing rooms Each birthing room should include a vitreous china lavatory provided with a gooseneck spout and wrist-blade handles or hands-free controls. Each labor room should have access to a water closet and a lavatory. A shower should be provided for the labor-room patients. The shower controls, including pressure/thermostatic mixing valve, should be located outside the wet area for use by the hospital's nursing staff. A water closet should be accessible to the shower facility.

Anesthesia workrooms This area is designed for the cleaning, testing, and storing of the anesthesia equipment and should contain a work counter-mounted sink. The sink is usually made of stainless steel. The faucet should be of the gooseneck spout design with wrist-blade handles and/or hands-free controls.

Fracture rooms A large-size, vitreous china plaster, work sink equipped with a combination water-supply fitting and wrist-blade handles, gooseneck spout, and plaster trap on the waste line (located for convenient access) should be provided.

Kitchens and Laundries

The plumbing designer should consult with the architect and the food-service consultant for kitchen equipment utility requirements. Typically, one of these people should provide location and rough-in drawings for all kitchen equipment. Normally required are toilet fixtures for kitchen staff, food preparation sinks, hand-wash sinks, pot and pan-wash sinks, dishwashers, glassware washers, floor drains, hose bibbs, mixing stations, and grease interceptors. Kitchen grease traps shall be located and arranged to permit easy access without the necessity of entering food preparation or storage areas. Grease traps shall be of the capacity required and shall be accessible from outside the building without the necessity of interrupting any services. In dietary areas, floor drains and/or floor sinks shall be of a type that can be easily cleaned by the removal of a cover. Provide floor drains or floor sinks at all "wet" equipment (such as ice machines) and as required for the wet cleaning of floors. The location of floor drains and floor sinks shall be coordinated to avoid conditions where the location of equipment makes the removal of covers for cleaning difficult. Also, the kitchen equipment may require other utility services, such as fuel gas, steam, and condensate.

When considering laundry facilities, the plumbing designer should consult with the architect and the laundry consultant for equipment utility requirements. These facilities require large-capacity washers/extractors and dryers, presses, and folding machines. Waste-water drainage may require lint intercepters. These facilities are prime candidates for heat and water-recovery systems. Also, the laundry equipment may require other utility services, such as fuel gas, steam, and condensate.

The hot-water temperatures required for these areas (100, 140, and 180°F [38, 60, and 82°C]) are discussed in *Data Book*, Volume 2, Chapter 6, "Domestic Water-Heating Systems."

Unique Fixtures

Fixture-unit values for the unique fixtures found in health-care facilities can be found in Table 2-2.

Laboratory Rooms

Laboratory sinks Most of the time architects provide the countertops and sinks, usually made of epoxy or other acid-resistant materials, in their specifications. However, occasionally the plumbing designer is responsible for selecting the laboratory sinks. Laboratory sinks should be acid resistant and can be of stainless steel, stone, or plastic. Laboratory and cup sinks are currently available in epoxy resin, composition stone, natural stone, ceramic or vitreous china, polyester fiberglass, plastic, stainless steel, and lead. The lead type is not recommended where mercury, nitric, hydrochloric or acetic acids are used.

Often these laboratory sinks are furnished with the laboratory equipment as rectangular sinks or cup sinks mounted in, or as part of, counter tops and as cup sinks in fume hoods. Rules of thumb that can be used when the sink sizes are not recommended by the laboratory staff are as follows:

1. Sinks with a compartment size of 12 × 16 × 7.5 in. (304.8 × 406.4 × 190.5 mm) for general laboratory work areas.
2. Sinks with a compartment size of 18 × 24 × 10 in. (457.2 × 609.6 × 254 mm) for classroom work and tests.
3. Sinks with a compartment size of 24 × 36 × 12 in. (609 × 914.4 × 304.8 mm) for washing large equipment.

The sink itself and sink outlet should be chemically resistant, a minimum of 316 stainless steel, and so designed that a stopper or an overflow can be inserted and removed easily. The outlet should be removable and have a strainer to intercept any materials that might cause a stoppage in the line. Unless an industrial water system is employed that isolates the laboratory water systems from the potable water system, via a central backflow-prevention device, all faucets should be provided with vacuum breakers. Supply fittings for distilled or deionized water are usually either virgin plastic or tin lined and, where central systems are used, should be able to withstand higher pressures. Many fitting types, especially PVC, can handle pressures up to but not exceeding 50 psig (344.74 kPa). In these cases, pressure regulation is required.

Cup sinks These are small, 3 × 6 in., 3 × 9 in., or 3 × 11 in. (76.2 × 152.4 mm, 76.2 × 228.6 mm, or 76.6 × 279.4 mm) oval sinks for receiving chemicals, normally from a condensate or a supply line. They are designed to fit into the center section between the table tops; against a wall; or on raised, back ledges. These sinks are also common in fume hoods.

Laboratory glass washers are usually included, either furnished by the laboratory equipment supplier or selected by the plumbing designer. Automatic washers are available. In addition to waste or indirect waste services, these units require hot water (usually 140°F [60°C] boosted to 180°F [82°C]) internal to the unit, distilled or deionized water, and compressed air. Manual-type glass bottle and tube washers may also be required in these rooms. Tube washers may have manifold-type supply fittings using cold water only. The manifolds can be fitted with a number of individually serrated tip outlets provided with separate controls and vacuum breakers.

Emergency showers should be included throughout and located in the adjacent corridors or at the door exits. The showers must be accessible, require no more than 10 s to reach, and be within a travel distance of no greater than 100 ft (30.5 m) from the hazard rooms. The shower head is a deluge-type shower with a 1-in. (25.4 mm) nominal cold water, stay-open design, supply valve operated by a hanging pull rod, or a chain and pull ring, or a pull chain secured to the wall. A floor drain may be provided, if required. If floor drains are provided, trap primers should be incorporated.

Eye and face-wash fountains are also required. These are wall or counter-mounted units with a foot-pedal or wrist-blade-handle-operated, water-supply fixture; double side-mounted, full face-wash outlets; or deck-mounted, hand-held (with hose) face and body-spray units. The latest edition of the ANSI standard for emergency eyewash and shower equipment and local codes should be consulted. A tempered water supply should be considered.

Laboratory service outlets for gas, air, nitrogen, vacuum, and other required gas services may be furnished as part of the related equipment under another contract or may be included

Table 2-2 Hospital Plumbing Fixtures

Fixture	Fixture Units			GPM (L/S)		GPH (L/H)
	Total Water	Cold Water	Hot Water	Cold Water	Hot Water	Hot Water
Aspirator, fluid suction	2	2	—	3 (.19)	—	—
Aspirator, laboratory	2	2	—	3 (.19)	—	—
Autopsy table, complete	4	3	2	8 (.50)	4½ (.28)	20 (75.7)
Autopsy table, aspirator	2	2	—	3 (.19)	—	—
Autopsy table, flushing hose	2	2	—	3 (.19)	—	—
Autopsy table, flushing rim	3	3	—	4½ (.28)	—	—
Autopsy table, sink and faucet	3	2½	2½	4½ (.28)	4½ (.28)	20 (75.7)
Autopsy table, waste disposal	1½	1½	—	4 (.25)	—	—
Bath, arm	4	2	3	3 (.19)	7 (.44)	35 (132.5)
Bath, emergency	4	2	3	3 (.19)	7 (.44)	15 (56.8)
Bath, immersion	20	7	15	15 (.95)	35 (2.21)	450 (1,703.3)
Bath, leg	10	4	7	8 (.50)	16 (1.01)	100 (378.5)
Bath, sitz	4	2	3	3 (.19)	7 (.44)	30 (113.6)
Bed pan, washer, steam	10	10	—	25 (1.58)	—	—
Cleaner, sonic	3	2½	2½	4½ (.28)	4½ (.28)	20 (75.7)
Cuspidor, dental and surgical	1	1	—	2 (.13)	—	—
Cuspidor, dental chair	1	1	—	2 (.13)	—	—
Drinking fountain	1	1	—	2 (.13)	—	—
Floor drain, flushing type	10	10	—	25 (1.58)	—	—
Hose, bed pan general	2	1½	1½	3 (.19)	3 (.19)	5 (18.9)
Hose, bed pan private	1	1	1	3 (.19)	3 (.19)	8 (30.3)
Laundry tub	3	2½	2½	4½ (.28)	4½ (.28)	30 (113.6)
Lavatory, barber	2	1½	1½	3 (.19)	3 (.19)	15 (56.8)
Lavatory, dental	1	1	1	3 (.19)	3 (.19)	8 (30.3)
Lavatory, general	2	1½	1½	3 (.19)	3 (.19)	8 (30.3)
Lavatory, private	1	1	1	3 (.19)	3 (.19)	4 (15.1)
Lavatory, nursery	2	1½	1½	3 (.19)	3 (.19)	8 (30.3)
Lavatory, scrub-up	2	1½	1½	3 (.19)	3 (.19)	10 (37.9)
Lavatory, treatment	1	1	1	3 (.19)	3 (.19)	4 (15.1)
Microscope, electron	1	1	—	0.2 (.01)	—	—
Sanistan	10	10	—	25 (1.58)	—	—
Sanitizer, boiling, instrument	2	—	2	—	3 (.19)	10 (37.9)
Sanitizer, boiling, utensil	2	—	2	—	3 (.19)	10 (37.9)
Shower, general	4	2	3	1½ (.09)	3½ (.22)	50 (189.3)
Shower, private	2	1	2	1½ (.09)	3½ (.22)	20 (75.7)
Shower, obstetrical	4	2	3	1½ (.09)	3½ (.22)	50 (189.3)
Shower, therapeutic	15	6	11	15 (.95)	35 (2.21)	400 (1,514)
Sink, barium	3	2½	2½	4½ (.28)	4½ (.28)	15 (56.8)
Sink, clean-up room	3	2½	2½	4½ (.28)	4½ (.28)	15 (56.8)
Sink, central supply	3	2½	2½	4½ (.28)	4½ (.28)	15 (56.8)
Sink, clinical	10	10	3	25 (1.58)	3 (.19)	10 (37.9)
Sink, clinical, bed pan hose	10	10	4	25 (1.58)	4½ (.28)	15 (56.8)
Sink, floor kitchen	4	3	3	4½ (.28)	4½ (.28)	20 (75.7)
Sink, formula room	4	3	3	4½ (.28)	4½ (.28)	20 (75.7)
Sink, cup	1	1	—	3 (.19)	—	—
Sink, laboratory	2	1½	1½	3 (.19)	3 (.19)	5 (18.9)
Sink, laboratory and trough	3	2½	1½	5 (.32)	3 (.19)	5 (18.9)
Sink, pharmacy	2	1½	1½	3 (.19)	3 (.19)	5 (18.9)
Sink, plaster	4	3	3	4½ (.28)	4½ (.28)	15 (56.8)

in the plumbing work. In either case, the plumbing designer should be knowledgeable about the various types of service outlet currently available, the materials (or construction), and the usage (diversity). It is desirable to have bodies of cast red brass, brass forgings, or brass bar stock that are specially designed for laboratory use and, where possible, made by one manufacturer. Handles should be made of forged brass and provided with screw-in-type, color-coded index discs. All outlets should be properly labeled. Serrated tips should be machined from solid stock or forgings. The service fittings should be chrome plated over nickel plating or copper plating. The outlets in fume hoods should have an acid and solvent-resistant, plastic coating over the chrome-plated surface or be made of acid-resistant materials. Nonmetallic fittings are also available.

Special Equipment

Dialysis machines Dialysis machines require a funnel drain or floor sink and cold-water hose bibb with vacuum breaker.

Heart-and-lung machines Heart-and-lung machines also require a funnel-type drain. If the apparatus is located in the operating room, an indirect waste is required.

Electron microscopes Electron microscopes require filtered, backflow-protected, cold water or circulated chilled water.

Stills Stills for producing distilled water require cold water with a vacuum breaker and floor sinks or funnel drains.

Sterilizers Sterilizers require an acid-resistant floor sink or funnel drains, a backflow-protected water supply and sometimes steam and condensate connections.

Film-processing equipment Film-processing (x-ray) areas require an acid-resistant floor sink or funnel drains for indirect waste; and a hot, cold and/or tempered water supply operating between 40 and 90°F (4.4 and 32.2°C). Drain piping for any photo-developing equipment should not be brass or copper. Polypropylene, high-silica, cast-iron, corrosion-resistant piping and drains should be used. Silver recovery and neutralization may be required; consult with the local authority.

Dental equipment Dental areas should include console services (water, air, medical gas, nitrous oxide and waste); and for oral surgery a separate surgical vacuum system should be provided.

The plumbing engineer should always consult with the equipment manufacturer's authorized representative and the local administrative authority, in order to determine the equipment requirements and the acceptability under the jurisdiction's applicable codes, during the preliminary design.

DRAINAGE SYSTEMS FOR LABORATORIES

In addition to the conventional sanitary drainage systems (those found in most buildings), special sanitary drainage systems may be required in health-care facilities.

Insofar as possible, drainage piping shall not be installed within the ceiling or exposed in operating or delivery rooms, nurseries, food-preparation centers, food-serving facilities, food-storage areas, central services, electronic data-processing areas, electric closets, and other sensitive areas. Where exposed, overhead drain piping in these areas is unavoidable, special provisions shall be made to protect the space below from leakage, condensation, or dust particles.

Acid-Waste Drainage Systems

Acid-waste drainage systems require special design criteria because the corrosive solutions demand special handling from the actual work area to an approved point at which such acid waste (and fumes) can be safely neutralized and discharged. The plumbing engineer must exercise extreme care in this regard.

Acid-resistant waste and vent systems are necessary where acids with a pH lower than 6.5 or alkalis with a pH greater than 8.5 are present. These special conditions are commonly encountered in hospitals, research facilities, and laboratories. Since acid fumes are often more corrosive than the liquid acids themselves, proper drainage and venting is imperative.

Nationally recognized standards for sanitary systems that handle acid wastes and other reagents are set forth in model plumbing codes; such systems are often further regulated by local building and safety or health department

requirements. For these reasons, the plumbing engineer should check for all special design conditions that may affect the project.

Strong acids and caustics may enter the sanitary-waste system in large quantities and at elevated temperatures. These substances can mix to form highly corrosive and even dangerous compounds. Common laboratory procedures encourage neutralization or flushing with copious amounts of water in order to dilute and cool these chemicals to more acceptable levels. However, the plumbing engineer must protect the acid-waste system by designing for the maximum hazard conditions that might be brought about by any human error, poor housekeeping, or accidental spillage.

Corrosive-Waste Systems Materials

Borosilicate glass pipe Sizes range from 1½ to 6-in. (40 to 150-mm) pipe. Mechanical joint, flame resistance, and clear pipe allow for easy visual inspection and high corrosion resistance.

High-silicon cast iron Sizes range from 1½ to 4-in. (40 to 100-mm) pipe. Mechanical joint, flame resistance, high corrosion resistance, fire stop at floor penetration equal to cast iron. More fragile and heavier than standard-weight cast iron and easier to break in the field. Excellent application for moderate to high-budget project.

Polypropylene Sizes range from 1½ to 6-in. (40 to 150-mm) pipe. Mechanical or heat-fusion joints. Mechanical joints are not recommended for straight runs or sizes over 2 in. (50 mm); they should be used to access p-traps or other maintenance areas. Flame resistant and acceptable within most jurisdictions (meets 25/50 flame/smoke criteria), newer UL listed methods are close to glass in cost. Consult local authority for approval. Light weight and easy to install. Good application for moderate acids at low temperatures. Must be installed by qualified technicians. Inexpensive compared to borosilicate glass or high-silicone cast iron.

Double-containment waste piping With ever-increasing pressure to protect our environment, double-containment (pipe within a pipe) systems have become a consideration. Usually made of polypropylene inside and PVC or fiberglass outside. Systems should be pitched toward a containment vault for collection of leaking fluid.

Alarm systems can be employed to detect leaks at the collection basin or, if the budget and the nature of the liquid allow, sensors can be installed between the pipe walls that can pinpoint the original leak location. The latter could reduce the amount of excavation or exploration required to find the leak.

Discharge to Sewers

Many local jurisdictions require that the building's sanitary-sewer discharge be at an acceptable pH level before it can be admitted into a sanitary-sewage system. In such cases, it is recommended that a clarifying (or neutralizing) tank be added to the sanitary system. Small ceramic or polypropylene clarifiers with limestone can be located under casework for low flow rates; however, sufficient space must be allowed above the unit for servicing. Unless properly maintained and monitored, this type of system can be rendered ineffective. Large clarifiers and neutralizers may be regulated by the requirements of a local industrial-waste department.

Acidic-Waste Neutralization

The lower the pH number, the higher the concentration of acid. Discharging high concentrations of acid into a public sewer may cause considerable corrosion to piping systems and eventual failure. Most local authorities do not allow acid wastes to be discharged to a public sewer without some form of treatment.

The neutralization of acidic wastes is generally and most economically dealt with through an acid-neutralization tank. An acid-neutralization tank may be constructed of polyethylene, molded stone, stainless steel, or another acid-resistant material. Tanks are sized to provide a dwell time of 2 to 3 h (refer to Table 2-3). Limestone or marble chips fill the interior of the tank, helping to neutralize incoming acid wastes. Chips may be 1 to 3 in. (25.4 to 76.2 mm) in diameter and should have a calcium carbonate content in excess of 90%. A discharge pH sensor and routine maintenance schedule must be provided to ensure that the system operates properly. An example of a neutralization tank is depicted in Figure 2-1.

Acid-Waste Solids Interceptor

As with many sewer systems, it is impossible to control all materials discarded to the drain system. Unless building effluent is controlled, many unwanted items, such as glass fragments and needles, will find their way to the neutralization tank, thereby clogging the limestone or marble chips.

When this happens, replacement of the chips is required. One way to prolong chip life is to install an acid-waste solids interceptor immediately upstream of the neutralization tank, as shown in Figure 2-2, although maintenance of the interceptor may have to be done quite frequently.

Acid-Waste Metering Detail

Many local authorities require some means of sampling effluent from industrial, institutional, and laboratory buildings. An example of a device used for this purpose is a sampling manhole, depicted in Figure 2-3. This unit is installed as the last component before neutralized acidic wastes or treated industrial wastes are discharged to a public sewer. There are as many types of sampling point requirements as there are municipal

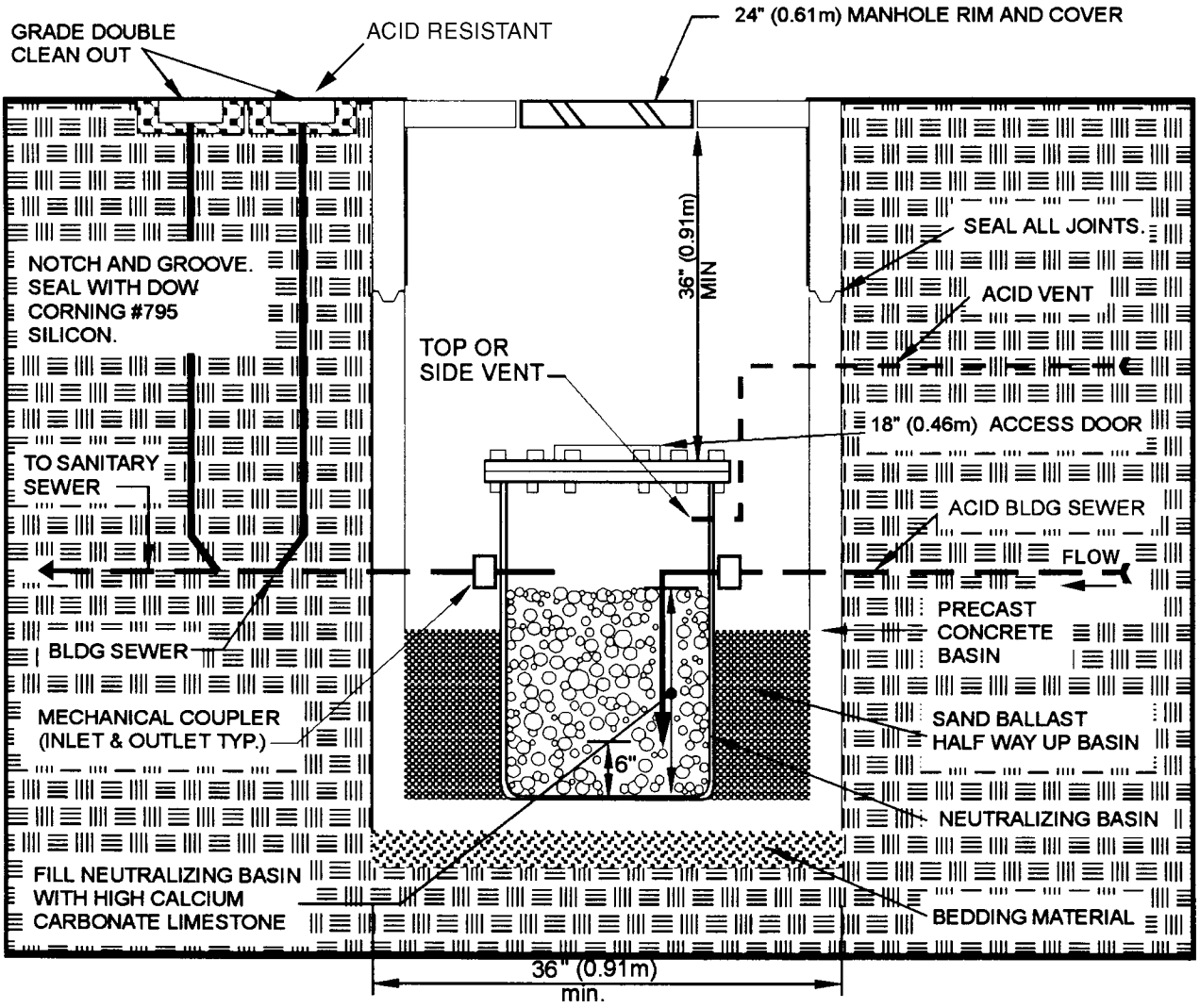

Figure 2-1 Acid-Neutralizing Tank Detail

Table 2-3 Acidic-Waste Neutralization Tank Sizing Table

Number of Lab Sinks	Tank Size, gal (L)	
2	5	(18.9)
4	15	(56.8)
8	30	(113.6)
16	55	(208.2)
22	75	(283.9)
27	90	(340.7)
30	108	(408.8)
40	150	(567.8)
50	175	(662.4)
60	200	(757.0)
75	275	(1 040.9)
110	360	(1 362.6)
150	500	(1 898.5)
175	550	(2 081.8)
200	650	(2 460.3)
300	1200	(4 542)
500	2000	(7 570)
600	3000	(11 355)

Note: For commercial and industrial laboratories, the number of lab sinks should be multiplied by a 0.5 use factor.

sewer authorities. Consult local code authorities for individual requirements.

