Daily, in hospitals throughout our country and increasingly throughout the world, hospital patients routinely depend on the assistance of various hospital plumbing systems for their recovery from illnesses and accidents. The range of hospital plumbing has expanded from conventional sanitation and potable water systems to include assistance in medical procedures and total life support.

This evolution is being demanded of the plumbing and the health care industries by forces that apply to both industries: patient and doctor insistence on technically superior products and services, new performance codes and standards, and serious economics.

The centrally piped medical gas system is one of the newer types of hospital plumbing systems to be introduced into the delivery of direct patient care. Gas piping is needed for oxygen, nitrous oxide, medical air, nitrogen, carbon dioxide, vacuum, and anesthesia waste exhaust. Piping gas from a central location directly to outlets at the points of patient use provides a level of safety unheard of in the past. The direct piping method removes obsolete, bulky, and dangerous pressurized cylinders from the patient’s bedside. Also, these piped systems provide easier quality control and pressure regulation because all gases are delivered from centralized pumps, compressors, or cylinder manifold systems. The piping is designed and installed under strict National Fire Protection Agency regulations (NFPA 99).

Medical gas installations have effectively placed hospital plumbing professionals directly into the loop of patient care. To guarantee patient safety, they must become knowledgeable about exactly how each of these systems affects the total care of the patient—just as the hospital’s medical staff must. This is no easy task. For example, consider the heart-lung machine described in the accompanying sidebar. The design, installation, and maintenance of medical gas systems that support this class of equipment clearly represent serious challenges for hospital plumbing professionals.

There are two major purposes of this article. The first is to emphatically urge hastened improvement of national and international safety factors in the engineering, manufacturing, installation, inspection, verification, maintenance, and renovation of medical gas systems. The second major purpose is to provoke discussion by introducing an innovative method of enhancing safety; I call this concept human factors.

Introducing Human Factors

It is remarkable that there have been extremely few reported accidents or deaths resulting from the utilization of medical gas systems during their rapid period of growth. Responsibility for this outstanding record, although even one accident must be considered unacceptable, I credit to the dedicated professionals who periodically introduce more rigorous performance standards, formalize installation and maintenance procedures, continually improve the design and manufacturing techniques of increasingly reliable tangible equipment, and install and inspect these systems.

Our challenge for today and the future, however, should be to reduce this minuscule accident rate to zero while our population, medical gas usage, and future unknown medical gas requirements continue to increase exponentially. Without this zero-accident goal, the long-term trend of expansion is paving the way for an intolerable number of accidents even if this already enviable accident rate remains the same.

With our future unlikely to yield the numerous technological advances that improved the safety of medical gas systems in the past, this task will be enormous. Clearly, we are approaching a point where the next significant improvement in safety will require a disproportionate effort from medical gas professionals. To achieve our zero-accident goal, we must rely on improving the human factors of medical gas systems.

What are human factors, how do they affect the safety and performance of medical gas systems, and where do opportunities for improvement exist? In the context of this article, the term human factors refers to the total influence of human nature on every ingredient related to the existence and safe operation of our medical gas systems.

In a bit of a negative context, human factors refers to the determination of our human nature, especially in our modern technical society, to improve our quality of life tremendously but then to become complacent. For example:
• We have the grand vision to invent an incredible machine like the computer and then integrate it as a manager into a life-critical medical system - but then we are inclined to let the computer “run the show” while we shift our attention to a new challenge.

• Our grand vision becomes tunnel vision when we choose not to interact with other related professional groups to share information that, if our expertise were to combine with theirs, would tremendously improve the lives of everyone.

The chief positive context of human factors, however, is the insatiable desire of human beings to improve our quality of life continually and the creativeness and ability - when properly motivated - to join forces to make it happen!

The downside of our human nature is evident in the problems that we often cause ourselves and others. The positive side of our nature is evident in our ability to prevent or resolve these problems. To illustrate where human factors, negative and positive, are reflected in medical gas systems, I will now describe some problems that I am aware of based on my interactions with hospital plumbing professionals. I will then present a synopsis of recent progress in resolving problems in the medical gas field and conclude with recommendations toward further progress.