Traps for Laboratory Sinks

The trap is recognized by most plumbing engineers as the weakest link in the acid-waste system. The trap must be acid resistant. If strong acids and solvents collect in an ordinary trap, failure of the system will occur. Three types of acid-waste traps are currently in common use: p-traps, drum traps, and centrifugal drum traps. (Running and s-traps are not allowed by many local plumbing codes because of the potential for trap siphoning.)

1. *P-traps* maintain a water seal to keep the acid fumes from reentering the work area.
2. *Drum traps* provide a greater water seal and are frequently used to separate either precious metals or other matter before they enter the drainage system to become lost or cause a stoppage in the sink. Drum traps with removable bottoms should be installed high enough above the floor for servicing. P-traps, including some of the simple drum traps, can easily be back-siphoned if the head pressures are extreme.
3. *Centrifugal drum traps* are designed to prevent back-siphonage conditions.

Laboratory Waste and Vent Piping

Sizing for under-table waste and vent piping, as determined by the local plumbing codes, should be suitable for the installation and allow for future expansion. Approved corrosion-resistant piping should be used for vent piping as well, since acid fumes are also highly corrosive. Space is often limited under tables and in vent areas. The space-saving features of mechanical joint piping have proven to be useful in many installations.

Note: When fusion-joint, plastic piping systems are used, mechanical joints should be installed at traps and trap arms for maintenance reasons.

Special island (or loop) venting is frequently used when cabinets or work tables are located in the center of the laboratory area.

The transportating of acid waste, above and below the ground, must be done in approved, corrosion-resistant piping (acceptable to the local administrative authority) and continued to a suitable point where neutralization can occur or where sufficient water or chemicals can be introduced to bring the pH level of the solution to an acceptable level. Acids below a pH of 6.5 normally may not be admitted into the sanitary-sewage system or emitted into surrounding soil, polluting (or degenerating) local ground water. High-silicon cast iron with hub-and-spigot joints may be caulked with teflon, or neoprene gaskets may be used for sealing. This type of joint will allow flexibility and, when properly supported, is particularly recommended on the horizontal runs where the expansion and contraction of pipe from heated chemicals can cause leaking. Plumbing codes require proper bed preparation and careful backfilling on all below-ground piping, particularly plastic piping.

The plumbing engineer should check the manufacturer's recommendations in order to evaluate the severity of the chemicals to be used. A listing of the common chemicals and how these substances react with the various materials must be considered by the designer.

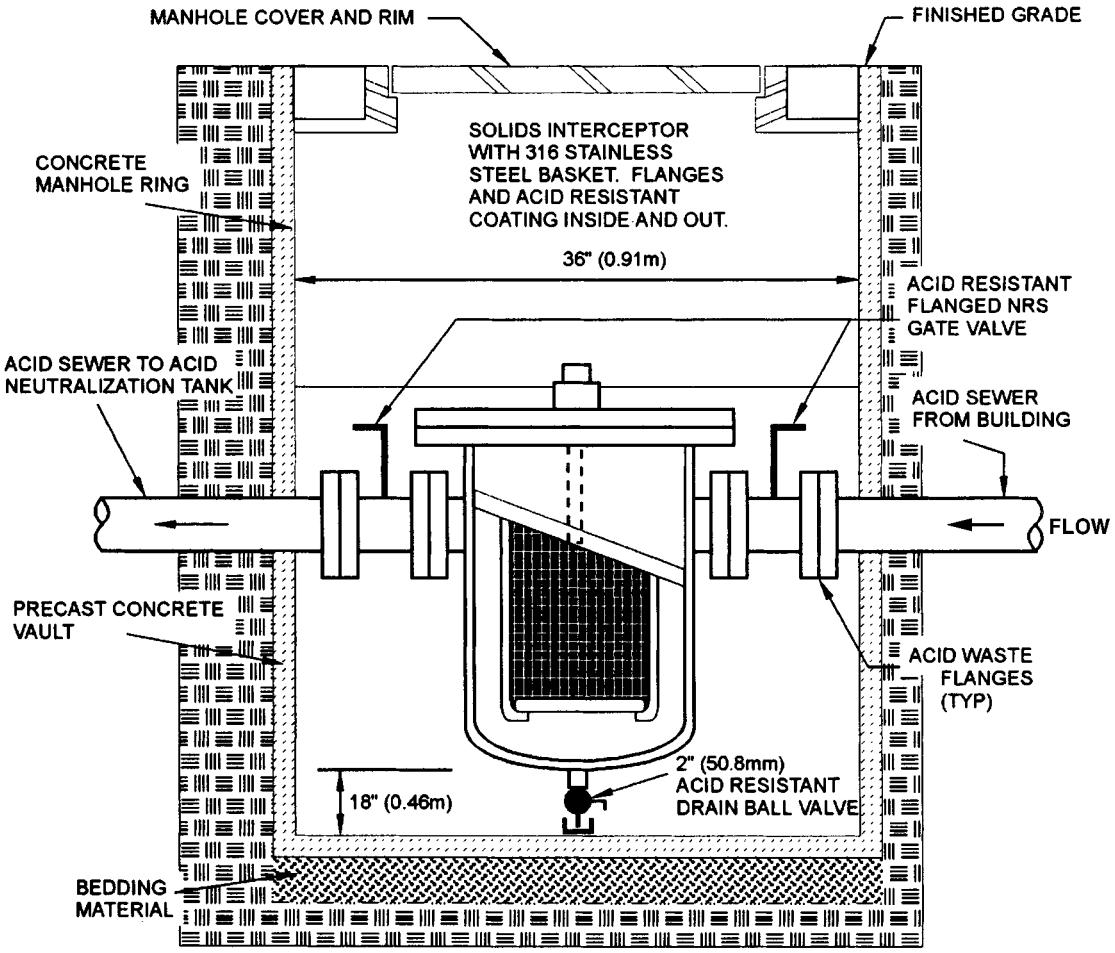

Figure 2-2 Acid-Waste Solids Interceptor Detail

WATER-SUPPLY SYSTEMS

A domestic-water supply of adequate flow volume and pressure must be provided for all the plumbing fixtures and related equipment. Systems typically encountered in these types of facility are as follows:

1. Potable-water systems.
   A. Cold water.
   B. Hot water (at various temperatures).
   C. Chilled water.
   D. Controlled-temperature (tempered) water.
   E. Hot water recirculation.
2. Non-potable water systems.
3. Pure-water systems.
   A. Distilled water.
   B. Deionized (or demineralized) water.
   C. Reverse osmosis.

Health-care facilities should have dual domestic-water services installed to ensure provision of an uninterrupted supply of water. The design should consider water-conservation provisions. Many local jurisdictions have strict water-conservation laws in effect. Water recycling may be a consideration for use in landscaping,

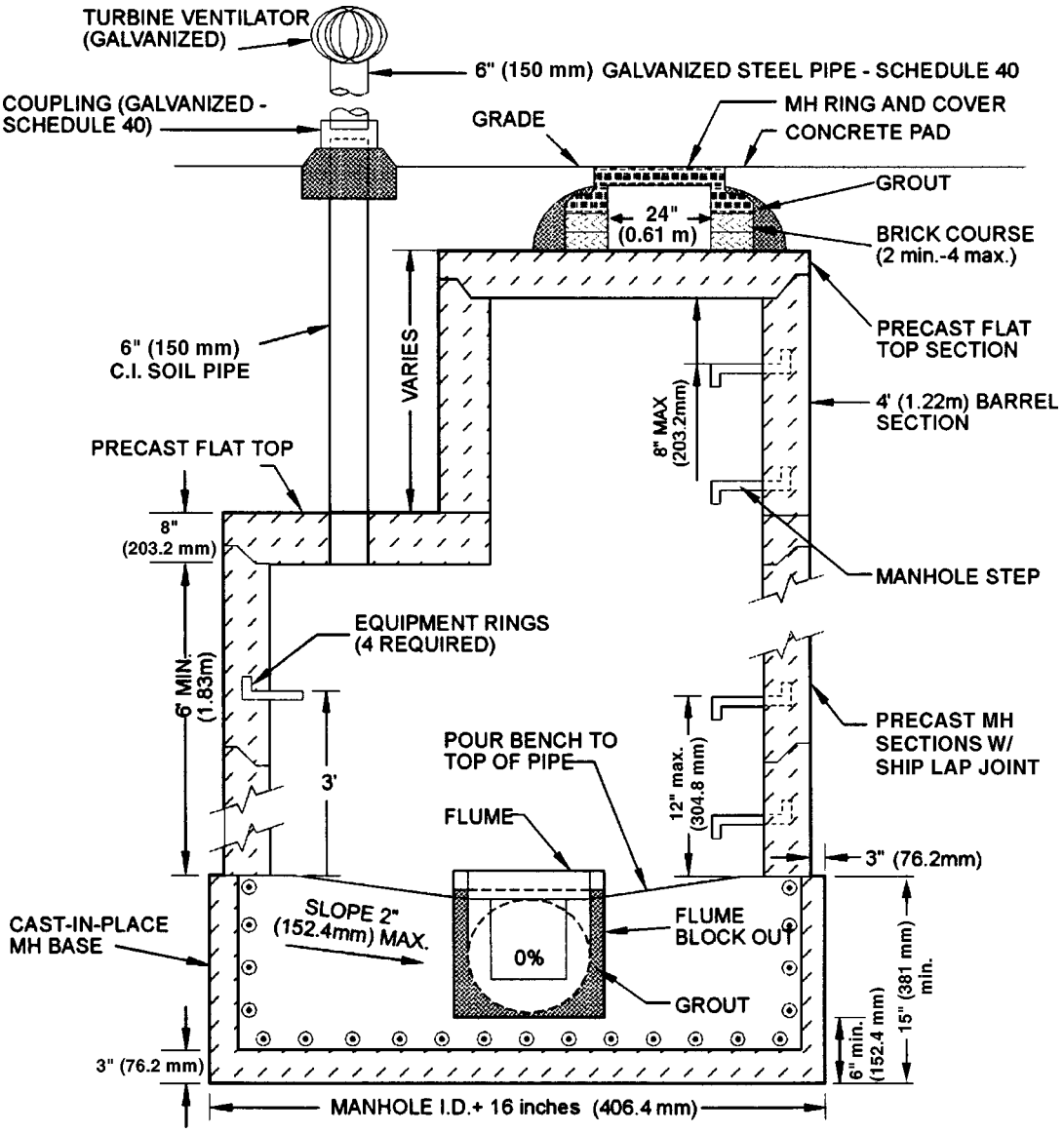

Figure 2-3 Sampling Manhole

etc., depending on local code and health-department regulations. (For more information, see *Data Book*, Volume 2, Chapter 2, "Gray-Water Systems.")

Water supply through a tank (suction or gravity type) should be considered by the plumbing engineer when the water-supply source may be subjected to some unusual demands, pressure fluctuations, and/or interruptions that will cause a sudden excessive draw and pressure loss on the main system. The tank will act as a buffer. Inadequate flow and pressure require the design of a water-storage tank and/or a booster pump for the water-supply system. Excessive pressure fluctuations are highly undesirable in medical-research laboratories. When such facilities are supplied from street pressure systems, the engineer may provide pressure-reducing valves on the branch lines, or a gravity tank system.

Use of diversity factors for sizing the water systems must be carefully analyzed by the designer. Medical-school laboratory classrooms have higher rates of simultaneous use than most research laboratories. Emergency rooms, out-patient treatment rooms, and operating-room wash-up areas also have high rates of simultaneous use.

Extreme care must be taken in order to protect the potable-water supply from contamination (cross connection). When an industrial (non-potable) system is not present, the engineer should specify the appropriate type of vacuum breakers (necessary for each fixture below the rim connection), hose-end outlet, and an aspirator or other serrated-tip laboratory outlet, whether they are required by the local plumbing regulations or not. The vacuum breakers provided for fume-hood outlets should be located outside the hood. Built-in (or integral) vacuum breakers are preferred to the hose-end type units.

Potable-Water Systems

Cold water should be provided at all required locations. The hot water should be generated with the most economical heating medium available.

With today's technology, several reliable methods can be applied to produce and store domestic hot water. Refer to ASPE's *Domestic Water Heating Design Manual* and *ASPE Data Book* Volume 2, Chapter 6, "Domestic Water-Heating Systems," for in-depth explanations of design methods for hot-water systems and a discussion of the various hot-water systems available. When large "dump" loads are anticipated (kitchens and laundries), storage of hot water is recommended. Hot-water usage in patient-care areas requires consideration of water temperature and bacterial growth. The most common water-borne bacterium of concern is Legionella pneumophila.

Recommended water temperatures for specific applications are as follows:

1. Patient-care and hospital general usage requires water temperatures between 105 and 120°F (40.5 and 49°C), except where the local plumbing codes or other regulations require other maximum temperatures. Hot-water distribution systems serving patient-care areas shall be under constant recirculation to provide continuous hot water at each hot-water outlet. The temperature of hot water for bathing fixtures and hand-wash lavatories shall be appropriate for comfortable use but shall not exceed 120°F (49°C).
2. Kitchen general usage requires 140°F (60°C) to fixtures, except the dishwasher's sanitizing cycle. The sanitizing cycle requires 180 to 190°F (82 to 88°C) to the dishwasher, with 180°F (82°C) minimum required at the dish rack. (Consult local health-department regulations.) Also, some health departments set a maximum temperature of 105 to 120°F (40.5 to 49°C) for hand-washing lavatories.
3. Laundry facilities should be supplied with two water temperatures, 140°F (60°C) for general usage and 160°F (71°C) minimum to washers/extractors for laundry sterilizations.

Providing a point-of-use booster heater for high-temperature applications instead of a central water-heater system is often more economical.

A closed system of chilled water may be required for the cooling of electron microscopes and x-ray tubes and should be of a recirculating design.

Film processors operate at a normal range of 40 to 30°F (4.4 to –1.1°C). Some models do require controlled water temperature for film processing. Depending on the quality of the water supply, a 5 to 75-μ filter may be required.

A thermometer should also be provided on the outlets of water heaters and thermostatically controlled valves. A pressure regulator, gauge, and flow meter may also be desired on the inlet side of pressure-sensitive equipment.

Non-Potable Water Systems

Non-potable water systems are usually employed in areas having multiple water requirements that could contaminate the potable-water supply. Areas in this category include: flushing-rim floor drains in animal rooms, all outlets in autopsy rooms, outlets in isolation rooms, and all outlets in infectious-disease and tissue-culture rooms. These systems normally use reduced-pressure-type backflow preventers as the means to protect the potable-water system. Hot water, when required, may be provided by a separate generator supplied from the non-potable water system.

Pure-Water Systems

"Pure water" is the term generally used to describe water that is free from particulate matters, minerals (soluble ions), bacteria, pyrogens, organic matters, and dissolved gases, which frequently exist in the potable water supply. Pure-water systems are usually required in the hospital's pharmacy, central-supply room, laboratories, and laboratory-glassware washing facilities.

There are two basic types of pure water available in hospital facilities: bio-pure water (water containing no bugs or other life forms) and high-purity water (pure water that is free from minerals, dissolved gases, and most particulate matters). Refer to *ASPE Data Book,* Volume 2, Chapter 11, "Water Treatment, Conditioning, and Purification," for additional information on water purity.

Water purity is most easily measured as specific resistance (in ohm-centimeter [Ω-cm] units) or expressed as parts per million (ppm) of an ionized salt (NaCl). The theoretical maximum specific resistance of the pure water is given as 18.3 MΩ-cm at 77°F (25°C). This water purity is difficult to produce, store, and distribute. This water is "starved" for impurities and constantly attempts to absorb contaminants. It is important to note that the specific resistance of the pure water is indicative only of its mineral contents and in no way shows the level of bacterial, pyrogenic, or organic contamination. An independent laboratory analysis should be made, whenever possible.

The five basic methods of producing pure water are as follows: distillation, demineralization, reverse osmosis, filtration, and recirculation. Depending upon the type of pure water required in the facility, one (or more) of these methods will be needed. Under certain conditions, a combination of several methods may be necessary.

1. *Distillation* produces bio-pure water, which is completely free from particulate matters, minerals, organics, bacteria, pyrogens, and most of the dissolved gases and has a minimum specific resistance of 300,000 Ω. An important consideration in this case is that the water is free from bacteria and pyrogen contamination, which is dangerous to the patients, particularly where intravenous solutions are concerned. Bio-pure water is needed in the hospital's pharmacy, central-supply room, and other areas where there may be patient contact. Bio-pure water may also be desired in certain specific laboratories at the owner's request and as a final rinse in the laboratory's glassware washer.

   The typical water-distillation apparatus consists of an evaporator section, an internal baffle system, a water-cooled condenser, and a storage tank. The best material for its construction is a pure block-tin coating for both the still and the tank. The heat sources, in order of preference based on economy and maintenance, are as follows: steam, gas, and electricity. The still may be operated manually or automatically. The distilled water may be distributed from the storage tank by gravity or by a pump. A drain is required for system drainage and flushing. On stills larger than 50 gph (189.3 L/h), a cooling tower should be considered for the condenser water.

2. *Demineralization,* sometimes called "deionization," produces high-purity water that is completely free from minerals, most particulate matters, and dissolved gases. Depending upon the equipment used, it can have a specific resistance ranging from 50,000 Ω to nearly 18 MΩ. However, it could be contaminated with bacteria, pyrogens, and organics (these contaminants may be produced inside the demineralizer itself). Demineralized water can be employed in most laboratories, the laboratory's glass-washing facilities (as a final rinse) and as the pre-treatment for still feedwater.

   The typical demineralizer apparatus consists of either a two-bed deionizing unit (with a resistivity range of 50,000 Ω to 1 MΩ) or a mixed-bed deionizing unit (with a resistivity range of 1 to 18 MΩ). The columns are of an inert material filled with a synthetic resin, which removes the minerals by an ionization process. Since the unit operates on pressure, a storage tank is not required or recommended (as bacteria will grow in it). A demineralizer must be chemically regenerated periodically, and during that regeneration time no pure water is produced. If a continuous supply of pure water is needed, a backup unit should be considered by the engineer, as the regeneration process takes several hours. The regeneration process can be done manually or automatically. An atmospheric, chemical-re-

sistant drain is required. High-flow water is required for backwash during the regeneration.

3. *Reverse osmosis (RO)* produces a high-purity water that does not have the high resistivity of demineralized water and is not bio-pure. Under certain conditions an RO process can offer economic advantages over demineralized water. In areas that have high mineral contents, an RO process can be used as a pre-treatment for a demineralizer or still.

   There are several types of reverse osmosis units currently available. Units consist of a semipermeable membrane, in either a roll form or a tube containing numerous hollow fibers. The water is then forced through the semipermeable membrane under high pressure. A drain is required with these systems.

   Note: Chlorine must be removed from the water, otherwise it will destroy the RO membrane.

4. *Filtration* Various types of filter are currently available to remove the particulate matters from the water as a pre-treatment. Depending upon the type of filter, a drain may be required. Bacteria may be eliminated through ultraviolet sterilization.

5. *Recirculation* High-purity systems should be provided with a circulation loop. Dead-end legs should be avoided whenever possible or limited to 50 in. (1.52 m). System design velocity should be between 4 and 7 fps (1.22 and 2.13 m/s) so as to discourage bacteria accumulation and provide transport back to an ultraviolet sterilizer and filtration for removal.

Pure-water piping system materials Water-treatment system components are selected to remove various impurities from the influent water. Connecting various system components together involves the use of interconnecting piping. The use of this piping should not contribute to adding any such impurity back into the treated water.

Selection of piping-system materials is determined by the application intended, the availability of the material, and the cost of the material. Pure-water applications, such as exist in the health-care industry, can be very sensitive to the piping methods selected.

General pure-water piping requirements include:

1. Inert materials—must not leach contamination into water.
2. Clean joining methods—avoid solvents, lubricants, and crevices.
3. No material erosion—must not flake off particles.
4. Material should not enhance microorganism growth.
5. Material should be smooth, crack and crevice-free, and nonporous.
6. Avoid dead legs—system should have continuous flow through piping.
7. Provide chemical cleaning connections.
8. Install (slope) with future cleaning and disinfection in mind.

A wide variety of piping materials are available on the market today. Their properties and cost cover a wide range.

Common pure-water materials

1. Stainless steel—various grades (304L & 316L).
2. Aluminum.
3. Tin-lined copper.
4. Glass or glass-lined pipe.
5. PVC/CPVC—Polyvinyl chloride/chlorinated polyvinyl chloride.
6. Polypropylene.
7. Polyethylene.
8. ABS—Acrylonitrile butadiene styrene.
9. PVDF—Polyvinylidene fluoride.

Metal pipe Aluminum, tin-lined copper, and stainless-steel pipe have all been used in pure-water treatment systems. Tin-lined pipe was once the material of choice in ultra-pure water systems. However, it does leach tin and eventually copper into the process fluid. Methods of joining tin-lined pipe can also leave non-smooth joints with crevices.

Aluminum pipe has also been used in pure-water systems. Pure water creates an oxide layer inside the pipe that continually erodes, producing particles and aluminum in the water.

Stainless steel has been used extensively in high-purity water systems. It can be joined with threads, butt welded, flanged, or manufactured with sanitary-type connection ends. Because it can use sanitary joints and can handle steam sterilizing, the sanitary-type connection method has been used in many pharmaceutical applications. However, experience has shown that even the best grades of stainless steel, with the best joints, still leach material from the metal that can cause problems in critical water systems.

Glass or glass-lined pipe Glass piping has been used in some special laboratory applications but, because it is fragile and does leach material into the water, it is not generally considered applicable for high-purity water systems.

PVC PVC pipe has been used on equipment and in piping systems successfully for many years. Advances in technology, especially in electronics, have now raised questions about the "true purity" or inertness of PVC.

PVC pipe contains color pigments, plasticizers, stabilizers, and antioxidants that can all leach out of the plastic and into ultra-pure water. Remember that 18,000,000-Ω quality water is highly aggressive. When PVC pipe is made (extruded), bubbles of air exist, some of which are covered over with a thin film of PVC on the interior walls of the pipe. As the pipe ages, these thin coverings wear away, exposing small holes which then serve as debris-collecting or microorganism-breeding sites, not to mention the contribution of PVC particles and the potential release of organic dispersants, stabilizers, etc., originally trapped in these bubbles (holes).

Joints, either solvent welded or threaded, can leave crevices for the accumulation of particles and bacteria. Solvents from the weld can also leach into the water.

Premium grades of PVC, which reportedly have fewer leachables than standard PVC, are now being marketed.

CPVC is a special high-temperature PVC that has similar erosion and leachable characteristics.

Polypropylene Polypropylene is a very inert, strong piping material. However, in the manufacture of the pipe antioxidants and other additives are used to control embrittlement. These additives are potential sources of contaminants that can leach into the water. However, a virgin material with no leachable products is now available.

Polypropylene pipe shows good ability to withstand both corrosive chemicals and high temperatures, up to 220°F (104°C). The natural toughness of the material minimizes damage to pipe during installation and service.

Polypropylene is generally joined by the butt-fusion method, resulting in smooth joints.

ABS Acrylonitrile butadiene styrene (ABS) plastic pipe has been used in the primary stages of water-treatment systems because of relatively low cost and ease of installation.

ABS has some of the same contamination leach problems as PVC. In its manufacture, pigment dispersants, surfactants, styrene, and other additives are used that can leach into water over time. Hydrogen peroxide (used for system cleaning) will also attack ABS plastic.

PVDF There are numerous types of high-molecular-weight fluorocarbon pipes on the market, SYGEF, KYNAR, and HALAR, to name a few. Polyvinylidene fluoride (PVDF) plastic can be extruded without the use of additives that can leach out later. The different polymerization techniques used by each manufacturer can produce slightly different properties.

PVDF pipe is currently considered to be the state of the art in pure-water piping systems. It has exceptional chemical resistance; temperature range, –40 to 320°F (–40 to 160°C); impact strength; resistance to UV degradation; abrasion resistance; and smooth, clean, inside surfaces that discourage the collection of bacteria and particles. Most laboratory test reports show virtually zero leachables from PVDF piping systems.

PVDF pipe is joined by the butt-fusion method, resulting in clean, smooth joints.

When system pressures exceed 70 psig (482.6 kPa) or temperatures exceed 75°F (24°C), plastic piping system manufacturers should be consulted for compatibility. Polypropylene or PVDF-lined metal piping systems may be incorporated to meet pressures up to 150 psig (1034.2 kPa).

MEDICAL-GAS AND VACUUM SYSTEMS

General

Health care is in a constant state of change, which forces the plumbing engineer to keep up with new technology to provide innovative approaches to the design of medical-gas systems. In designing medical-gas and vacuum systems, the goal is to provide a safe and sufficient flow at required pressures to the medical-gas outlet or inlet terminals served. System design and layout should allow convenient access by the medical staff to outlet/inlet terminals, valves, and equipment during patient care or emergencies.

This section focuses on design parameters and current standards required for the design of nonflammable medical-gas and vacuum systems used in therapeutic and anesthetic care. The plumbing engineer must determine the needs of the health-care staff. Try to work closely with the medical staff to seek answers to the following fundamental design questions at the start of a project:

1. How many outlet/inlets are requested by staff?
2. How many outlet/inlets are required?
3. Based on current conditions, how often is the outlet/inlet used?
4. Based on current conditions, what is the average duration of use for each outlet/inlet?
5. What is the proper usage (diversity) factor to be used?

Medical-Gas System Design Checklist

As any hospital facility must be specially designed to meet the applicable local code requirements and the health-care needs of the community it serves, the medical-gas and vacuum piping systems must also be designed to meet the specific requirements of each hospital.

Following are the essential steps to a well-designed and functional medical-gas piped system, which are recommended to the plumbing engineer:

1. Analyze each specific area of the health-care facility to determine the following items:
   A. Which piped medical-gas systems are required?
   B. How many of each different type of medical-gas outlet/inlet terminal are required?
   C. Where should the outlet/inlet terminals be located for maximum efficiency and convenience?
   D. Which type and style of outlet/inlet terminal best meet the needs of the medical staff?
2. Anticipate any building expansion and plan in which direction the expansion will take place (vertically or horizontally). Determine how the medical-gas system should be sized and valved in order to accommodate the future expansion.
3. Determine locations for the various medical-gas supply sources.
   A. Bulk oxygen (0_2).
   B. High-pressure cylinder manifolds (0_2, N_20 or N_2).
   C. Vacuum pumps (VAC).
   D. Medical-air compressors (MA).
4. Prepare the schematic piping layout locating the following:
   A. Zone valves.
   B. Isolation valves.
   C. Master alarms.
   D. Area alarms.
5. Calculate the anticipated peak demands for each medical-gas system. Appropriately size each particular section so as to avoid exceeding the maximum pressure drops allowed.
6. Size and select the various medical-gas and vacuum supply equipment that will handle the peak demands for each system, including future expansions. If this project is an addition to an existing facility, determine the following:
   A. What medical gases are currently provided and what are the locations and number of the stations?
   B. Can the current gas supplier (or the hospital's purchasing department) furnish the consumption records?
   C. Are the capacities of the existing medi-

cal-gas supply systems adequate to handle the additional demand?

D. Are any existing systems valved that could be used for an extension? Are the existing pipe sizes adequate to handle the anticipated additional loads?

E. What type of equipment is in use and who is the manufacturer? Is this equipment state-of-the-art?

F. Is it feasible to manifold the new and existing equipment?

G. What is the physical condition of the existing equipment?

H. Is there adequate space available for the new medical-gas supply systems and related equipment at the existing location?

I. Is existing equipment scheduled to be replaced? (A maintenance history of the existing equipment may help in this determination.)

Number of Stations

The first step is to locate and count the outlet/inlets, often called "stations," for each respective medical-gas system. This is usually done by consulting a program prepared by the facility planner or architect. This program is a list of all the rooms and areas in the facility and the services that are required in each. If a program has not been prepared, the floor plans for the proposed facility shall be used.

There is no code that specifically mandates the exact number of stations that must be provided in various areas or rooms for all healthcare facilities. In fact, there is no clear consensus of opinion among medical authorities or design professionals as to how many stations are actually required in the facility areas. Guidelines are published by the American Institute of Architects (AIA), National Fire Protection Association (NFPA), and ASPE that recommend the minimum number of stations for various services in specific areas.

The most often-used recommendations in determining the number of stations for hospitals are those necessary to be accredited by the Joint Commission for the Accreditation of Hospitals Organization (JCAHO). Accreditation is required for Medicare and Medicaid compensation. The JCAHO publishes a manual that refers to the AIA guidelines for the minimum number of stations for oxygen, medical air, and vacuum that must be installed in order to obtain accreditation. If this is a factor for the facility, these requirements are mandatory. Other jurisdictions, such as state or local authorities, may require plans to be approved by local health or building officials. These approvals may require adhering to the state or local requirements and/or NFPA 99, *Health-Care Facilities*.

If accreditation or the approval of authorities is not a factor, the number and area locations of stations are not mandated. The actual count then will depend upon requirements determined by each individual facility or another member of the design team using both past experience and anticipated future use, often using the guideline recommendations as a starting point. Table 2-4 provides those recommendations.

Medical-Gas Flow Rates

Each station must provide a minimum flow rate for the proper functioning of connected equipment under design and emergency conditions. The flow rates and diversity factors vary for individual stations in each system depending on the total number of outlets and the type of care provided.

The flow rate from the total number of outlets, without regard for any diversity, is called the "total connected load." If the total connected load were used for sizing purposes, the result would be a vastly oversized system, since not all of the stations in the facility will be used at the same time. A diversity, or simultaneous-use factor, is used to allow for the fact that not all of the stations will be used at once. It is used to reduce the system flow rate in conjunction with the total connected load for sizing mains and branch piping to all parts of the distribution system. This factor varies for different areas throughout any facility.

The estimated flow rate and diversity factors for various systems, area stations, and pieces of equipment are found in Tables 2-5, 2-6, and 2-7.

Total demand for medical-gas systems varies as a function of time of day, month, patient-care requirements, and facility type. The number of stations needed for patient care is subjective and cannot be qualified based on physical measurements. Knowing the types of patient care and/or authority requirements will

Table 2-4 Inlet /Outlet Station Data

Room	O_2	VAC	N_2O	Air	N_2	EVAC	Typical Uses
Anesthesia workroom	1	1	[a]	1			Equipment repair testing
Animal oper. (research surgery)	1	1	[a]				Animal anesthesia and surgery
Animal research lab	1	1		1			Routine animal care
Autopsy	1	1					Suction waste materials from body
Bed holding	1	1					Cardiac arrest, O_2 therapy
Biochemistry	[b]	1		1			Standard lab use[a]
Biochem. lab	[b]	1		1			Standard lab use[a]
Biophysics / biochemical	[b]	1		1			Standard lab use[a]
Blood processing		1		1			Standard lab use[a]
Blood receiving (blood donors)	1	1		1			Emergency use
Cardiac catheterization room	1	2					Cardiac arrest and other emergencies
Chem analysis lab (sm. lab in hosp.)		1		1			Standard lab use[a]
Chemical lab		1		1			Standard lab use[a]
Cystoscopy	1	3				1	Emergency use
Decontamination room (attached to inhalation therapy dept.)	1	1		1			Equipment testilng
Deep therapy	1	2					Cardiac arrest and other emergencies
Demonstration room (in-service training)	1	1					Demo. equip. to new empl. & students
Dental repair	1	1		1	[b]		Power drills (dental)
Dispensary (minor surgery, first aid, student health & exams)	[a]			[a]			Emergency use
Ear-nose-throat exam	1	1		1			Aspiration; topical spray
ECG (electrocardiogram)	1	1					Cardiac arrest and other emergencies
EEG (electro-encephalograms)	1	1					Cardiac arrest and other emergencies
Electron microscopy	1	1		1			Standard lab use[a]
Emergency room	1	2		1			Cardiac arrest and other emergencies
EMG (electromyogram)	1	1					Cardiac arrest and other emergencies
Examination room	1	1		1			Drive air tools and vacuum cleaning
Exam room and proctoscopic	1	1		1			Cardiac arrest and other emergencies
Experimental lab	[b]	1		1			Standard lab use[a]
Eye examination	1	1					Stock and cardiac arrest
Fluoroscopy (x-ray)	1	2					Cardiac arrest and other emergencies
Heart catheterization lab	1	1		1			Cardiac arrest and other emerg. respir.
Hematology	1	1		1			Standard lab use[a]
Intensive-care areas	2	3		1			For critically ill
Isolation (infectious & contagious diseases)	1	1		1			Patient care
Isolation room (patient room for contagious diseases)	1	2		1			Oral, gastric or thoracic
Lab annex		1		1			Pull waste evac. tubing drying apparatus
Lab cleanup area		1		1			Drying glassware
Lab—workroom		1		1			Standard lab use[a]

(Continued)

(Table 2-4 continued)

Room	O_2	VAC	N_2O	Air	N_2	EVAC	Typical Uses
Labor rooms—O.B.	1	1	[a]				Analgesia, patient care
Linear accelerator vault	1	1		1			
Microbiology		1		1			Standard lab use[a]
Microbiology lab—constant temp room		1		1	[b]		Standard lab use[a]
Multi-service room	1	1					Cardiac arrest and other emergencies
Neurological pharmacy teaching lab	1		1				Standard lab use[a]
Neurological physiology teaching lab	1	1		1			Standard lab use[a]
Nursery (full-term)	1	2		1			Incubators, respirators
Nursing floor	1	2		1			Therapy, oral, gastric; IPPB, aerosols
Nursing, security (psychiatric violent patients use lock box)	1	1		1			Patient care
Observation	1	1					Cardiac arrest and other emergencies
Obstetrics (delivery room)	1	3	[a]				Analgesia, anesthesia, patient care
Operating room (surgery—major and minor	2	3	1	1	[a]	1	Patient care
Oral lab (dental)	[a]	1	[a]	1	[a]		Standard lab use[a]
Orthopedic exam room	1	1					Cardiac arrest and other emergencies
Pathology (Drs. office special lab tests)		1		1			Standard lab use[a]
Patient room	1	1		1			Patient care
Pharma. room (drug prep.)		1		1			Standard lab use[a]
Physiology lab—general	1	1		1			Standard lab use[a] plus teaching
Premature nursery and obs.	2	1		1			Incubators—respirators
Radiation, low-level (x-ray dept.)	1	2		1			Cardiac arrest and other emergencies
Radio-chemical lab		1		1			Standard lab use[a]
Radioisotope, high level (x-ray dept.)	1	2		1			Cardiac arrest and other emergencies
Radioisotope room (research room for animal lab)		1		1			Standard lab use[a]
Recovery beds	2	3		1			2 thoracic, 1 oral, 1 gastric or wound
Recovery room—private (same as regular recovery)	1	3		1			Note: Need 1 more VAC for thoracic
Respiratory therapy	1	1		1			For out-patient treatments IPPB
Scanning room (part x-ray)	1	2					Cardiac arrest and other emergencies
Serology		1		1			Standard lab use[a]
Sterilization (CS or OR)	1	1		1			Equipment testing
Surgical preparation room	1	1		1			Pre-medication for anesthesia
Teaching lab	1	1		1			Standard lab use[a]
Treatment room	1	1		1			Special therapy
Urinalysis		1		1			Standard lab use[a]
Standard x-ray rooms	1	2		1			Cardiac arrest and other emergencies

Source: Information furnished courtesy of Puritan-Bennett, modified by ASPE.

[a] One outlet per area.

[b] Consult owner for number and location.

Table 2-5 Medical-Air Peak-Demand Chart

Area	Free-Air Design Flow, scfm (L/min)			Simultaneous Use Factor (%)
	Per Room	Per Bed	Per Outlet	
Anesthetizing locations[a]				
Special surgery	0.5 (15)	—	—	100
Major surgery	0.5 (15)	—	—	100
Minor surgery	0.5 (15)	—	—	75
Emergency surgery	0.5 (15)	—	—	50
Radiology	0.5 (15)	—	—	25
Cardiac catheterization	0.5 (15)	—	—	50
Acute-care locations				
Recovery room	—	2 (60)	—	50
ICU/CCU	—	2 (60)	—	50
Emergency room	—	2 (60)	—	50
Neonatal ICU	—	1.5 (40)	—	75
Dialysis unit	—	—	0.5 (15)	10
Subacute-care locations				
Nursery	—	—	0.5 (15)	25
Patient rooms	—	0.5 (15)	—	10
Exam & treatment	1 (30)	—	—	10
Pre-op holding	—	—	1.5 (40)	10
Respiratory care	—	1 (30)	—	50
Pulmonary function lab	—	—	1 (30)	50
Other				
Anesthesia workroom	1.5 (40)	—	—	10
Respirator-care workroom	1.5 (40)	—	—	10
Nursery workroom	1.5 (40)	—	—	10
Equipment repair	—	—	1.5 (40)	10

[a]These design flows are based on the use of air in the patient breathing circuit only. If air is to be used to power equipment such as an anesthesia ventilator, the design flow should be increased accordingly.

Table 2-6 Outlet Rating Chart for Medical-Vacuum Piping Systems

Location of Medical-Surgical Vacuum Outlets	Free-Air Allowance, cfm (L/min) at 1 atmosphere		Zone Allowances—Corridors, Risers, Main Supply Line, Valves	
	Per Room	Per Outlet	Simultaneous Usage Factor (%)	Air to Be Transported, cfm (L/min)[a]
Operating rooms:				
Major "A" (Radical, open heart; organ transplant; radical thoracic)	3.5 (100)	—	100	3.5 (100)
Major "B" (All other major ORs)	2.0 (60)	—	100	2.0 (60)
Minor	1.0 (30)	—	100	1.0 (30)
Delivery rooms	1.0 (30)	—	100	1.0 (30)
Recovery room (post anesthesia) and intensive-care units (a minimum of 2 outlets per bed in each such department):				
1st outlet at each bed	—	3 (85)	50	1.5 (40)
2nd outlet at each bed	—	1.0 (30)	50	0.5 (15)
3rd outlet at each bed	—	1.0 (30)	10	0.1 (3)
All others at each bed	—	1.0 (30)	10	0.1 (3)
Emergency rooms	—	1.0 (30)	100	1.0 (30)
Patient rooms:				
Surgical	—	1.0 (30)	50	0.5 (15)
Medical	—	1.0 (30)	10	0.1 (3)
Nurseries	—	1.0 (30)	10	0.1 (3)
Treatment & examining rooms	—	0.5 (15)	10	0.05 (1)
Autopsy	—	2.0 (60)	20	0.04 (1)
Inhalation therapy, central supply & instructional areas	—	1.0 (30)	10	0.1 (3)

[a] Free air at 1 atmosphere.

allow placement of stations in usage groups. These groups can establish demand and simultaneous-use factors (diversities), which are used in the calculation for sizing a particular system. All medical-gas piping systems must be clearly identified using an approved color-coding system similar to that shown in Table 2-8.