Latent Failures

Latent failures are tied to decisions that may not have visible consequences. Although an obvious mechanical or work-practice failure may cause a life-threatening situation, the root cause may be poor system design, operating procedures, maintenance procedures, or communications between those involved in the installation and maintenance of the associated hospital plumbing system. Here are some examples of potential, or real-life, latent failure events.

• Condensation in gas lines. Plumbing engineers who design hospital medical air lines for use in northern climates often route them through building areas that may periodically have very cold temperatures. Because there are no published guidelines for this situation, the engineers fail to realize that this may result in dew point temperatures. Because there are no published guidelines for this situation, the engineers fail to realize that this may result in dew point temperatures.  There may be no visible consequences through years of use of any of these northern climate medical air systems designed this way, but one day one of them may finally cause a life-threatening contamination problem in an intensive care unit.

If a formal national committee existed, one that could accept and act upon a report of any hospital that encountered this problem, a directive could be written and forwarded to hospital plumbing engineering organizations urging their vigilance for this design condition.

• Inadequate budget. The hospital plumbers have found that internal parts of medical air wall outlets were beginning to corrode, and respiratory therapy reported damp and semi-clogged filters in its ventilators. The plumbers and respiratory therapy reported the problems to hospital engineering, who discovered that the dryers were in need of either total renovation or, because of a recent construction expansion, extensive upgrading. Unfortunately, there was no money in the present budget, so temporary measures were taken to help, but not solve, the problem.

Although this particular latent failure was basically an ignored recognized hazard, luckily it did not cause a major accident because the hospital eventually upgraded its medical air dryer system. However, the existence of mandated - and enforced - periodic medical gas system quality control recertification regulations could have prevented this latent failure from even occurring.

• CAD abuse. From discussions with engineers, I have found that excessive use of CAD systems is becoming a controversial subject. I call this “automation dependency.” An example of this occurred in medical vacuum lines of a surgical suite. A CAD system was used to design a vacuum system that looked adequate on paper; however, during the installation, the plumbers had to add changes of direction and elevations. This made the CAD-designed pipe sizes inadequate. The actual installation was never field-verified for engineering accuracy. Five years later, a surgical patient faced a life-threatening situation because his individual operating room’s suction system was clogged with dried accumulations in the piping system. Inspection of other medical vacuum lines of the same surgical floor revealed that other pipes were also slowly becoming clogged with accumulations.

A knowledgeable national committee could create a guideline suggesting appropriate use of CAD software for design by hospital plumbing engineers. It could also furnish a system for engineering firms to confirm that every phase, both technical and procedural, of their CAD automation operations is continually functioning properly. Also, a legally mandated, periodic medical gas system recertification and quality control program could have aided the hospital in discovering this latent failure before the life-threatening event. The surgery vacuum outlets, even though they would pass the minimum static 12 in. Hg test, would have indicated an eventual failure of the minimum 3 scfm test that alerts that the lines are clogged.

• Failure to purify. Another example of poor practice is the unawareness or the wanton failure of the installing plumbers of the need to use a nitrogen purge while silver brazing pipe fitting joints. This lack of purging allows copper-oxide particles to form on the piping walls that could break loose and either be directly breathed by the patient, clog ventilator filters, or actually corrode aluminum

The Heart-lung Machine

The heart-lung machine, used in open heart bypass surgery, relies totally on piped medical gas systems. The effectiveness and reliability of the gas systems depend on the capabilities and procedures of hospital plumbing professionals. The combination of machinery and plumbing professionalism is all that keeps the patient alive during this surgical procedure.

Centrally piped carbon dioxide purges the machine of life-threatening ambient air. When the patient’s heart is stopped and the blood is pumped through the machine, piped oxygen, medical air and sometimes CO₂ are blended and added directly to the patient’s blood. The piped anesthesia waste exhaust system, also connected to the machine, removes wasted carbon dioxide and anesthetic taken from the blood and conveys it safely out of the building. During open heart procedures, centrally piped nitrogen is used to power surgical tools.

The Heart-lung Machine
parts of the ventilators.

The existence of permit and periodic inspection requirements by governmental agencies regarding installation of medical gas systems, such as presently exist for plumbing systems providing sanitation, would guarantee that all the life-critical systems are purged during brazing. Also, the design engineer should have specified that the plumbing contractor's plumbers be certified not only in the brazing of medical gas piping but also that they possess an extensive knowledge of all medical gas system design needs as well. Another check would have been the hospital investigating funds to certify its own plumbers in medical gas installation. These plumbers would have observed that the contractor's plumbers were not using proper installation procedures and stopped their work.