Medical-Gas System Dispensing Equipment

Medical-gas outlet/inlet terminals Most manufacturers of medical-gas system equipment offer various types of medical-gas outlets. These medical-gas outlets are available in various gas orders (e.g., 0_2-N_20-Air), center-line spacing, and

Table 2-7 Medical-Vacuum Peak-Demands Chart (Medical-Surgical Vacuum System)

Area	Free-Air Design Flow, scfm (L/min)			Simultaneous Use Factor (%)
	Per Room	Per Bed	Per Outlet	
Anesthetizing locations:				
Specialized surgeries (open heart, organ transplant, etc.)	4 (115)	—	1.5 (40)	100
Major operating rooms	3.5 (100)	—	—	100
Cystoscopy	2 (60)	—	—	100
Delivery room	1 (30)	—	—	100
Emergency operating room	3 (85)	—	—	100
Other anesthetizing areas (minor O.R., orthopedic O.R., cardiac catheterization, radiology, induction rooms, etc.)	1 (30)	—	—	50
Waste anesthetic gas evacuation	1 (30)	—	—	100
Acute care (non-anesthetizing locations):				
Post-operative recovery room	—	3 (85)	—	50
O.B. recovery room	—	2 (60)	—	50
Intensive care units (except cardiac)	—	2 (60)	—	75
Emergency room	—	1 (30)	—	100
Cardiac intensive care	—	2 (60)	—	50
Neonatal I.C.U.	—	1 (30)	—	50
Subacute patient care areas:				
Normal nursery	—	—	1 (30)	10
Premature nursery	—	1 (30)	—	20
Labor / birthing	—	1 (30)	—	10
Patient room (surgical)	—	1.5 (40)	—	50
Patient room (medical)	—	1 (30)	—	10
Exam & treatment rooms	—	—	1 (30)	10
Other areas:				
Autopsy			2 (60)	20
Central supply			1.5 (40)	10
Respiratory care department			1.5 (40)	5
Equipment repair, calibration, and teaching			1.5 (40)	10
Medical lab			1 (30)	10

Table 2-8 Color Coding for Piped Medical Gases

Gas Intended for Medical Use	United States Color	Canada Color
Oxygen	Green	Green on white[a]
Carbon dioxide	Gray	Black on gray
Nitrous oxide	Blue	Silver on blue
Cyclopropane	Orange	Silver on orange
Helium	Brown	Silver on brown
Nitrogen	Black	Silver on black
Air	Yellow*	White and black on black and white
Vacuum	White	Silver on yellow[a]
Gas mixtures (other than mixtures of oxygen and nitrogen)	Color marking of mixtures shall be a combination of colors corresponding to each component gas.	
Gas mixtures of oxygen and nitrogen		
19.5 to 23.5% oxygen	Yellow[a]	Black and white
All other oxygen concentrations	Black and green	Pink

Source: Compressed Gas Association, Inc.

[a] Historically, white has been used in the United States and yellow has been used in Canada to identify vacuum systems. Therefore, it is recommended that white *not* be used in the United States and yellow *not* be used in Canada as a marking to identify containers for use with any medical gas. Other countries may have differing specific requirements.

for exposed and concealed mountings. Outlet types and configurations must meet the requirements of the local jurisdictional authority and NFPA 99. All outlets must be properly identified and confirmed. Care should also be taken to accurately coordinate the various pieces of medical-gas dispensing equipment with the architect and medical staff involved in the given project. If the project is a renovation, the outlet types should match existing equipment. With prefabricated patient headwall units, the medical-gas outlets are generally furnished by the equipment manufacturer, and it is very important that coordination be maintained by the engineer so that unnecessary duplication of work is avoided. Also, with regard to the over-the-bed medical-gas service consoles, these consoles are often specified in the electrical or equipment section of the specification and medical-gas service outlets are specified, furnished, and installed under the mechanical contract.

Gas-outlet sequence, center-line spacing, and multiple-gang-service outlets are some of the considerations to be taken into account when requesting information from the various equipment manufacturers. It is more practical, in terms of both the cost of the equipment and the installation, to specify and select the manufacturer's standard outlet(s). Details and specifications regarding the individual standard outlets are usually available from all manufacturers upon request.

The existing outlets are compatible with the adapters found on the hospital's anesthesia machines, flow meters, vacuum regulators, etc. Care should be taken to make sure all future expansions in the same facility have compatible equipment.

Patient head-wall systems A recent and growing trend in hospital construction is the

requirement for patient head-wall systems, which incorporate many services for the patient's care. These units may include the following:

1. Medical-gas outlets.
2. Electrical-service outlets (including emergency power).
3. Direct and indirect lighting.
4. Nurse-call system.
5. Isolation transformers.
6. Grounding outlets.
7. Patient-monitoring receptacles.
8. Vacuum slide and IV brackets.
9. Night lights.
10. Electrical switches.

Bed locator units are also available, which serve to provide power for the more advanced patient beds, telephone, night lights, and standard power. These units also function to protect the walls from damage as beds are moved and adjusted.

Head walls currently vary in shape, size, type, and cost from a simple over-the-patient-bed standard configuration to elaborate total-wall units. Most manufacturers of medical-gas equipment offer medical-gas outlets for all types of patient consoles available in today's market. When specifying head-walls outlets, the plumbing engineer should consider the following:

1. Is the service outlet selected compatible with the existing outlet component?
2. Does the patient head-wall manufacturer include the type of medical-gas outlets required as part of the product?

Special types of ceiling-mounted, medical-gas outlets In critical-care areas, which are generally considered by most individuals to be those locations of the hospital providing a special treatment or service for the patient (such as surgery, recovery, coronary, or intensive-care units), the designer's selection and placement of the medical-gas service equipment must be done very carefully in order to provide efficient work centers around the patient for the medical staff.

Manufacturers of medical-gas service equipment usually provide a wide range of equipment that is available for use in these areas. Depending upon the customer's preference and the available budget, the equipment is selected to provide the necessary individual gas services and accessories.

Table 2-9 provides a quick reference guide for the engineer to use as a basis for selecting the commonly used types of outlet dispensing equipment.

Example 2-1

The following illustrative example presents some of the most important critical-care area equipment and options for the selection of the equipment.

Surgery medical-gas services to be piped include:

1. Oxygen.
2. Nitrous oxide.
3. Nitrogen.
4. Medical compressed air.
5. Vacuum.
6. Waste anesthetic-gas disposal.

Providing medical-gas service outlets in the surgery room may be accomplished in several ways, such as the following:

1. *Ceiling outlets* Individual medical-gas outlets mounted in the ceiling with hose assemblies providing the medical staff with connections from the outlets to the administering apparatus.

   This method is considered by most to be the most economical means of providing an adequate gas service to the surgery areas. The ceiling gas-service outlets are generally located at both the head and the foot of the operating table in order to provide alternate positioning of the operating table.

2. *Surgical ceiling columns* Surgical ceiling columns are usually available in two designs: rigid (a predetermined length from the ceiling height above the floor) and retractable. Both surgical ceiling columns provide medical-gas services within an enclosure that projects down from the ceiling. The ceiling columns are usually located at opposite ends of the operating table in order to provide convenient access to the medical-gas outlets by the anesthesiologist. In addition to the medical-gas outlets, these ceiling columns can be equipped with electrical outlets,

Table 2-9 Types of Dispensing Equipment for Specific Areas

	Medical Gas Outlet Dispensing Equipment						
Hospital Areas	Wall-Mounted Outlets	Patient Care Head Wall	Ceiling-Mounted Outlets with Hose Stops	Rigid Ceiling Columns	Retractable Ceiling Columns	Ceiling with Gas Stacks	Nitrogen Control Cabinets
Autopsy rooms	●		●				
Delivery rooms	●		●				
Emergency examination and treatment rooms	●		●				
Emergency operating rooms	●						●
Induction rooms	●						
Labor rooms	●	●					
Major surgery rooms	●		●	●	●	●	●
Minor surgery, cystoscopy	●		●				●
Neonatal intensive care units	●	●					
Normal nursery rooms	●	●					
Nursery workrooms	●						
O.B. recovery rooms	●	●					
Patient rooms	●	●					
Pediatric and youth intensive care unit	●	●	●				
Post-operative recovery rooms	●	●	●				
Premature and pediatric nursery rooms	●	●	●				
Pre-op holding rooms	●	●					
Radiology rooms	●						
Respiratory care unit	●						
Specialized surgeries (cardiac and neuro)	●		●				

grounding receptacles, physiological monitor receptacles, and hooks for hanging intravenous-solution bottles.

Most manufacturers offering surgical ceiling columns allow for many variations in room arrangements of medical-gas services and related accessories, depending upon the specific customer's needs and the engineer's specifications. When specifying this type of equipment, it is necessary to specify carefully all medical-gas service requirements and their desired arrangement(s). Also, the engineer must coordinate all other required services with the electrical engineer and medical staff.

3. *Surgical gas tracks* Surgical gas tracks are forms of ceiling outlet and hose-drop arrangements that allow the movement of the hose drops from one end of the operating table to

the other on sliding tracks mounted on the ceiling. These products are currently available from various manufacturers and all provide the same basic services. The proper selection and specification of specific types are based on individual customer preference. Many variations in products and particular product applications are available in critical (intensive) care areas. Consultation with appropriate manufacturers for recommendations is always advisable.

4. *Articulating ceiling-service center* Articulated ceiling-service centers are moved by pneumatic drive systems and are designed for the convenient dispensing of medical-gas and electrical services in operating rooms. The medical-gas and electrical systems are complete for single-point connection to each outlet at the mounting support platform.

High-pressure nitrogen (N_2) dispensing equipment Special consideration must be given by the plumbing engineer to the placement of the nitrogen outlets. The primary use of nitrogen gas in hospitals is for driving turbo-surgical instruments. Variations of these turbo-surgical instruments, in both their manufacture and their intended use, will require that several different nitrogen-gas pressure levels be available. For this reason, it is necessary that the engineer provide an adjustable pressure-regulating device near the nitrogen gas outlet. A nitrogen control panel is usually located on the wall (in the surgery room) opposite the operating area sterile field. The installation should allow for the access and adjustment of pressure settings by a surgical nurse.

Piping from the nitrogen control panel to a surgical ceiling outlet will provide a convenient source of nitrogen for surgical tools. This will prevent hoses from being located on the floor or between the wall outlet and the operating table. Excess hose can be obstructive to the surgical team.

Medical-Gas Storage

After deciding the medical-gas services to be provided at the facility, the engineer should determine the storage capacity and the pipe sizing required and possible locations for the source. Local codes and references as well as the administrative authority having jurisdiction should be consulted for each medical-gas system.

Because of the unique characteristics of each medical-gas source, the gases are described separately in this section. Also, an explanation of the techniques currently employed to exhaust anesthetic gases is provided.

Figure 2-4 illustrates a typical layout of liquid oxygen, oxygen emergency reserve supply (equal to one day's supply), cylinder nitrous oxide supply, and cylinder nitrogen supply.

Oxygen (O_2) Several factors must be known when estimating the monthly consumption of oxygen in new or existing health-care facilities:

1. Type of medical care provided.
2. Number of oxygen outlets *or*
3. Number of patient beds.
4. Future expansion of facility.
5. In existing facilities, approximate consumption.

Two methods can be used by the plumbing engineer to estimate the consumption of oxygen. The more accurate method is to obtain a detailed consumption record from the health-care facility or obtain monthly oxygen shipment invoices from the supplier. If inventory records are not available from the health-care facility or the supplier, use consumption records from a comparably sized facility, with good judgment.

The second method is to apply the following rule of thumb to estimate the monthly supply of oxygen. This estimating method should be used with good judgment. Always coordinate estimated demand with the oxygen supplier during the design process.

1. In non-acute-care areas, allow 500 ft^3 (14 m^3) per bed per month for supply and reserve oxygen storage.
2. In acute-care areas, allow 1000 ft^3 (28 m^3) per bed per month for supply and reserve oxygen storage.

Oxygen supply sources are divided into two categories: (1) bulk-oxygen systems and (2) cylinder-manifold-supply systems. Bulk-oxygen systems should be considered for health-care facilities with an estimated monthly demand above 35,000 ft^3 (991 m^3) or equal to 70 oxygen outlets. Manifold systems are used in small general hospitals or clinics.

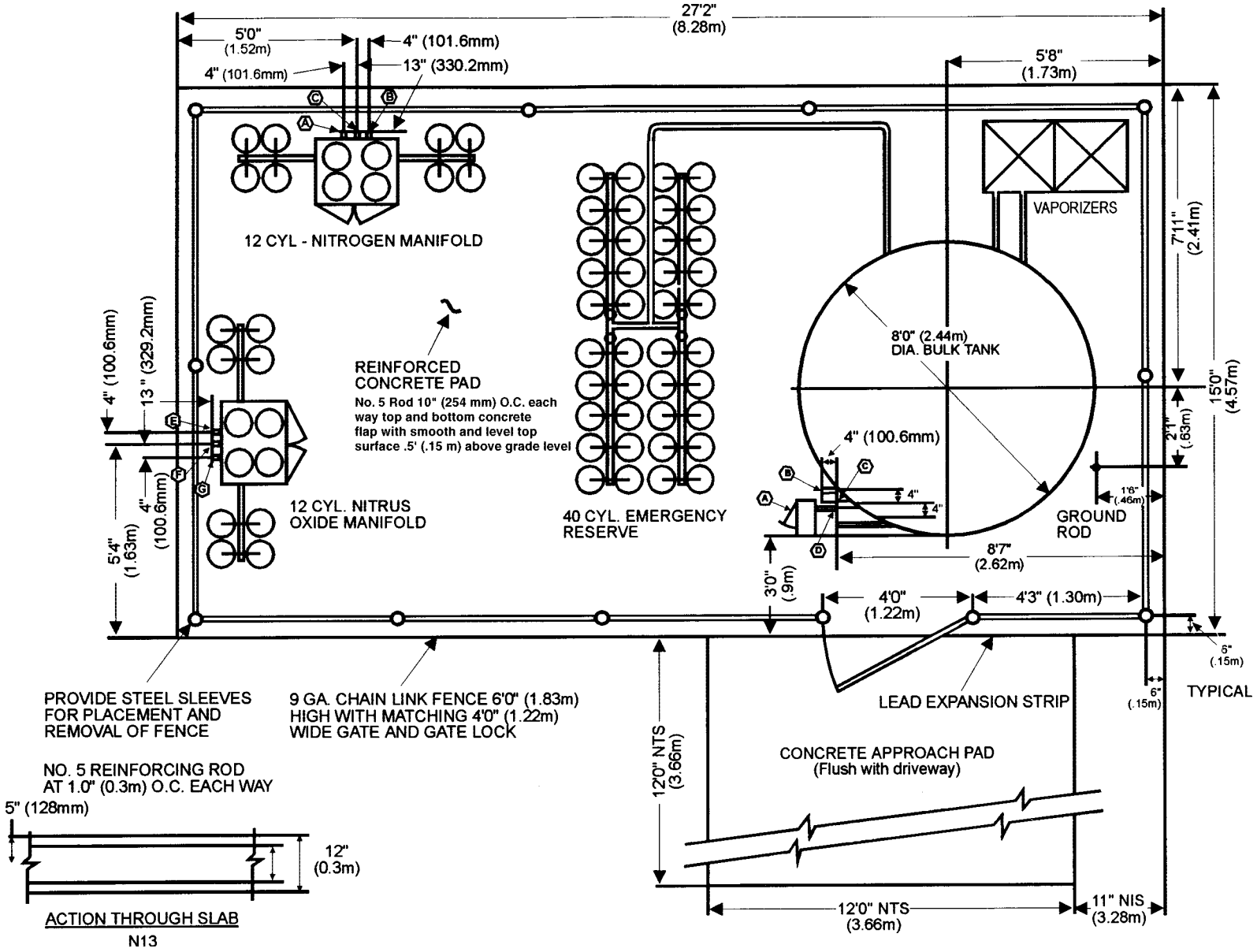

Figure 2-4 Typical Layout of Liquid Oxygen, Oxygen Reserve Supply, Cylinder Nitrous-Oxide Supply, and Cylinder Nitrogen Supply

Bulk-oxygen systems When selecting and placing bulk-oxygen systems, there are several factors to be considered: Oxygen transport truck size, truck access to bulk-storage tanks, and NFPA 50, *Standard for Bulk Oxygen Systems at Consumer Sites*. Bulk-oxygen equipment, construction, installation, and location must comply with NFPA 50 recommendations. If liquid oxygen is spilled or leaked, an extreme fire or explosive hazard could occur. NFPA has design standards to minimize fire exposure to and from surrounding structures. The location of bulk-oxygen storage tanks and equipment must be certain distances from specified structures and materials, as shown in Table 2-10.

Bulk-storage systems consist of cryogenic tanks that store liquid oxygen at low pressures (225 psi [1551.3 kPa] or less). Cryogenic tanks are ASME unfired, double-walled, vacuum-insulated, pressure vessels. Liquid oxygen has a boiling point (nbp) of –297.3°F (–182.9°C) and a liquid density of 71.27 lb/ft^3 (1141.8 kg/cm^3). When vaporized into gas, it produces 900 times its liquid volume. Furthermore, since the tank is changed less often, process stability is maximized and the introduction of atmospheric impurities is reduced. Tank systems are furnished with an integral pressure-relief valve vented to the atmosphere should the liquid oxygen convert to a gas. Table 2-11 depicts currently available cryogenic tank capacities.

Most bulk-oxygen storage systems are furnished with vaporizers. Vaporizers are banks of finned-tube heat exchangers that convert the liquid to its gaseous state. The vaporizers come in several styles—including atmospheric, powered (forced-air, steam, and electric), waste-heat, and hybrid—and sizes. The selection of vaporizers should be based on demand, intermittent or continuous usage, energy costs, and temperature zones. Poorly ventilated sites or undersized heat exchangers can cause ice to form on vaporizers during the conversion process. Excessive ice formations can clog and damage the vaporizer. Also, ice could allow extremely cold gas or the cryogenic liquid to enter the piped system; damage the valves, alarms, and medical components; and even injure patients. Figure 2-5 illustrates a typical bulk-oxygen system schematic.

Table 2-10 Exterior Bulk Oxygen-Storage Installation Criteria

Bulk Tank Separation Distances, ft (m)	Item
1 (0.30)	Building structure (except wood frame)
5 (1.52)	Property line
10 (3.05)	Parked vehicles, sidewalk, structure openings
15 (4.57)	All classes of flammable and combustible liquids stored below ground. Class III B liquid, 1000 gal (3785 L) or less, above-ground storage.
25 (7.62)	Solid slow-burning material, coal, lumber, etc., underground tank vent or fill openings. Above-ground flammable and combustible liquids, 1000 gal (3785 L) or less, except Class III B liquids.
35 (10.67)	Clearance for ventilation one side.
50 (15.24)	Public assembly area, open or enclosed. Wood-frame structure. Non-ambulatory patient area.
75 (22.86)	Liquefied hydrogen storage above ground. Clearance for ventilation one side.
25 (7.62)	1000 gal (3785 L) liquefied gas or 25,000 ft^3 (700 m^3) non-liquefied gas.
50 (15.24)	Over 1000 gal (3785 L) of liquefied gas or over 25,000 ft^3 (700 m^3) of non-liquefied gas.

Source: NFPA no. 50.

Table 2-11 Cryogenic Storage Tank Capacities

Gross Volume, gal (L)	Net Liquid Capacity, gal (L)	Capacity Oxygen, ft^3 (10^6 L)	Approximate Weight Empty Vessel, lb (kg)	Approximate Weight Vessel Loaded with Oxygen, lb (kg)
330 (1249.1)	314 (1188.5)	36,200 (1.02)	4,000 (1816)	7,000 (3178)
575 (2176.4)	535 (2025)	61,500 (1.74)	5,800 (2633.2)	10,900 (4948.6)
975 (3690.4)	920 (3482.2)	105,700 (2.99)	9,300 (4222.2)	18,100 (8217.4)
1,625 (6150.6)	1,533 (5802.4)	176,100 (4.99)	10,400 (4721.6)	25,000 (11 350)
3,400 (1286.9)	3,250 (12 301.3)	374,000 (10.59)	18,500 (8399)	49,400 (22 427.6)
6,075 (22 993.9)	5,935 (22 463.9)	684,999 (19.40)	27,999 (12 711.5)	83,500 (37 909)
9,200 (34 822)	8,766 (33 179.3)	1,009,000 (28.57)	34,000 (15 436)	117,500 (53 345)
11,000 (41 635)	10,500 (39 742.5)	1,215,000 (34.41)	40,000 (18 160)	139,750 (63 446.5)

Note: Consult local supplier for available tank capacities.

Automatic controls furnished with the tanks regulate the flow of liquid through the vaporizers. When there is a demand for oxygen, the supply system draws liquid from the bottom of the cryogenic storage tank through the vaporizers. The gas moves through a final line regulator. Thus, a constant supply of oxygen at a regulated pressure is provided.

In case of mechanical difficulty or the depletion of the liquid-oxygen supply, the reserve supply will begin to feed into the distribution system automatically.

An alarm signal should alert appropriate hospital personnel when the liquid in the oxygen storage tank reaches a predetermined level. The alarm signals should indicate low liquid levels, reserve in use, and reserve low.

Cylinder-manifold supply systems Compressed-oxygen systems are comprised of cylinder manifolds that allow a primary supply source of oxygen cylinders to be in use and an equal number of oxygen cylinders to be connected as a reserve supply. The controls of the cylinder manifold will automatically shift the flow of the oxygen gas from the service side to the reserve side when the service side is depleted. Refer to Figure 2-6 for a typical oxygen manifold-system schematic.

Manifold systems can be located indoors or outdoors. When manifolds are located indoors, the engineer should observe the following:

- *Location* Preferably, the manifold should be in a dedicated room on an outside wall near a loading dock and have adequate ventilation and service convenience.
- *Adjacent areas* There should be no doors, vents, or other direct communications between the anesthetizing location or the storage location and any combustible agents. If locating near or adjacent to an elevated temperature area is unavoidable, the engi-

neer should specify sufficient insulation to prevent cylinder overheating;

- *Fire rating* The fire-resistance rating of the room should be at least 1 h.
- *Ventilation* Outside ventilation is required.
- *Security* The room (or area) must be provided with a door or a gate that can be locked and labeled.

Oxygen manifolds are sized taking into consideration the following:

1. The size of the cylinders, 244 ft^3 (6909 L) H-cylinder (see Table 2-12 for a sizing chart).
2. The hospital's usage of oxygen, in ft^3 (L) per month.

Table 2-12
Selection Chart for Oxygen Manifolds

Hospital Usage		Duplex Manifold Size	
Cu. Ft. (10^3 L) per month		Total Cylinders	Cylinders per Side
5,856	(165.8)	6	3
9,760	(276.4)	10	5
13,664	(386.9)	14	7
17,568	(497.5)	18	9
21,472	(608.0)	22	11
25,376	(718.6)	26	13
29,280	(829.1)	30	15
33,154	(938.8)	34	17

Note: Based on use of 244 ft^3 (6909.35 L) H-cylinders.

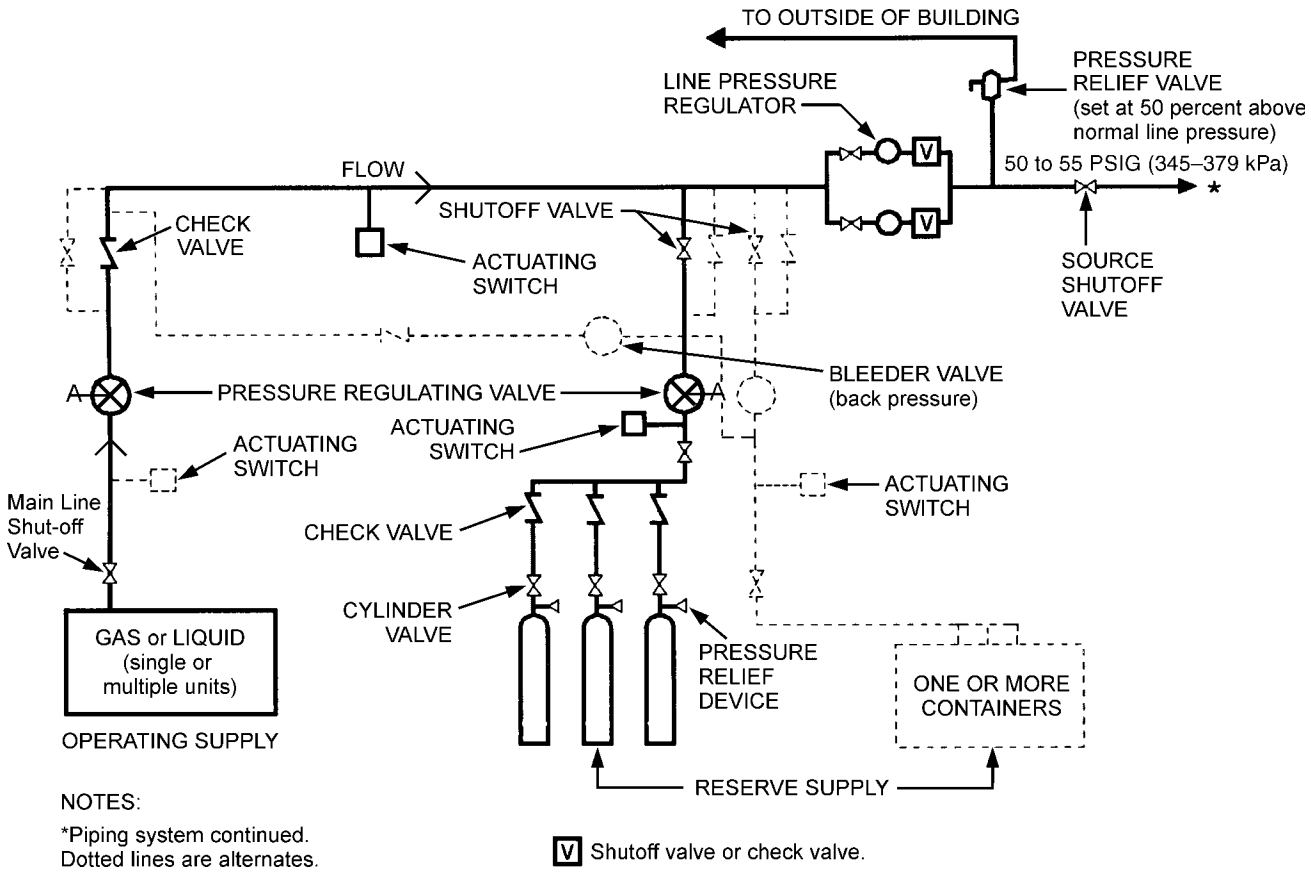

Figure 2-5 Typical Bulk Supply System (Schematic)

Nitrous oxide (N_2O) The common source of nitrous oxide is a cylinder-manifold system. High-pressure manifold systems consist of two banks of cylinders, primary and reserve. (See discussion under "Oxygen," above.)

System demands for nitrous oxide can be more difficult to determine than they are for other medical gases. The number of surgeries scheduled, the types and lengths of surgery, and the administering techniques used by the anesthesiologists cause extreme variations in the amount of nitrous oxide used. Because of this variation, considerations must be given to the size and selection of the nitrous-oxide manifold system.

Avoid locating the nitrous-oxide manifold system outdoors in areas with extremely cold climates. Nitrous oxide is supplied liquefied at its vapor pressure of 745 psi (5136.6 kPa) at 70°F (21.1°C). At extremely cold temperatures, the cylinder pressure will drop dramatically, reducing the cylinder pressure to a point where it is impossible to maintain an adequate line pressure. This is due to a lack of heat for vaporization.

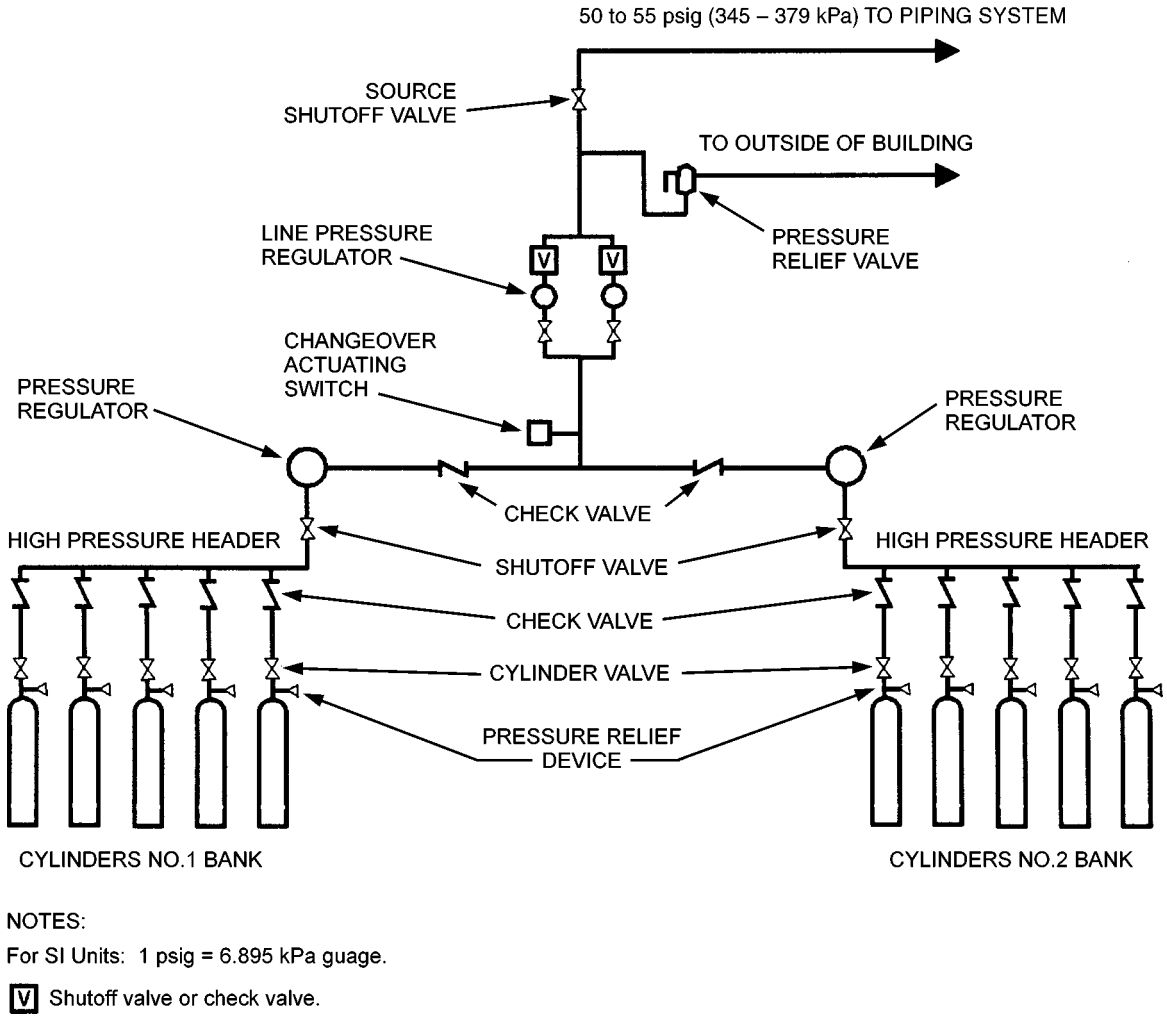

Figure 2-6 Typical Cylinder Supply System without Reserve Supply (Schematic)

Note: Supply systems with different arrangements of valves and regulators are permissible if they provide equivalent safeguards (Level 1 gas system).

For nitrous-oxide manifolds located indoors, the same precautions previously listed for oxygen systems must be observed.

The following should be considered when selecting and sizing nitrous-oxide manifolds and determining the number of cylinders required:

1. The size of the cylinders: 489 ft^3 (13 847 L) K-cylinders (see Table 2-13).
2. The number of anesthetizing locations or operating rooms.
3. Provide ½ of 1 cylinder per operating room for in-service and reserve supplies.

Table 2-13 Sizing Chart for Nitrous Oxide Cylinder Manifolds

Number of Operating Rooms	Duplex Manifold Size			
	Indoor		Outdoor	
	Total Cylinders	Cylinders per Side	Total Cylinders	Cylinders per Side
4	4	2	4	2
8	8	4	10	5
10	10	5	12	5
12	12	6	14	7
16	16	8	20	10

Note:Based on use of 489 ft^3 (13.85 X 10^3 L) K-cylinders.

Medical compressed air Medical compressed air may be supplied by two types of system: (1) a high-pressure cylinder-manifold system; and (2) a medical air-compressor system.

The manifold systems for compressed air are similar in configuration to those for oxygen and nitrous oxide (see discussion under "Oxygen," above). Air supplied from cylinders or that has been reconstituted from oxygen U.S.P. and nitrogen N.F. must comply, as a minimum, with Grade D in ANSI ZE86.I, *Commodity Specification for Air*.

Medical compressed air can be produced on site from atmospheric air using air compressors designed for medical applications. There are three major types of air compressor in the marketplace today: the centrifugal, reciprocating, and rotary screw. The reciprocating and rotary screw are "positive-displacement" type units, while the centrifugal compressor is a "dynamic" type compressor. The medical air compressor shall be designed to prevent the introduction of contaminants or liquid into the pipeline by one of two methods: Type 1 air compressors eliminate oil anywhere in the compressor. Type 2 air compressors separate the oil-containing section from the compression chamber. Examples of a type 1 compressor are the liquid ring, rotary screw, and permanently sealed bearing compressor. Type 2 compressors have extended heads.

A positive-displacement compressor is normally rated in actual cubic feet per minute (acfm). This is the amount of air taken from atmospheric conditions that the unit will deliver at its discharge. Within a broad range, changes in inlet air temperature, pressure, and humidity do not change the acfm rating of either the reciprocating or the rotary screw compressor. The centrifugal compressor's capacity, however, is affected slightly by the inlet air conditions due to the nature of the compression process. For example, as the air temperature decreases, the capacity of the dynamic compressor will increase. The capacity of a centrifugal compressor is normally defined in inlet cubic feet per minute (icfm) . In an effort to obtain an "apples to apples" comparison of various compressors, many manufacturers specify their capacity requirements in standard cubic feet per minute (scfm). This sometimes causes much confusion because many people do not fully understand how to convert from acfm or icfm to scfm. The design engineer specifying scfm must define a typical inlet air condition at the building site and their set of "standard" conditions (normally 14.7 psia [101.4 kPa], 60°F [15.6°C], and 0% relative humidity). Typically, the warmest normal condition is specified because as the temperature goes up scfm will go down.

To convert from acfm to scfm, the following equation is used.

Equation 2-1

$$scfm = acfm \times \frac{P_i - (P_{pi} \times \%RH)}{P_{std} - (P_{p\,std} \times \%RH_{std})} \times \frac{T_{std}}{T_i}$$

where

P_i = Initial pressure

P_{pi} = Partial initial pressure of water vapor in 100% humid air at the temperature in question

RH = Relative humidity

P_{std} = Pressure under standard conditions

$P_{p\ std}$ = Partial standard pressure of water vapor in 100% humid air at the temperature in question

RH_{std} = Relative humidity at standard conditions

T_{std} = Temperature at standard conditions, °F (°C)

T_i = Inlet temperature, °F (°C)

Equation 2-1a

This equation is derived from the Perfect Gas law, which is:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

or:

$$V_2 = V_1 \times \frac{P_1}{P_2} \times \frac{T_2}{T_1}$$

where

P_1 = Initial pressure

V_1 = Initial volume

T_1 = Initial temperature

P_2 = Final pressure

V_2 = Final volume

T_2 = Final temperature

For a reciprocating or rotary-screw compressor, the conversion from acfm to scfm is simple. The inlet air conditions and standard conditions are inserted into the above formula and multiplied by the acfm capacity of the unit. It makes no difference what the design conditions are for that compressor, as these do not figure into the formula. In the case of a dynamic compressor, the icfm air flow at the given inlet conditions is inserted in place of the acfm in the formula. Another design issue that the engineer should be aware of is how altitude affects the output of the compressor. At altitudes above sea level, all medical-air systems have reduced flow. In these cases, the required sizing will need to be adjusted to compensate. To do this, multiply the scfm requirements by the correction factor in Table 2-14.

In other words, to correctly size the medical-air system, you would apply the correction factor listed in the chart above to the peak-calculated load (scfm) at sea level.

Table 2-14 Altitude Correction Factors for Medical-Air Systems

Altitude, ft (m)	Normal Barometric Pressure, in. Hg (mm Hg)	Correction Factor for SCFM (L/min)
Sea level	29.92 (759.97)	1.0 (28.31)
1,000 (304.8)	28.86 (733.04)	1.01 (28.6)
2,000 (609.6)	27.82 (706.63)	1.03 (29.16)
3,000 (914.4)	26.82 (681.23)	1.05 (29.73)
4,000 (1219.2)	25.84 (656.33)	1.06 (30.01)
5,000 (1524)	24.90 (632.46)	1.08 (30.58)
6,000 (1828.8)	23.98 (609.09)	1.10 (31.14)
7,000 (2133.6)	23.09 (586.48)	1.12 (31.71)
8,000 (2438.4)	22.23 (564.64)	1.15 (32.56)
9,000 (2743.2)	21.39 (543.3)	1.17 (33.13)
10,000 (3048)	20.58 (522.7)	1.19 (33.69)

Example 2-2

A facility is located at 5000 ft (1524 m) above sea level and the system demand is 29.4 SCFM. Take the 29.4 scfm and multiply it by 1.08 (correction factor from Table 2-14) to get the adjusted scfm requirement of 31.8 scfm at 5000 ft above sea level. Therefore, a medical-air system of greater capacity is needed at higher altitudes.

Another handy formula for compressed-air systems is the following: to convert scfm to L/min multiply by 28.31685.

Each compressor must be capable of maintaining 100% of the medical-air peak demand regardless of the standby compressor's operating status. The basic compressor package consists of filter intakes, duplex compressors, after-coolers, receiving tanks, air dryers, in-line filters, regulators, dew-point monitors, and valves. The compressor components are connected by piping that allows equipment isolation, provides pressure relief, and removes condensate from receivers. Medical-air compressors must draw outside air from above the roof level, remote from any doors, windows, and exhaust or vent openings. Where the outside atmospheric air is polluted, special filters can be attached to the compressor's intake to remove carbon monoxide and other contaminants. Refer to NFPA 99 for

proper location of medical-air intakes. Medical compressed air must comply with NFPA 99 and/or Canadian Standards Association's (CSA's) definition of air-quality standards.

Where more than two units are provided for the facility, any two units must be capable of supplying the peak calculated demands (see Table 2-5). Provide automatic alternators (duty-cycling controls) to ensure even wear in normal usage. Alternator controls incorporate a positive means of automatically activating the additional unit (or units) should the in-service pump fail to maintain the minimum required pressure.

Medical compressed air produced by compressors may be defined as "outside atmosphere to which no contaminants (in the form of particulate matter, odors, oil vapors, or other gases) have been added by the compressor system." Not every compressor is suitable for use as a source for medical compressed air in health-care facilities. Only those compressor units specifically designed and manufactured for medical purposes should be considered as a reliable source of oil-free, moisture-free, and low-temperature compressed air. Acceptable compressor types include oil-free, oil-less, and liquid-ring compressors. Separation of the oil-containing section from the compression chamber by at least two seals is required by the compressor manufacturers.

Air compressed for medical-breathing purposes are to be used for this purpose only and should not be used for other applications or cross-connected with other compressed air systems. See Figure 2-7 for a typical arrangement of a medical air-compressor system.

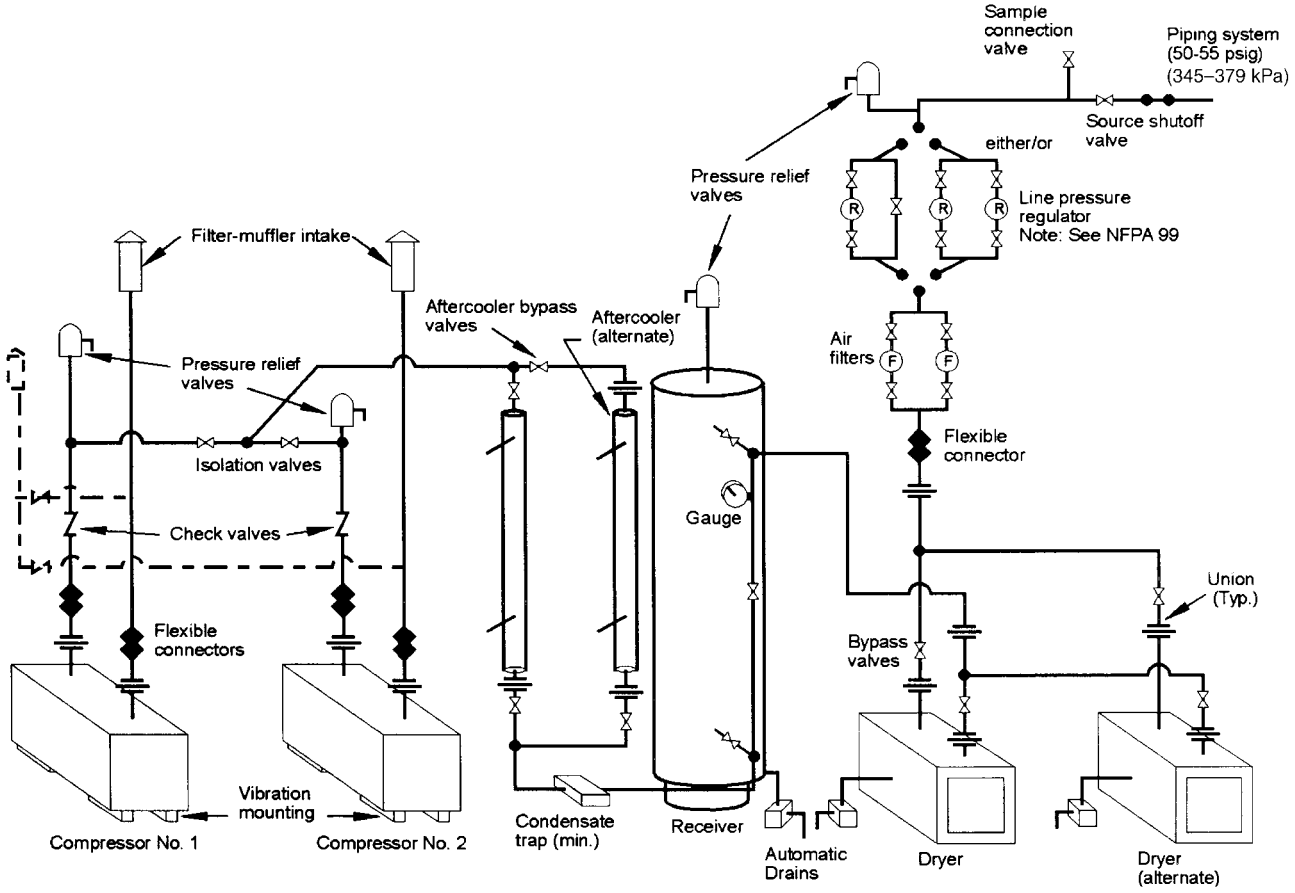

Figure 2-7 Typical Duplex Medical Air-Compressor System (Type 1 Gas System)

Table 2-15 provides the minimum pipe sizes for medical air-compressor intake risers. Consult with the compressor manufacturer on intake recommendations and allowable friction loss for the intake riser before finalizing the pipe size equipment selection.