- Poor communications and practice. Hospital plumbing crews routinely perform many multiple medical gas service interruptions for renovation projects. Because there is no formally approved medical gas service interruption procedure in existence, and they are usually in the "hurry-up syndrome," they always simultaneously relieve pressure from all the medical gas lines, perform the tie-ins, and then simultaneously turn the lines back on. This is actually a life-threatening practice. Because there are no visible consequences to this procedure - as of yet - it constitutes a latent failure.

A formal medical gas service interruption procedure needs to be published that discourages the practice of simultaneous interruption. This procedure would assist the plumbing crew in avoiding the incident of simultaneously turning these lines back on into a live system and discovering, to their horror, that in their haste they had actually crossed different types of medical gas pipes.

- Uncertified practitioners. Uncertified hospital plumbers allowed an uncertified contractor to renovate routinely downstream of multiple live zone valves. They were all aware of the need for the nitrogen test on the gas piping, but instead of disconnecting the lines from the live zone valves before renovation and testing, they ignorantly placed 150 psi of nitrogen against all of the live zone valves. The contractor routinely caused this latent failure at other hospitals, fortunately with no visible consequences there either, but on any occasion, an oxygen zone valve could have leaked and nitrogen could have been introduced into a live oxygen piping system from which patients were breathing!

If an approved, published medical gas service interruption procedure existed with a directive prohibiting testing against live zone valves, this latent failure might never occur anywhere. Also, if it was law that medical gas systems must be installed by certified plumbing contractors and the pressure testing of these systems be witnessed by a government-certified inspector of record, this situation would never occur. Finally, if the design engineer, and the hospital itself, specified that any medical gas installation be performed by a medical gas certified plumbing contractor, this serious consequence would be avoided.

- Inadequate preventive maintenance. Hospital plumbing crews routinely ignore manufacturers' preventive maintenance recommendations regarding automatic changeover manifolds (Fig. 1). With the extensive redundancies built into these systems, these manifolds give the perception of being capable of "running themselves" for years, even while detectable anomalies are ignored - with no visible consequences. In one case, the primary line pressure regulator of a surgical nitrous oxide manifold failed, and the system switched over to the redundant regulator. After months of ignoring the repair needs of the primary regulator, the redundant line pressure regulator also failed, and there was a massive nitrous oxide failure during surgery.

Renovation Problems

One major latent failure worthy of extended discussion is the link between our nation's managed care system and hospital renovations. Unlike the old, noncompetitive fee-for-service reimbursement system, the managed care system is a competitive system that pits every hospital against each other to maintain its customer (patient) base. Hospitals must now bid against other hospitals, just like contractors do in the construction industry, for managed care contracts - and their multitude of patients.

This system has created a very competitive health care delivery atmosphere, with many hospitals joining forces against others to deliver unique and better services to retain its present patients and attract new ones.

To provide these enhanced services, many hospitals are undertaking renovation projects. Some of these are added structures but most are smaller, very complex renovation projects in existing buildings. These renovation projects usually require alterations to the medical gas system, which requires temporary service interruptions of each medical gas line. The interruption of medical gases presents the most serious challenge to the hospital plumbers.

To remain alive, many patients in intensive care, in surgery, or on the floors require the use of a continuous source of piped oxygen medical air, or wall suction. During these critical medical gas interruptions, it is the hospital plumbers who have the direct, hands-on responsibility of temporarily supplying these life-supporting medical gases directly to the patients. They must also supervise or actually perform the pipe work and, when the pipe work is complete, guarantee the verification of the integrity of all aspects of the system.

Each service interruption performed, because of its potentially fatal consequences to the patients, must be taken very seriously. To avoid becoming complacent or careless, the plumbers must treat each interruption - no matter how many have previously been completed successfully - like the first one. Each interruption can be unique, and the plumbers must be very creative to plan far in advance every procedure and piece of equipment that will be needed. Sometimes the renovation requires only the relocation of wall outlets in an unoccupied, single room. In this case, only a zone valve may need to be shut off and the outlets relocated and recertified according to code. Other times, an entire riser must be shut down. This will require the isolation of, and the supply of temporary services to, each zone on the riser. To provide temporary oxygen or medical air, one can use a simple two "H" cylinder manifold system that will feed an entire zone. This system allows each zone valve on the riser to be shut off and the entire zone to be back-fed through one or two wall outlets in the zone - usually at an empty bed space. When the zone valve is shut off, this system provides normal service to each wall outlet with no disruption to patient care. Also, this method eliminates the need for nursing or respiratory therapy to spend time attaching each patient to individual oxygen cylinders.