Table 2-15 Minimum Pipe Sizes for Medical Air-Compressor Intake Risers

Pipe size, in. (mm)		Flow rate, cfm (L/min)	
2.5	(63.5)	50	(1416)
3	(76.2)	70	(1985)
4	(101.6)	210	(5950)
5	(127.0)	400	(11 330)

Nitrogen (N_2) The supply source for nitrogen is generally in the form of high-pressure cylinder manifolds (see discussion under "Oxygen," above). The primary use of nitrogen is to power surgical pneumatic instruments. The selection and size of nitrogen manifolds should be based on the instruments with the highest pressure requirements at the greatest gas consumption rate.

High-pressure gas (nitrogen) systems Surgical instruments are used to drill or cut bones and metals. Surgical applications include neurology, where instruments are used to cut the cranium; in orthopedic service for bone work and joint replacement; for facial reconstruction; and during open-heart surgery.

There is currently available a series of instruments with the highest pressure requirements and the greatest flow rates of all instruments: 200 psig (1379 kPa) at the instrument and a maximum flow rate of 15 scfm (7.08 L/s) to operate effectively. Recent developments have resulted in a new series of tools that requires only 120 psig (827.4 kPa) with a maximum flow rate of 12 scfm (5.66 L/s) to achieve the same effectiveness as the older, higher-pressure line of tools. Other manufacturers of pneumatically operated instruments commonly use a pressure of 160 psig (1103.2 kPa) and a maximum flow rate of 15 scfm (7.08 L/s). For the foreseeable future, there will be a mixture of instruments in use by various facilities.

The tools are operated by a foot pedal. The gas supply to the tool and discharge from the tool are both brought to the floor where the foot pedal is located.

Revisions in NFPA 99 made provisions for pressures up to 300 psig (2068.4 kPa), up from a maximum of 200 psig (1379 kPa) previously allowed. Care must be taken to ensure that all components of a proposed distribution system, including connectors, hose, etc., are rated and approved for the higher pressures.

The following should be considered when selecting and sizing nitrogen manifolds and determining the number of cylinders required:

1. The size of the cylinder: 224 ft^3 (6343 L) H-cylinder (see Table 2-16).
2. The number of operating rooms served by the nitrogen gas.
3. Provide 1 cylinder per operating room for in-service and reserve supplies.
4. Determine the flow rate and pressure requirements of utilized instruments.

Table 2-16 Selection Chart for Nitrogen Cylinder Manifolds

Number of Operating Rooms Piped with Nitrogen	Duplex Manifold Size	
	Total Cylinders	Cylinders per Side
1	2	1
2–4	4	2
5–8	8	4
9–12	12	6
13–16	16	8
17–20	20	10
21–24	24	12
25–28	28	14

Note: Based on use of 224 ft^3 (6343.35 L) H-cylinders.

Vacuum Systems

"Vacuum" is a negative pressure created by the vacuum pumps within the piping system. The evacuation of the air from the piping system allows ambient air to be pulled from station inlets

and exhausted to the outside. The volume of air, in cubic feet per minute (cfm) (liters per minute [L/min]), in the piping is greater than the volume of the ambient air (cfm) (L/s) at atmospheric pressure entering the system, due to expansion under vacuum. In a vacuum system acfm is the air that has been expanded in a vacuum volumetric flow. Values of acfm are much greater than values of scfm. To convert acfm to scfm at 19 in. Hg (482.6 mm Hg), divide acfm by 2.73. For the ratio of scfm to acfm at other pressures, refer to Table 2-17.

At altitudes above sea level, all vacuum systems have reduced flow. In these cases, the required sizing will need to be adjusted to compensate. To do this, multiply the total demand in scfm by the appropriate multiplier shown in Table 2-18.

In other words, to size the medical vacuum system correctly in accordance with NFPA 99 recommendations of scfm at 19 in. Hg (482.6 mm Hg), apply the correction factor listed in Table 2-18 to the peak calculated demand in scfm at 19 in. Hg (482.6 mm Hg).

Table 2-17 ACFM to SCFM Conversion Table

Vacuum Level (in. Hg)	Ratio at Sea Level (scfm:acfm)
0	1:1
15	1:2
18	1:2.5
19	1:2.73
20	1:3
21	1:3.33
22	1:3.75
23	1:4.28
24	1:5
25	1:6
26	1:7.5
27	1:10
28	1:15
29	1:30
29.5	1:60

Table 2-18 Altitude Correction Factors for Vacuum Systems

Altitude, ft (m)	Normal Barometric Pressure	Multiplier used for required SCFM
0 (0)	29.92" Hg	1.0
500 (152.4)	29.39" Hg	1.02
1,000 (304.8)	28.86" Hg	1.04
1,500 (457.2)	28.33" Hg	1.06
2,000 (609.6)	27.82" Hg	1.08
2,500 (762)	27.32" Hg	1.10
3,000 (914.4)	26.82" Hg	1.12
3,500 (1066.8)	26.33" Hg	1.14
4,000 (1219.2)	25.84" Hg	1.16
5,000 (1524)	24.90" Hg	1.20
6,000 (1828.8)	23.98" Hg	1.25
7,000 (2133.6)	23.09" Hg	1.30
8,000 (2438.4)	22.23" Hg	1.35
9,000 (2743.2)	21.39" Hg	1.40
10,000 (3048)	20.58" Hg	1.45

Example 2-3

A facility total demand is 27.5 scfm to produce a 19 in. Hg (482.6 mm Hg) vacuum at sea level. If this facility is located at 5000 ft (1524 m) above sea level, you take the 27.5 scfm and multiply it by 1.20 (the correction factor from Table 2-18) to get the adjusted total requirement of 33.3 scfm at 5000 ft (1524 m) above sea level.

Be sure to use actual cubic feet per minute (acfm) (actual liters per minute [aL/min]) to size vacuum pumps. The patient vacuum system is intended to be a dry vacuum system. However, occasionally fluids enter the piping system accidentally. This should not affect the operations of the vacuum pumps, but it will eventually restrict flow, as the pipes' inner walls become coated with dry body fluids, dust, and debris. Some facilities use the vacuum system to remove airborne smoke particles from electrosurgical or laser-surgery areas. This is not a recommended application for the vacuum system. The smoke contains particulates, hydrocarbons, and water, which, if captured, will condense on the pipes' inner walls, producing a tar-like substance that will eventually restrict flow.

The vacuum-pump system includes duplex (or more) vacuum pumps, a receiver tank and automatic drain, controls, exhaust piping, muffler, and valves. System components are connected by piping that allows equipment isolation and drainage of a receiver tank. The receiver serves as a reservoir and an interceptor for fluids that may enter the vacuum system. Fluid must be periodically drained to the sanitary sewer from the receiver.

The vacuum pump system must be selected, sized, and specified to provide the estimated peak flow demand and a dependable source of medical vacuum at all required times.

Each vacuum pump of a duplex system must be sized for 100% of the estimated peak demand. When a triplex or quadruplex system is specified, each pump shall be sized so that in the event of one pump failing, the remaining pumps are capable of maintaining the required vacuum at 100% of the peak calculated demand. Provide automatic alternators (duty-cycling controls) to ensure even wear in normal usage. Alternator controls incorporate a positive means of automatically activating the additional unit (or units) should the in-service pump fail to maintain the minimum required vacuum.

Individual exhaust stacks should be straight and as short as possible. The collection of the duplex stacks to a single stack is permissible if it is assured that back pressure will not be a potential problem for the system in the future. The exhaust system should be piped to the outside environment, have a gooseneck termination, and be properly screened to prevent insects, leaves, and debris from entering. The exhaust vents should be a minimum distance of 25 ft (7.6 m) from any door, window, outside air intakes, or other opening and a minimum distance of 20 ft (6.1 m) above the ground. The prevailing wind currents and the proximity of the power vents and intake louvers are very important factors to be considered when locating the outdoor vacuum-pump exhaust.

Laboratories should be served by a dedicated vacuum line that is separate from the medical vacuum system; be equipped with drainable fluid traps; and be connected by separate laterals, risers, and mains to the receiver.

Because the vacuum requirements vary considerably in the different sections of a hospital, in both peak demands and in the frequency of use, the total demand for the entire vacuum system should be calculated by the following:

Equation 2-2

$$FR \times UF \times NI = EPF$$

where

FR = Room or station inlet flow rates (scfm)

UF = Simultaneous usage factors

NI = Number of rooms or station inlets

EPF = Estimated peak flow (scfm)

Table 2-19 provides minimum pipe sizes for vacuum exhaust risers. Consult with the vacuum-pump manufacturer on back pressure (friction loss) before finalizing pipe-size equipment selection.

Table 2-19 Minimum Pipe Sizes for Vacuum Exhaust Risers

Pipe Size, in. (mm)	Flow Rate, cfm (L/min)
1¼ (31.75)	12 (340)
1½ (38.1)	23 (655)
2 (50.8)	40 (1 140)
2½ (63.5)	70 (1 990)
3 (76.2)	130 (3 685)
4 (101.6)	160 (4 535)
5 (127.0)	350 (9 915)
6 (152.4)	525 (14 875)

Figure 2-8 illustrates the schematic of a typical, duplex, medical-surgical, vacuum-pump system.

Waste Anesthetic-Gas Management

Anesthesia is as common to medical care as the antiseptic care of wounds. For too long, however, exposure to and control of waste anesthetic gases (WAGs) and vapors during surgical procedures have put health-care workers in jeopardy. At any given time, more than 250,000 people who work in hospitals, operating rooms, dental offices, and veterinary clinics might be exposed unnecessarily to harmful levels of WAGs.

The waste anesthetic gases and vapors of concern are nitrous oxide and halogenated agents (vapors) such as halothane, enflurane, methoxyflurane, trichloroethylene, and chloroform. The list of workers with the potential for exposure to

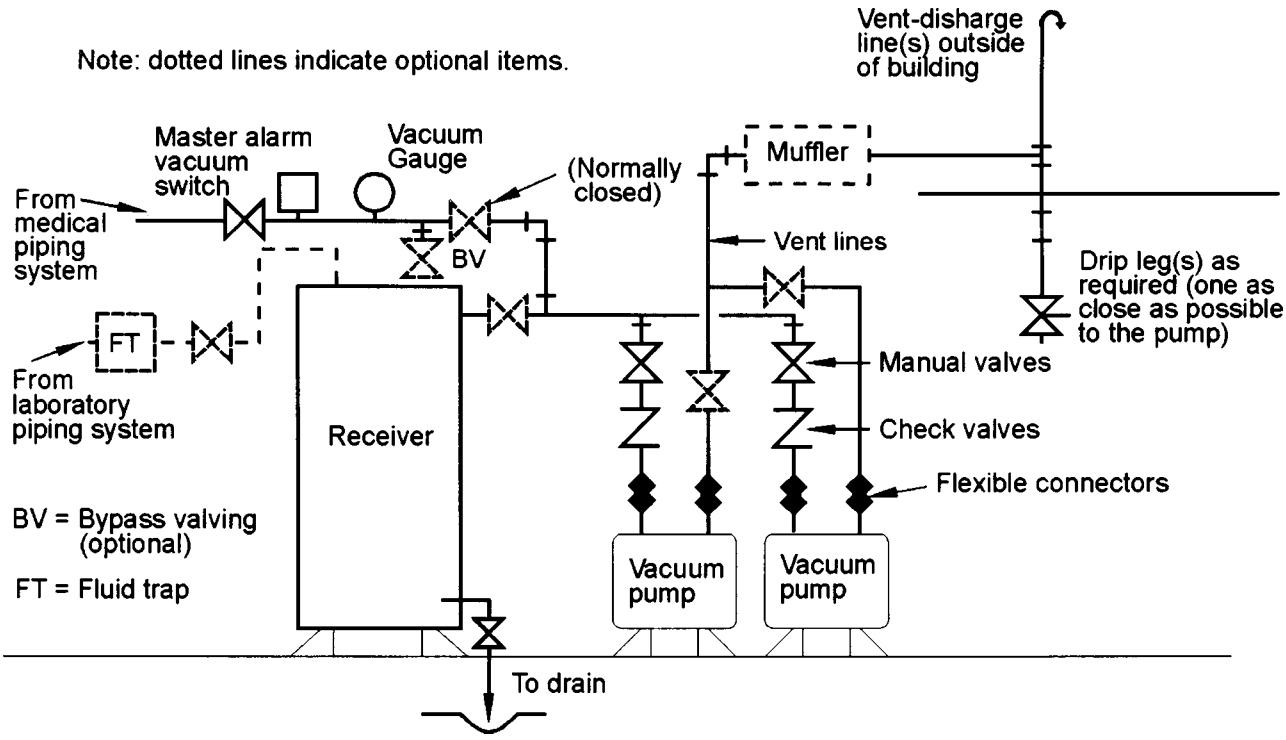

Figure 2-8 Schematic of a Typical, Duplex, Medical-Surgical, Vacuum-Pump System

WAGs includes nurses, physicians—surgeons, obstetricians, and gynecologists—operating-room technicians, recovery-room personnel, dentists and veterinarians and their assistants, and other auxiliaries. Hospital emergency-room personnel may also be exposed, but not on a regular basis.

A complete WAGs management program includes at the outset the application of a well-designed WAGs scavenging system. Such a system consists of a collecting device (scavenging adapter) to collect WAGs and vapors from breathing systems at the site of overflow, a ventilation system to carry WAGs from the operating room, and a method or device for limiting both positive and negative pressure variations in the breathing circuit that may be used by the scavenging systems. Most anesthesia equipment being manufactured today includes scavenging systems.

The remainder of the WAGs management program should include work practices minimizing gas leakage, the application of a routine equipment-maintenance program so that gas leaks are minimized, periodic exposure monitoring, and the provision of adequate general ventilation.

System-Control Valves

General After the proper selection of the medical-gas system source has been made by the plumbing engineer, the next step in the design of such a system is the specification and installation of the pipeline and controls. These typically include 1) source shut-off valves, 2) main shut-off valves, 3) in-line shut-off valves, and 4) zone valve-box assemblies. The purpose of including these intermediate valves in the medical-gas system is to provide the capability of isolating various portions of the systems, in total or by area. This is useful in case of an emergency and in order to allow for maintenance without interruption of the total medical-gas system. Often, future remodeling connections should be considered in the determination of valve placement. All valves in medical-gas systems must be totally accessible, labeled, and, if concealed,

identified. This allows area shutdown, purge, and certification to be done while the remainder of the system stays in service. Based upon the latest recommendations of the NFPA, zone valves that are accessible to other than authorized personnel should be installed inside of valve boxes that are provided with breakable or removable windows. This valve is to be readily operable from a standing position in the corridor on the same floor it serves.

Shut-off valves should be located in medical-gas systems at the following locations:

1. Source equipment outlet shut-off valves.
2. The main supply line entering the building.
3. The base of each medical-gas riser adjacent to the riser connection.
4. Each floor distribution zone serving patient areas.
5. Each anesthetizing locations.
6. Each critical (intensive) care area, emergency room, and recovery room.

Valves, fittings, and other components The valve(s) and box assemblies should be full-port ball valve(s) with 90° from the open to the closed position. The size of the valves should be based upon the size of pipe they serve so as not to provide a reduction (or restriction) in the flow of the pipeline system.

A gauge, installed downstream of the zone valve, is required in the patient room.

The locations cited above are the minimum recommendations; local plumbing codes, NFPA standards, and site conditions should prevail in the final determination of the valve placement. All piping, except control-line tubing, shall be identified. All service-main, branch-main, and riser valves shall be tagged, and a valve schedule shall be provided to the facility owner for permanent record and reference.

Valves and fittings and other components shall be cleaned for oxygen service.

Warning Systems

The facility's gas-dispensing equipment is adjusted to deliver a particular gas at a given flow and pressure. Fluctuations in the given pressure may cause the dispensing equipment to stop functioning or to function inaccurately. For this reason, line-pressure sensing switches should be installed in all medical-gas lines immediately downstream from the source's main shut-off valve. Monitoring of the design conditions is extremely important because any alarms require a certain response from the maintenance engineers, nursing personnel, and supply personnel.

Warning systems are classified into two basic groups: (1) master alarms and (2) area alarms. Additionally, interface controls (relays) are now being provided in computerized signal equipment.

Master alarms NFPA requires that two master-alarm panels be provided, located (1) in the engineer's office and (2) in an area where a 24-hour surveillance is maintained. The master alarm provides its signals by a pressure switch (vacuum switch) located immediately downstream from the source's main shut-off valve or at the site of the source. For example, with a liquid-oxygen system, various pressure switches are located at the bulk site, which provide signals to main of reserve changeover, reserve in use, reserve failure, and low reserve. Additional oxygen signals needed for the master alarm are line pressure high and line pressure low.

Typical manifold gases, such as nitrous oxide, require signals to the master alarm to indicate line pressure high, line pressure low, and reserve supply in use.

Area alarms Area alarms are local alarms usually provided with a self-contained pressure switch and a gauge located in the panel. These area alarms monitor the line pressure in areas in order to indicate if the pressure increases or decreases from the normal operating pressure. Except in the operating or delivery area, locations where each operating or delivery room is valved, the area alarm signals are from the specific line supplying the area, with the individual room shut-off valve being the only one between the actuating switch and the room outlets.

Care should be taken by the engineer to locate the area alarm in convenient view of the nursing personnel who normally work in the area covered. In case of a stoppage of the medical gas or any other alarm condition, the proper personnel must take prompt and precise corrective actions. Area alarm signals for critical zones should be interfaced with the master-alarm panels.

Interface controls In order to advise total building maintenance systems of any malfunctions in the medical-gas systems, most manufacturers usually provide a relay interface control so that easy and compatible signals can be provided by the total building maintenance and control system.

Medical-Gas Piping

Installation guide The basic principles to be considered by the plumbing engineer and kept in mind during the design phase are as follows:

1. *Buried piping* Always protect against leakage, frost, corrosion, and physical damage. Conduit or castings may be used as necessary. Medical-gas piping may be installed in the same utility tunnel with fuel-gas pipelines, electrical lines, or stream lines, provided that there is adequate natural or forced-air ventilation. The medical-gas pipelines must not be placed in a tunnel, trench, or duct where they may be exposed to physical contact with oil or corrosive materials.
2. *Concealed locations* In concealed spaces, always protect against any physical damage by installation within a pipe or conduit. Openings for pipelines installed in combustible partitions must be fire stopped with a type of construction having a fire resistance equal to, or greater than, the original construction.
3. *Pipe shafts* Medical-gas systems may be installed in a pipe and duct shaft if suitably protected against any possible physical damage, effects of excessive heat, corrosion, or contact with oil. Shafts that penetrate multiple floors must meet local code requirements regarding fire rating and sealing of shaft penetrations.
4. *Prohibited piping locations* The following installation locations are prohibited by codes and must not be considered by the plumbing engineer:
   A. Elevator shafts.
   B. Kitchens.
   C. Electrical switch-gear rooms.
   D. Storage rooms for combustible materials.
5. *Exposure in an activity area (such as a corridor where movement of portable equipment may effect damage)* Installation in these locations should be avoided if possible. If unavoidable, use a hard-temper tubing and provide adequate identification, protective shields, and monitoring.
6. *Pipe hangers* Pipe and supports should be supported from the building structure in accordance with MSS or the schedule given in Table 2-20.

Table 2-20 Medical-Gas Pipe Support Schedule

Pipe Size, in. (mm)	Max. Span Between Hangers, ft (m)
¼ (6)	5 (1.52)
⅜ (10)	6 (1.83)
½ (12.5)	6 (1.83)
¾ (20)	7 (2.13)
1 (25)	8 (2.44)
1¼ (32)	9 (2.74)
1½ (40) and larger	10 (3.05)

Medical-gas pipe sizing criteria

General Pipe sizing is one of the most important aspects of designing medical-gas systems. Oversized piping is required for future expansions. However, undersized pipes will never provide adequate flow or pressure during peak-demand conditions. The friction loss or pressure drop between the supply source and outlets must be designed within acceptable limits. Each medical-gas system has a system operating pressure and maximum pressure loss (drop), which are given later in this section.