There are times when an entire wing must be shut down. This, depending on the wing's piping and valve configuration, may require that temporary service be supplied to most or all of the building. In
the case of oxygen, it is possible to feed oxygen into the building’s emergency inlet from a truck. This method makes the shutdown simpler, but it requires considerable lead time to be arranged.

When performing renovations that require service interruptions, hospitals are relying on their own ingenuity or word-of-mouth advice from other hospitals. This is because there are no nationally approved medical gas service interruption procedures and because some hospitals neither employ medical gas certified plumbers nor hire certified plumbing contractors.

These numerous renovation projects, some with very accelerated completion dates that encourage a hurry-up attitude when performing medical gas service interruptions, are prime sources of latent failures. These are potential problems that should be addressed immediately. Again, the creation and publishing of a single, nationally approved medical gas service interruption manual would be a priceless safety aid that would help to prevent a serious mishap that could result in patient fatalities.

**Progress**

Progress is already being made in coordinating and guiding the activities of those working on hospital plumbing systems. Activities that treat different segments of medical gas systems are occurring at state and local levels across a wide spectrum of organizations and institutions.

- **Inspection.** Presently, only California and Texas have permit-driven medical gas inspections with their own certified inspectors. As of this writing, however, many other states have acknowledged the necessity of these inspections and are commencing inspection programs with their own certified inspectors of record. For example, on January 1, 1998, the State of Ohio began to regulate medical gas piping systems through the Dept. of Commerce’s Div. of Pressure Piping. This regulatory service is limited to the inspection of brazed joints and the observance of pressure testing. Verifiers must be privately hired to guarantee the integrity of the rest of the system.

- **Accreditation.** The two original and major accreditation agencies in the country that pioneered training and certifying of individuals in medical gas installation, inspection, verification, and maintenance are Piping Industry Progress and Education Trust Fund (PIPE) of Los Angeles, Calif., and American Medical Gas Institute (AMGI) of Metairie, La.

- **Manufacturers** are responsible for the dependability of the tangible components of our medical gas systems. Without their advanced level of expertise in the design and manufacture of high-quality components that will, for many years, perform perfectly to meet mandated requirements, we could never breathe from a medical gas outlet and be absolutely positive that the proper gas at the correct pressure will always be delivered.

- **The Joint Commission on Accreditation of Health Care Organizations (JCAHO),** in its plant, technology, and safety management standards, is becoming very active in requiring system quality control and preventive maintenance programs.

- **The Compressed Gas Association (CGA)** writes specifications and standards for the manufacture of all cylinders. CGA also writes safety standards for the cylinders regarding the gas-specific indexing of their threaded cylinder connections, including automatic changeover cylinder manifold connections. This indexing consists of the designing of a distinct, gas-specific cylinder thread connection for each type of gas. This safeguard guarantees that the correct gas cylinder is always connected to its gas-specific inlet on equipment.

- **Medical Gas Manufacturers** - Set, place into service, monitor, and maintain our bulk source systems. They also precisely manufacturer the gases our piping systems distribute and that the patients inhale or use.

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**Relevant Organizations**

- **The National Fire Protection Agency (NFPA),** through its health facilities code, especially NFPA 99’s “Nonflammable Medical Piped Gas Systems” section, presents the details and methodologies of medical gas system installation. NFPA 99 also describes the exact contents, configurations, redundancies, performance standards, and testing procedures of all mechanical components in an entire medical gas system, including the piping system, compressors, pumps, filters, automatic changeover cylinder manifolds, backup systems, patient gas outlets and alarms.

- **The American Society of Sanitary Engineering (ASSE)** is a professional plumbing organization, established in 1906, whose membership represents every discipline related to the plumbing industry. In the spirit of its slogan, “Prevention Rather than Cure,” it has long been known for its work in disease research, national standard plumbing codes, safety-related plumbing product standards, professional qualification standards, plumbing dictionary, and the establishment of a recognized national testing laboratory for the plumbing and allied products industry.