To determine the approximate pressure loss for a system, start by measuring the longest pipe run from the source to the last station outlet/inlet. Multiply the longest pipe run by a fitting factor (30 to 50% is normal) to establish the equivalent length. Divide the allowable pressure drop by the equivalent length, and multiply by 100 (30.48) to obtain an allowable friction loss per 100 ft (30.48 m). Friction-loss tables provided later in this chapter give the friction loss per 100 ft (30.48 m) of various sizes of pipe. The system's peak probable demand is calculated by multiplying the number of stations by the flow allowance by the simultaneous use factor. Pipe diameters are determined by reading the friction-loss tables at the proper correlating flow rate

and friction loss per 100 ft (30.48 m) of pipe. Refer to the following equations:

Equation 2-3

$$EL = DM \times ff,$$

then

Equation 2-3a

$$PL = \frac{APD}{EL} \times 100$$

$$\left(PL = \frac{APD}{EL} \times 30.48\right)$$

where

EL = Equivalent length, ft. (m)

DM = Longest pipe length/run, ft (m)

ff = Fitting factor

PL = Pressure loss, ft per 100 ft (m per 30.48 m)

APD = Allowable pressure drop, ft (m)

Acceptable pipeline-system design criteria require that the risers be sized larger than the laterals and the laterals larger than the drops to the outlets. In general, the diameters tend to reduce from the source to the end of the distribution system.

Oxygen The flow rate for oxygen outlets is 1 cfm (.47 L/s). A source pressure of 55 psi (379.2 kPa) and maximum pressure drop of 5 psi (34.47 kPa) should be used in the design. Adult and infant ventilators require volumes of oxygen that exceed the 1 cfm (.47 L/s) flow rate. The recommended flow rate for adult ventilators is 6.36 cfm (3.0 L/s) with no diversity factor. Infant ventilators require 1 cfm (.47 L/s) with no diversity factor. Refer to Table 2-21 for outlet rating and diversity factors.

The friction-loss data for oxygen-pipe systems are given in Table 2-22.

Nitrous oxide The flow rate for nitrous oxide outlets is 1 cfm (0.47 L/s). A source pressure of 55 psi (379.2 kPa) and maximum pressures drop of 5 psi (34.47 kPa) should be used in the design. Refer to Table 2-21 for outlet rating and diversity factors.

Base oxygen and nitrous-oxide pipe-size selection on the more stringent of the following requirements:

1. Maximum friction loss of 1 psi (6.90 kPa) per 100 ft (30.48 m).
2. Maximum friction loss of 5 psi (34.47 kPa) to the farthest outlet.

The friction-loss data for nitrous oxide pipe systems are given in Table 2-22.

Nitrogen The flow rate for nitrogen outlets is 15 cfm (7.1 L/s) per operating room. The source pressure range is 200 to 300 psi (1378.96 to 2068.44 kPa) and the maximum pressure drop is 10% of total system pressure. Specific pressue requirements for tools may dictate the pressure required at a specific point in the system. Refer to Table 2-21 for outlet rating and diversity factors.

Base nitrogen pipe-size selection on the more stringent of the following requirements:

1. Maximum friction loss of 2 psi (13.79 kPa) per 100 ft (30.48 m).
2. Maximum friction loss not to exceed 10% of total system pressure to the farthest outlet.

The friction-loss data for nitrogen pipe systems are given in Table 2-23.

Medical air The flow rate for medical-air outlets is generally 1 cfm (30 L/min), although this may vary. A source pressure of 50 psi (344.74 kPa) and a maximum pressure drop of 5 psi (34.47 kPa) should be considered. Specific pressure requirements for equipment may dictate the pressure required at a specific point in the system. Refer to Table 2-21 for outlet rating and diversity factors.

The friction-loss data for medical-air pipe systems are given in Table 2-24.

Vacuum The flow rate for vacuum inlets is different than it is for other systems because areas vary in demand. Table 2-21 provides outlet rating data and diversity factors. Consider a source vacuum of 19 in. (64.2 kPa) Hg at the service inlet with a maximum pressure drop of 5 in. (16.9 kPa) Hg.

The friction-loss data for vacuum-pipe systems are given in Table 2-25.

Piping materials Pipe and fittings installed in medical-gas systems shall be thoroughly cleaned suitably for oxygen service, with the removal of oil, grease, and other readily oxidizable materials. Such piping systems shall be plugged or capped to prevent contamination until final as-

Table 2-21 Medical-Gas Diversity (Simultaneous-Use) Factors

System	Abbreviation	Quantity of Outlets	Diversity (%)	Minimum Flow, cfm (L/min)
Oxygen & nitrous oxide	O_2 and N_2O	1–3	100	— —
		4–12	75	2 (56.64)
		13–20	50	4 (113.28)
		21–40	33	5 (141.60)
		41 & over	25	6 (169.92)
High-pressure nitrogen	N_2	1 & 10	100	— —
		11–20	75	2.5 (70.8)
		21 & over	66	3.75 (106.2)
Medical laboratory compressed air	MA	1–2	100	— —
		3–12	80	3 (84.96)
		13–38	60	10 (283.2)
		39–115	40	25 (708.0)
		116–316	30	50 (1 416.0)
		317–700	20	95 (2 690.4)
		701–1880	15	145 (4 106.4)
		1881–4400	10	285 (8 071.2)
		4401–16,000	5	445 (12 602.4)
		16,001–80,000	2	800 (22 656.0)
		80,000 & over	2	800 (22 656.0)
Laboratory vacuum	VAC	1–4	100	— —
		5–12	80	5 (141.60)
		13–33	60	10 (283.20)
		34–80	50	21 (594.72)
		81–150	40	40 (1 132.80)
		151–315	35	61 (1 727.52)
		316–565	30	111 (3 143.52)
		566–1000	25	171 (4 842.72)
		1001–2175	20	251 (7 108.32)
		2176–4670	15	436 (12 347.52)
		4671 & over	10	701 (19 852.32)

Minimum recommended pipe sizes, in. (mm)

Service	O_2	N_2O	N_2	MA	MV
Minimum system pipe/tube size	½ (12.5)	½ (12.7)	½ (12.7)	½ (12.7)	¾ (19.1)
Minimum riser size	¾ (19.1)	¾ (19.1)	1 (25.4)	¾ (19.1)	1 (25.4)
Minimum branch size	½ (12.7)	½ (12.7)	½ (12.7)	½ (12.7)	¾ (19.1)
Minimum single outlet supply size	⅜ (9.5)	⅜ (9.5)	⅜ (9.5)	⅜ (9.5)	⅜ (9.5)

Table 2-22 Data for Sizing Oxygen and Nitrous Oxide Supply Piping

O_2 and N_2O, cfm (L/min)	Nominal Pipe Size, in. (mm)								
	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)	4 (101.6)
	Pressure Drop per 100 Ft (30.48 m) of Pipe, psi (kPa)								
1.76 (50)	0.04 (0.28)								
3.53 (100)	0.16 (1.1)								
4.41 (125)	0.25 (1.72)								
5.3 (150)	0.33 (2.27)	0.04 (0.28)							
6.18 (175)	0.48 (3.31)	0.06 (0.41)							
7.06 (200)	0.63 (4.34)	0.07 (0.48)							
8.83 (250)	0.99 (6.83)	0.11 (0.76)							
10.89 (300)	1.41 (9.72)	0.16 (1.1)	0.04 (0.28)						
14.12 (400)	2.51 (17.31)	0.29 (2.0)	0.07 (0.48)						
17.66 (500)	3.92 (27.03)	0.45 (3.1)	0.11 (0.76)						
26.48 (750)		1.02 (7.03)	0.24 (1.65)						
35.31 (1 000)		1.80 (12.41)	0.42 (2.9)	0.13 (0.9)	0.05 (0.34)				
44.14 (1 250)		2.81 (19.37)	0.66 (4.55)	0.21 (1.45)	0.09 (0.62)				
52.97 (1 500)			0.95 (6.55)	0.30 (2.07)	0.12 (0.83)				
70.62 (2 000)			1.05 (7.24)	0.67 (4.62)	0.22 (1.52)	0.05 (0.34)			
88.28 (2 500)				0.83 (5.72)	0.34 (2.34)	0.08 (0.55)			
105.93 (3 000)				1.19 (8.2)	0.49 (3.38)	0.11 (0.76)			
141.24 (4 000)				2.11 (14.55)	0.88 (6.07)	0.20 (1.38)	0.06 (0.41)		
176.55 (5 000)				3.30 (22.75)	1.36 (9.38)	0.32 (2.2)	0.10 (0.69)		
264.83 (7 500)					3.10 (21.37)	0.71 (4.9)	0.22 (1.52)	0.09 (0.62)	
353.11 (10 000)						1.27 (8.76)	0.40 (2.76)	0.16 (1.1)	
529.66 (15 000)						2.82 (19.44)	0.89 (6.14)	0.35 (2.41)	0.08 (0.55)
706.21 (20 000)						5.00 (34.47)	1.58 (10.9)	0.63 (4.34)	0.15 (1.03)
882.77 (25 000)							2.47 (17.03)	0.98 (6.76)	0.23 (1.59)
1059.32 (30 000)							3.55 (24.48)	1.40 (9.65)	0.31 (2.14)
1412.43 (40 000)								2.48 (17.1)	0.59 (4.07)
1765.54 (50 000)								3.90 (26.9)	0.92 (6.34)

sembly. Piping materials allowed by code, subject to local requirements, shall be hard-drawn, seamless medical-gas tube, type K or L (ASTM B819), cleaned and capped, and shall bear one of the following markings: "oxy, med"; "oxy/med"; "acr/oxy"; or "acr/med." Mains and branches in piping systems shall not be less than ½ in. (12.5 mm) in nominal size. For systems operated at pressures between 200 and 300 psig (1379 and 2068.4 kPa), ASTM B819, type K copper shall be used. Joints in medical-gas tube shall be brazed except that "memory metal" couplings having temperature and pressure ratings not less than those of a brazed joint are also acceptable. Unions are not permitted in any distribution pipeline system.

Hoses and flexible connections Metallic and nonmetallic hoses or flexible connections are to be no longer than required and should not be permanently concealed in walls, floors, ceilings, or partitions. Hoses are to have a flame-spread rating of 200 in accordance with NFPA 255.

Certification of Medical-Gas Systems

Testing shall be in strict accordance with state and local regulations, NFPA 99-1996, and the following:

Note: The alternative test specified in NFPA 99-1996 4-3.4.1.3(a)2 is not recommended for our purposes. Because of the possibility of line-pressure drops, malfunction of test gauges, and/or

Table 2-23 Data for Sizing Nitrogen Supply Piping

		Nominal Pipe Size, in. (mm)					
cfm	(L/min)	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)
		Pressure Loss, psi per 100 ft (kPa per 3.48 m) of 160 psi (1103.2 kPa) Piping					
5	(145)	0.11 (0.76)	0.01 (0.07)				
10	(284)	0.43 (2.96)	0.07 (0.48)	0.02 (0.14)	0.01 (0.07)		
15	(425)	0.96 (6.62)	0.12 (0.83)	0.04 (0.28)	0.01 (0.07)		
20	(567)	1.70 (11.72)	0.26 (1.79)	0.07 (0.48)	0.02 (0.14)	0.01 (0.07)	
25	(708)	2.66 (18.34)	0.42 (2.90)	0.11 (0.76)	0.03 (0.21)	0.01 (0.07)	
30	(850)		0.59 (4.07)	0.17 (1.17)	0.04 (0.28)	0.02 (0.14)	
35	(992)		0.81 (5.58)	0.22 (1.52)	0.05 (0.34)	0.02 (0.14)	
40	(1133)		1.06 (7.31)	0.29 (2.00)	0.07 (0.48)	0.03 (0.21)	
45	(1275)		1.34 (9.24)	0.37 (2.55)	0.09 (0.62)	0.04 (0.28)	0.01 (0.07)
50	(1416)		1.65 (11.38)	0.46 (3.17)	0.11 (0.76)	0.05 (0.34)	0.01 (0.07)
60	(1700)		2.37 (16.34)	0.66 (4.55)	0.15 (1.03)	0.07 (0.48)	0.02 (0.14)
70	(1984)			0.90 (6.21)	0.21 (1.45)	0.09 (0.62)	0.02 (0.14)
80	(2266)			1.17 (8.07)	0.27 (1.86)	0.12 (0.83)	0.03 (0.21)
90	(2550)			1.48 (10.20)	0.34 (2.34)	0.15 (1.03)	0.04 (0.28)
100	(2833)			1.83 (12.62)	0.43 (2.96)	0.19 (1.31)	0.05 (0.34)
110	(3116)			2.21 (15.24)	0.51 (3.52)	0.23 (1.54)	0.06 (0.41)
120	(3400)				0.62 (4.27)	0.27 (1.86)	0.07 (0.48)
130	(3683)				0.72 (4.96)	0.32 (2.21)	0.09 (0.62)
140	(3966)				0.83 (5.72)	0.37 (2.55)	0.10 (0.69)
150	(4250)				0.96 (6.62)	0.42 (2.90)	0.11 (0.76)

Table 2-24 Pressure Loss, psi per 100 ft (kPa per 30.48 m) in 50 psi (344.74 kPa) Compressed-Air Piping

		Nominal Pipe Size, in. (mm)								
cfm	(L/s)	½ (12.7)	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)	4 (101.6)
5	(2.36)	0.30 (2.07)	0.03 (0.21)	0.01 (0.07)						
10	(4.72)	1.15 (7.93)	0.18 (1.24)	0.05 (0.34)	0.01 (0.07)					
15	(7.08)		0.40 (2.76)	0.11 (0.76)	0.03 (0.21)					
20	(9.44)		0.69 (4.76)	0.20 (1.38)	0.05 (0.34)	0.02 (0.14)				
25	(11.80)		1.14 (7.86)	0.31 (2.14)	0.07 (0.48)	0.03 (0.21)				
30	(14.16)			0.44 (3.03	0.10 (0.69)	0.05 (0.34)				
35	(16.52)			0.61 (4.21)	0.14 (0.97)	0.06 (0.41)				
40	(18.88)			0.80 (5.52)	0.18 (1.24)	0.08 (0.55)				
45	(21.24)			1.00 (6.89)	0.23 (1.59)	0.10 (0.69)	0.03 (0.21)			
50	(23.60)				0.29 (2.00)	0.13 (0.90)	0.04 (0.28)			
60	(28.32)				0.42 (2.90)	0.18 (1.24)	0.05 (0.34)			
70	(33.04)				0.56 (3.86)	0.25 (1.72)	0.07 (0.48)	0.03 (0.21)		
80	(37.76)				0.74 (5.10)	0.33 (2.28)	0.09 (0.62)	0.03 (0.21)		
90	(42.48)				0.93 (6.41)	0.41 (2.83)	0.11 (0.76)	0.04 (0.28)		
100	(47.20)				1.15 (7.93)	0.51 (3.52)	0.14 (0.97)	0.05 (0.34)		
110	(51.92)					0.62 (4.27)	0.17 (1.17)	0.06 (0.41)		
120	(56.64)					0.73 (5.03)	0.20 (1.38)	0.08 (0.55)		
130	(61.36)					0.86 (5.93)	0.23 (1.59)	0.09 (0.62)	0.03 (0.21)	
140	(66.08)					1.00 (6.89)	0.27 (1.86)	0.11 (0.76)	0.03 (0.21)	
150	(70.80)						0.31 (2.14)	0.12 (0.83)	0.04 (0.28)	
175	(82.60)						0.42 (2.90)	0.16 (1.10)	0.05 (0.34)	
200	(94.40)						0.54 (3.72)	0.21 (1.45)	0.07 (0.48)	
225	(106.20)						0.69 (4.76)	0.29 (2.00)	0.08 (0.55)	
250	(118.00)						0.85 (5.86)	0.33 (2.28)	0.10 (0.69)	
275	(129.80)						1.03 (7.10)	0.40 (2.76)	0.13 (0.90)	
300	(141.60)							0.48 (3.31)	0.15 (1.03)	
325	(153.40)							0.56 (3.86)	0.18 (1.24)	
350	(165.20)							0.65 (4.48)	0.20 (1.38)	
375	(177.00)							0.74 (5.10)	0.23 (1.59)	
400	(188.80)							0.84 (5.79)	0.27 (1.86)	
450	(212.40)							1.06 (7.31)	0.32 (2.21)	
500	(236.00)								0.42 (2.90)	
550	(259.60)								0.50 (3.45)	0.12 (0.83)
600	(283.20)								0.60 (4.14)	0.14 (0.97)
650	(306.80)								0.70 (4.83)	0.17 (1.17)
700	(330.40)								0.82 (5.65)	0.19 (1.31)
750	(354.00)								0.94 (6.48)	0.22 (1.52)
800	(377.60)								1.06 (7.31)	0.25 (1.72)
850	(401.20)									0.28 (1.93)
900	(424.80)									0.32 (2.21)
950	(448.40)									0.36 (2.48)
1000	(472.00)									0.39 (2.69)
1100	(519.20)									0.48 (3.31)
1200	(566.40)									0.57 (3.93)
1300	(613.60)									0.67 (4.62)
1400	(660.80)									0.77 (5.31)
1500	(708.00)									0.89 (6.14)
1600	(755.20)									1.00 (6.89)

Table 2-25 Data for Sizing Vacuum Piping Systems

Air Flow, cfm (L/s)	Nominal Pipe Size, inches (mm)							
	¾ (19.1)	1 (25.4)	1¼ (31.8)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)	4 (101.6)
	Pressure Drop per 100 Ft (30.48 m) of Pipe, in. Hg (kPa)							
1 (0.5)	0.15 (0.51)							
2 (0.9)	0.39 (1.32)	0.10 (0.34)						
3 (1.4)	0.77 (2.60)	0.19 (0.64)						
4 (1.9)	1.24 (4.19)	0.31 (1.05)	0.10 (0.34)					
5 (2.4)	1.78 (6.01)	0.44 (1.49)	0.14 (0.47)					
6 (2.8)	2.40 (8.10)	0.60 (2.03)	0.19 (0.64)					
7 (3.3)		0.77 (2.60)	0.24 (0.81)	0.12 (0.41)				
8 (3.8)		0.95 (3.21)	0.31 (1.05)	0.15 (0.51)				
9 (4.3)		1.17 (3.95)	0.38 (1.28)	0.18 (0.61)				
10 (4.7)		1.38 (4.66)	0.45 (1.52)	0.22 (0.74)				
15 (7.1)		2.80 (9.46)	0.88 (2.97)	0.44 (1.49)	0.12 (0.41)			
20 (9.4)			1.46 (4.93)	0.72 (2.43)	0.19 (0.64)			
25 (11.8)			2.20 (7.43)	1.09 (3.68)	0.29 (0.98)	0.10 (0.34)		
30 (14.2)				1.52 (5.13)	0.41 (1.38)	0.14 (0.47)		
35 (16.5)				2.00 (6.75)	0.54 (1.82)	0.18 (0.61)		
40 (18.9)				2.50 (8.44)	0.67 (2.26)	0.22 (0.74)	0.10 (0.34)	
45 (21.2)					0.81 (2.74)	0.27 (0.91)	0.12 (0.41)	
50 (23.6)					0.99 (3.34)	0.33 (1.11)	0.14 (0.47)	
60 (28.3)					1.34 (4.53)	0.45 (1.52)	0.19 (0.64)	
70 (33.0)					1.79 (6.04)	0.60 (2.03)	0.26 (0.88)	0.07 (0.24)
80 (37.8)					2.30 (7.77)	0.77 (2.60)	0.32 (1.08)	0.09 (0.30)
90 (42.5)						0.96 (3.24)	0.41 (1.38)	0.11 (0.37)
100 (47.2)						1.17 (3.95)	0.50 (1.69)	0.14 (0.47)
125 (59.0)						1.71 (5.77)	0.74 (2.50)	0.20 (0.68)
150 (70.8)						2.30 (7.77)	0.99 (3.34)	0.27 (0.91)
175 (82.6)							1.28 (4.32)	0.35 (1.18)
200 (94.4)							1.61 (5.43)	0.44 (1.49)

human error, it should not be allowed in cross-connection testing of vital life-support gases.

Medical-gas certification checklist It is recommended that a step-by-step checklist be followed to ensure that every aspect of the medical-gas and vacuum system is tested properly.

Prior to having the system certified, the plumbing contractor should perform items 1, 2, 3, 4, 5, and 6 below. Typically these are inspected by local inspectors.

1. Clean the piping system by clearing it with pressurized, oil-free, dry air or nitrogen. This cleaning shall be performed just after the installation of the piping system but before the installation of the alarm switches, manifolds, pressure gauge, and other "peripheral" components.
2. Visually inspect each brazed joint. This inspection shall be done to make sure that the brazing alloy has been properly applied to the joint and that there are no discernible defects. During the inspection, excess flux shall be removed.
3. Before the wallboard application, pressurize each section of the piping system to 150 psig (1034.22 kPa) using oil-free, dry air or nitrogen. After the system has been pressurized, each joint shall be checked for leakage using a soap-water solution or another nontoxic leak-detecting agent. If leaks are detected, the system shall be repaired and retested.
4. After testing each individual medical-gas system, the completely assembled station outlets and all other components shall be installed and subjected to a 24-h standing pressure test at 20% above normal operated line pressure. This test gas shall be oil-free, dry nitrogen. The source valve shall be closed. Leaks, if any, shall be located, repaired, and retested.
5. Each dedicated gas system shall be tested with oil-free, dry nitrogen, to verify that there are no cross-connections to any other system. To determine the presence of cross connections, pressurize only one system to 50 psig (344.74 kPa) at a time, and then test each outlet to verify that the gas exists only at each of the expected outlets. (See item no. 7.)
6. Each gas piping system shall be purged of contaminants by flushing it with the appropriate source gas while under system pressure. The piping system for each gas shall be purged by successively opening each outlet in progressive order, starting with the outlet that is nearest the pressure source and ending at the outlet that is farthest from the pressure source. The gas shall be purged through a white cloth material at a flow rate of at least 3.5 cfm (100 L/min) until there is no longer any evidence of discoloration or particulates. It is also important to purge for a sufficiently long time so that all of the test gas previously used is removed from the system. (See item no. 11.)

   Start-up, testing, and certification of the medical-gas systems shall be conducted by an independent, third-party, trained representative with a minimum of 5 years experience in medical-gas pipeline testing and certification. Proof of liability insurance should be requested by the owner/general contractor.

   After successful start-up of all systems and components, vital information regarding the proper operation of the equipment shall be made a part of the medical-gas certification. This shall include, but not be limited to:

   - The medical air compressors, dryers, purifiers, filters, regulators, and dew-point and carbon-monoxide monitors.
   - The medical-vacuum pumps.
   - The bulk liquid-oxygen field and oxygen, nitrous-oxide, nitrogen, and carbon-dioxide manifolds.
   - The master and area alarms and their signal devices.
   - The medical-gas valves and zone-valve boxes.
   - The outlets, nitrogen-control panels, columns, and hose drop assemblies.

7. *Cross-connection test*

   A. After the closing of walls and the completion of requirements of NFPA 99-1996 4-3.4.1.2, it shall be determined that no cross connection of piping systems exists. All medical-gas systems shall be reduced to atmospheric pressure. All sources of test gas from all of the medical-gas systems, with the exception of the one system to be checked, shall be disconnected. This system shall be

pressurized with oil-free nitrogen to 50 psig (344.74 kPa gauge). With appropriate adapter matching outlet labels, each individual station outlet of all medical-gas systems installed shall be checked to determine that test gas is being dispensed only from the outlets of the medical-gas system being tested.

a. The source of the test gas shall be disconnected and the system tested reduced to atmospheric pressure. Proceed to test each additional piping system in accordance with 7A.

b. Where a medical-vacuum piping system is installed, the cross-connection testing shall include that piped vacuum system with all medical-gas piping systems.

B. The presence and correctness of labeling required by this standard for all components (e.g., station outlets, shut-off valves, pipelines, and signal panels) shall be verified.

8. *Valve test* Valves installed in each medical-gas piping system shall be tested to verify proper operation in rooms or areas of control. Records shall be made listing the rooms or areas controlled by each valve for each gas. The information shall be utilized to assist and verify the proper labeling of the valves.

9. *Flow test*

A. All outlets shall be tested for flow. Tests shall be performed with the use of oil-free, dry nitrogen as described in CGA P-9, *Inert Gases: Argon, Nitrogen and Helium.*

B. Oxygen, nitrous-oxide, and air outlets shall deliver 3.5 scfm (1.65 L/s) with a pressure drop of no more than 5 psig (34.47 kPa) and static pressure of 50 psig (344.74 kPa).

C. Nitrogen outlets shall deliver 5.0 scfm (2.36 L/s) with a pressure drop of no more than 5 psig (34.47 kPa) and static pressure of 160 psig (1103 kPa).

10. *Alarm testing*

A. *General* All warning systems for each medical-gas piping system shall be tested to ensure that all components function properly prior to placing the piping system in service. Permanent records of these tests shall be maintained.

Warning systems that are part of an addition to an existing piping system shall be tested prior to the connection of the new piping to the existing system.

B. *Warning systems* Tests of warning systems for new installations (initial test) shall be performed after the cross-connection testing discussed in item 7 but before the purging and verifying in item 12. Initial tests of warning systems that may be included in an addition or extension to an existing piping system shall be completed before connection of the addition to the existing system. The test gas for the initial tests shall be oil-free, dry nitrogen.

C. *Master alarm systems*

a. The master alarm system test shall be performed for each of the nonflammable medical-gas piping systems. Permanent records of these tests shall be maintained with those required under NFPA 99-1999 4-3.5.3.

b. The audible and noncancellable visual signals of NFPA 99-1999 4-3.1.2.1(b)3e shall indicate pressure in the main line increases or decreases 20% from the normal operating pressure.

D. *Area alarm systems* The warning signals for all medical-gas piping systems supplying anesthetizing locations and other vital life-support and critical-care areas, such as post-anesthesia recovery, intensive-care units, and coronary-care units shall indicate the pressure in the piping system if it increases or decreases 20% from the normal operating pressure.

11. *Piping purge test* To remove any traces of particulate matter deposited in the pipelines as a result of construction, a heavy, intermittent purging of the pipeline shall be done. The appropriate adapter shall be obtained from the facility or manufacturer, and high purge rates of least 8 cfm (225 L/min) shall be put on each outlet. After the purge is started, it shall be rapidly interrupted several times until the purge produces no discoloration in a white cloth loosely held over the adapter during the purge. In order to

avoid possible damage to the outlet and its components, this test shall not be conducted using any implement other than the proper adapter.

For each positive-pressure gas system, cleanliness of the piping system shall be verified. Filter a minimum of 35 ft^3 (991.1 L) of gas through a clean, white 0.45-µ filter at a minimum flow of 3.5 scfm (99.12 L/min). Filter shall show no discoloration and shall accrue no more than 0.1 mg of matter. Each zone shall be tested at the outlet most remote from the source. Test shall be performed with the use of oil-free, dry nitrogen described in CGA P-9.

12. *Piping purity test* For each positive-pressure system, the purity of the piping system shall be verified. Test each zone at the most remote outlet for dew point, total hydrocarbons (as methane), and halogenated hydrocarbons, and compare with source gas. The two tests shall in no case exceed variation as specified in the the maximum allowable variation table that follows. Test shall be performed with the use of oil-free nitrogen gas as described in CGA P-9.

Maximum Allowable Variation Table

Dew Point	41°F @ 50 psig (5°C @ 375 kPa)
Total hydrocarbons as methane	±1 ppm
Halogenated hydrocarbons	±2 ppm

13. *Final tie-in test* Prior to connection of any work or any extension or addition to an existing piping system, the tests in items 7 through 12 shall be successfully performed. After connection to the existing system and before use of addition for patient care, the tests in 14 through 16 shall be completed. Permanent records of these tests shall be maintained in accordance with NFPA 99-1996 4-3.5.3.

The final connection between the addition and existing system shall be leak tested with the gas of system designation at the normal operating pressure. This pressure shall be maintained until each joint has been examined for leakage by means of soapy water or another equally effective means of leak detection safe for use with oxygen.

14. *Operational pressure test*

A. Piping systems, with the exception of nitrogen systems, shall maintain pressure at 50 +5/-0 psig (345 +35/-0 kPa gauge) at all station outlets at the maximum flow rate in 14D and 14E.

B. A nitrogen system shall be capable of delivering at least 160 psig (1103 kPa gauge) to all outlets at flow in 14E.

C. Piping systems that vary from the normal pressures in 14A and 14B shall be capable of delivering flows and pressures consistent with their intended use.

D. Oxygen, nitrous oxide, and air outlets shall deliver 3.5 scfm (1.65 L/s) with a pressure drop of no more than 5 psig (34.47 kPa) and static pressure of 50 psig (344.74 kPa).

E. Nitrogen outlets shall deliver 5.0 scfm (2.36 L/s) with a pressure drop of no more than 5 psig (34.47 kPa) and static pressure of 160 psig (1103 kPa).

15. *Medical-gases concentration test*

After purging each system with the gas of system designation, the following shall be performed:

A. Each pressure gas source and outlet shall be analyzed for concentration of gas, by volume.

B. Analysis shall be with instruments designed to measure the specific gas dispensed.

C. Allowable concentrations shall be within the following ranges:

Oxygen	99+% oxygen
Nitrous oxide	99+% nitrous oxide
Nitrogen	<1% oxygen or 99+% nitrogen
Medical air	19.5 to 23.5% oxygen
Other gases	Concentration as specified by their labeling ±1%, unless otherwise specified.

16. *Medical-air purity test (compressor)* Analyze medical air source for concentration of contaminants, by volume. Take samples for air system test at a sample point. The compared tests shall in no case exceed variation as specified under the maximum allowable

variation table below. Allowable concentrations shall be as follows:

Maximum Allowable Variation Table

Dew point	+39°F @ 50 psig (3.9°C @ 375 kPa)
Carbon monoxide	≤10 ppm
Carbon dioxide—air	±500 ppm
Gaseous hydrocarbons—air	≤25 ppm (as methane)
Halogenated hydrocarbons—air	≤2 ppm

Codes and Standards

This section on medical gases was limited to the pressurized gases generally piped throughout a hospital and to vacuum systems, including evacuation vacuum (which is a common method of exhausting the anesthetic gases from an operating room). It also included the diverse methods of providing the gases under pressure, including air compressors (designed and manufactured for supplying medical breathing air), cylinder gases via automatic manifolds, and liquid gas stations.

Care must be taken by the plumbing engineer to investigate and review the most recent local plumbing code and NFPA 99 provisions pertaining to the piping of nonflammable medical-gas systems. The plumbing engineer should note that, in many areas, state and/or local codes exist that may take precedence over the nationally recognized, voluntary standards.

GLOSSARY

ACFM (actual cubic feet per minute) The unit used to express the measure of the volume of gas flowing at operating temperature and pressure, as distinct from the volume of a gas flowing at standard temperature and pressure. (See "SCFM.")

Air, oil-free, dry (air for testing) Air complying, as a minimum, with Grade D in CGA, Inc., Pamphlet G-7.1, *Commodity Specification for Air,* and having a maximum dew point of –20°F (–28.9°C) at line pressure.

Alarm system, Level III An area alarm system for a patient nonflammable medical-gases system, typically oxygen, nitrous oxide, and medical air in dental-care facilities and medical-care facilities.

Alarm system, local A warning system that provides visible and audible signals for the monitoring functions of medical-gas and vacuum system source equipment at the equipment site.

Alarm system, master A warning system that provides visible and audible signals for the monitoring of medical-gas and vacuum sources and systems; it consists of alarm panel(s) and associated actuating device(s).

Ampacity Current-carrying capacity of electric conductors, expressed in amperes.

Anesthetic As used in this chapter, applies to any inhalation agent used to produce relative analgesia or general anesthesia.

Anesthetizing location Any area of a facility that has been designated to be used for the administration of nonflammable, inhalation, anesthetic agents in the course of examination or treatment, including the use of such agents for relative analgesia (see "anesthetic").

Authority having jurisdiction The organization, office, or individual responsible for approving equipment, an installation, or a procedure.

Clinic A health-care facility where patients are seen on an ambulatory basis, but where surgery involving general anesthesia is not performed.

Combustible A substance that, if ignited, will react with oxygen and burn.

Combustion products The gases, volatilized liquids and solids, particulate matter, and ash generated by combustion.

DISS connector A threaded medical-gas connector complying with the CGA Pamphlet V-5. *Diameter Index Safety System—Non-Interchangeable Low Pressure Connections for Medical Gas Applications.*

Flammable gas Any gas that will burn when mixed in any proportion with air, oxygen, or nitrous oxide.

Flash point The minimum temperature at which a liquid gives off vapor in sufficient concentration to form an ignitible mixture with air near the surface of the liquid within the vessel, as specified by appropriate test procedures and apparatus.

Health-care facilities Buildings or portions of buildings in which medical, dental, psychiatric, nursing, obstetrical, or surgical care is provided. Health-care facilities include, but are not limited to, hospitals, nursing homes, limited-care facilities, clinics, medical and dental offices, and ambulatory-care centers, whether permanent or movable.

Hyperbaric Pressures above atmospheric pressure.

Hypobaric Pressures below atmospheric pressure.

Laboratory A building, space, room, or group of rooms intended to serve activities involving procedures for investigation, diagnosis, or treatment in which flammable, combustible, or oxidizing materials are to be used. These laboratories are not intended to include isolated, frozen-section laboratories; areas in which oxygen is administered; blood-donor rooms in which flammable, combustible, or otherwise hazardous materials normally used in laboratory procedures are not present; and clinical-service areas in which hazardous materials are not used.

Limited-care facility A building or part thereof used on a 24-hour basis for the housing of four or more persons who are incapable of self-preservation because of age; physical limitation due to accident or illness; or mental limitations such as mental retardation/developmental disability, mental illness, or chemical dependency.

Medical air For the purposes of this chapter, air that (1) is supplied from cylinders, bulk containers, or medical air compressors or has been reconstituted from oxygen USP and nitrogen NF, and (2) complies with the following:

1. Medical Air USP.
2. Total hydrocarbons
   - Liquid: Nondetectable
   - Gaseous: <25 ppm
3. Pressure dew point at 50 psig: <39°F (4°C)
4. Permanent particulates: 5 mg/m^3 at normal atmospheric pressure of particulate at 1-μ size or greater

Note: Air supplied from an on-site compressor and associated air-treatment systems (as opposed to medical air USP supplied in cylinders) that complies with the above limits is considered medical air.

Hydrocarbon carryover from the compressor into the pipeline distribution system could be detrimental to the safety of the end user and to the integrity of the piping system. The mixing of air and oxygen is a common clinical practice, and the hazards of fire are increased if the air is thus contaminated.

Compliance with these limits is thus considered important to fire and patient safety. The quality of local ambient air should be determined prior to its selection for compressors and air-treatment equipment.

Medical compressed air has many uses in the health-care field. It is used in respiratory therapy applications in conjunction with high-humidity treatments using nebulizers in pediatrics and the nurseries. It is also used to power pneumatic surgical instruments that have a pressure range of 120 to 200 psi (827.4 to 1379 kPa).

Medical air compressor A compressor that is designed to exclude oil from the air stream and compression chamber and that does not under normal operating conditions or by any single fault add any toxic or flammable contaminants to the compressed air.

Miscellaneous gases Occasionally, in a teaching institution or in a hospital specializing in cardiovascular surgery, it is common to find the need for piping other gases, such as carbon dioxide ($C0_2$), helium (He), and mixtures of each of these two gases with oxygen.

Nitrogen (N_2) An element that, at atmospheric temperatures and pressures, exists as a clear, colorless, odorless, and tasteless gas. It is a nontoxic and inert gas that inhibits combustion by displacing the air. The principle use of nitrogen gas in a health-care facility is for powering pneumatic surgical instruments.

Nitrous oxide (N_20) Nitrous oxide is a nonflammable gas commonly used as an analgesic and, in combination with one or more agents, for the production of a balanced anesthesia.

Oxidizing gas A gas that supports combustion. Oxygen and nitrous oxide are examples of oxidizing gases. There are many others, including halogens.

Oxygen (O_2) The most widely used of all the medical gases, oxygen is colorless, odorless, and

tasteless. Of the three basic essentials for the maintenance of life—oxygen, water, and food—the deprivation of oxygen leads most rapidly to death. Tissue cells have no reserve; they must be continually supplied with oxygen by the body's circulation system. Oxygen is a nonflammable gas used for respiratory therapy and in surgery for anesthesia.

Note: Its outstanding properties are its ability to sustain life and to support combustion. Although oxygen is nonflammable, materials that burn in air will burn much more vigorously and create higher temperatures in oxygen or in oxygen-enriched atmospheres.

Oxygen, gaseous A colorless, odorless, and tasteless gas; also, the physical state of the element at atmospheric temperature and pressure.

Oxygen, liquid Exists at cryogenic temperature, approximately –300°F (–184.4°C) at atmospheric pressure. It retains all of the properties of gaseous oxygen, but, in addition, when allowed to warm to room temperature at atmospheric pressure, it will evaporate and expand to fill a volume 860 times its liquid volume.

Note: If spilled, the liquid can cause frostbite on contact with skin.

Oxygen-delivery equipment Any device used to transport and deliver an oxygen-enriched atmosphere to a patient. If an enclosure such as a mask, hood, incubator, canopy, or tent is used to contain the oxygen-enriched atmosphere, then that enclosure is considered to be oxygen-delivery equipment.

Oxygen-enriched atmosphere For the purpose of this chapter, and only for the purpose of this chapter, an atmosphere in which the concentration of oxygen exceeds 23.5% by volume.

Oxygen index The minimum concentration of oxygen, expressed as a percent by volume, in a mixture of oxygen and nitrogen that will just support combustion of a material under conditions of ASTM D2863, *Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics (Oxygen Index).*

Oxygen toxicity (hyperbaric) Physical impairment resulting from breathing gaseous mixtures containing oxygen-enriched atmospheres at elevated partial pressures for extended periods of time. Under the pressures and times of exposure normally encountered in hyperbaric treatments, toxicity is a direct function of concentration and time of exposure.

Patient vacuum (VAC) Patient vacuum is typically used to provide a source for patient drainage, aspiration, and suction in order to remove body fluids (such as saliva or blood) from an affected patient area. The body fluid is normally trapped in a container near the patient. The vacuum source only provides a source of subatmospheric pressure.

Piping The tubing or conduit of the system. There are three general classes of piping, as follows:

Main lines Those parts of the system that connect the source (pumps, receivers, etc.) to the risers or branches, or both.

Risers The vertical pipes connecting the system main line(s) with the branch lines on the various levels of the facility.

Branch (lateral) lines Those sections or portions of the piping system that serve a room or group of rooms on the same story of the facility.

Psia (pounds per square inch absolute) A unit of pressure measurement with zero pressure as the base or reference pressure.

Psig (pounds per square inch gauge) A unit of pressure measurement with atmospheric pressure as the base or reference pressure (under standard conditions, 0 psig is equivalent to 14.7 psia).

SCFM (standard cubic feet per minute) The unit used to express the measure of the volume of a gas flowing at standard conditions—a temperature of 68°F (20°C) and a pressure of 1 atmosphere (29.92 in. Hg).

Station inlet An inlet point in a Type I medical-surgical piped vacuum distribution system at which the user makes connections and disconnections.

Station outlet An outlet point in a piped medical-gas distribution system at which the user makes connections and disconnections.

Vacuum system, Level 1 A system consisting of central-vacuum-producing equipment with pressure and operating controls, shut-off valves, alarm warning systems, guages, and a network of piping extending to and terminating with suitable station inlets at locations where patient suction might be required.

Vacuum system, Level 3 A vacuum system, either a wet or dry piping system, designed to remove liquid, air/gas, and solids from the treated area.

Notes: (1) The system is not intended for Level 1 vacuum applications. (2) A wet piping system is designed to accommodate liquid, air/gas, and solids through the service inlet. (3) A dry piping system is designed to accommodate air/gas only through the service inlet. (Liquids and solids are trapped before entering the service inlet.)

Waste anesthetic gas disposal (WAGD) A surgical vacuum system that is used to evacuate the anesthetic gases from the operating room after the gases have been exhaled by the patient. Also, the process of capturing and carrying away gases vented from the patient breathing circuit during the normal operation of gas anesthetic equipment.

REFERENCES

1. Canadian Standards Association (CSA). *Non-flammable medical gas piping systems*, Z-305.1.
2. Compressed Gas Association, Inc. (CGA). *Characteristics and safe handling of medical gases*, CGA-P-2.
3. ——. *Commodity specification for air*, CGA-G-7.1/ ANSI ZE 86.1.
4. ——. *Commodity specification for nitrogen*, CGA-G-10.1.
5. ——. *Compressed air for human respiration*, CGA-G-7.0.
6. ——. *Diameter-index safety system—Non-interchangeable low pressure connections for medical gas applications*, CGA-V-5.
7. ——. *Inert gases: Argon, nitrogen and helium*, CGA-P-9.
8. ——. *Standard for color-marking of compressed gas cylinders intended for medical use*, CGA-C-9.
9. ——. *Standard for the installation of nitrous oxide systems at consumer sites*, CGA-G-8.1.
10. National Fire Protection Association International (NFPA). *Standard for bulk oxygen systems at consumer sites*, NFPA-50.
11. ——. *Standard for health-care facilities*, NFPA-99.

RESOURCES

1. Canadian Standards Association (CSA), 178 Rexdale Boulevard, Rexdale, Ontario, CANADA, M9W-1R3.
2. Compressed Gas Association, Inc. (CGA), 1725 Jefferson Davis Hwy., Arlington, VA 22202.
3. National Fire Protection Association International (NFPA), 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269.