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Traditional recommendations
 Training.  The United Association has challenged its local
unions to become very progressive in teaching their members
proper installation according to NFPA 99 using PIPE and AMGI
teaching methods.  A local that has taken this challenge very
seriously is Plumbers' Local 55 in Cleveland, Ohio.  At its apprentice
training facility, the members, in conjunction with the Cleveland
Plumbing Contractors' Association, have finished the construction of
The Cleveland Medical Gas Training Center.  All training meets
the requirements of NFPA 99, PIPE, and AMGI.  This very
impressive facility consists of four main components:

- A large classroom with audio visual and computer services.
- A mini-hospital totally piped for medical gas and completely
  furnished with beds and medical equipment that also includes a
  nurses station, patient rooms, an emergency room, and a medical gas
  supply room (Fig. 2).
- Twelve brazing stations for proper hands-on training in medical
gas line brazing.
- Four offices and a conference room.

Professional organizations are also making great strides in
Teaching proper medical gas installation techniques.

• New standards. While NFPA 99, Health Care Facilities, covers
the general field of medical gas and vacuum systems, it does not
specifically address requirements in these areas that would allow an
individual to be certified as a qualified installer, inspector, or verifier.
To cover these areas, the American Society of Sanitary Engineering
has just completed a standards series written in accordance with
procedures developed by the American National Standards Institute
(ANSI).  A SSE/ANSI Series 6000, Professional Qualifications Standard
for Medical Gas Systems Installers, Inspectors and Verifiers was released in
April, 1998.  The standard is currently in revision to include
requirements and recommended procedures for medical gas service
interruptions.  The revision is anticipated to be released in the
beginning part of the year 2000.

The A SSE Series 6000 qualifications standards are based on the
requirements of NFPA 99, 1996 edition, for both Level 1 systems
(hospitals, ambulatory care centers, clinics, and nursing homes), and
Level 2, 3, and 4 systems (typically limited-care nursing homes,
limited-care facilities, dental offices, and laboratories).

Recommendations

Because the problems described earlier reflect only conversations
about both concerns and real events that I've had with
engineers and my peers at other hospitals, they must touch just the
tip of the iceberg of numerous latent failures.  This emphasizes that
in many medical gas system installations and operations, there must
be numerous types of latent failures occurring daily that have yet to
present visible consequences.

However, at any time, combined with the perfect set of circumstances, any of these seemingly non-consequential latent
failures, now being performed repeatedly throughout the country,
could become the root cause of a major accident.

The progress that has been made so far is remarkable, but
intense collaborative efforts of all medical gas professionals on a
formal, multi-disciplinary committee are needed to make long-
lasting, systematic progress toward our zero-accident goal.  The
committee would be chartered to guide development, implementa-
tion, and enforcement of seamless codes, standards, and procedures.
It would implement policy where it can and develop plans to
coordinate with government where it can’t act independently.  The
committee would include individuals from all professional groups
affiliated with medical gas systems, including:

 Manufacturers.
 Plumbing engineers who design each individual system.
 Plumbing contractors and plumbers who install the systems.
 Governmental inspectors of record who witness the installa-
tion and pressure testing and certify the integrity and identification
markings of the rough-in piping system.
 Verifiers who not only confirm and certify that the installed
system, including every tangible component except the piping, is
installed and alarmed correctly but also verify that each individual
wall outlet delivers the correct type, concentration, quality, and
quantity of medical gas.
 Hospital facilities engineering departments who, using indus-
try-accepted maintenance and renovation procedures, must guaran-
tee the integrity of the entire system throughout its life.
 Progressive representatives of the professional medical
community.
 Medical gas manufacturing companies.
 Accreditation agencies, trade unions, and professional
organizations who teach installation and testing principles to the
installing plumbers, piping inspectors, verifiers, and facilities engi-
eering plumbers.

The committee should set a goal of total commitment to
establish the following programs to identify and act upon reported
risks in the human factors of medical gas operations.  These risks
affecting medical gas safety could then be successfully controlled
through proactive programs directed at identifying and eliminating
deficiencies such as those described above.  Programs could include:

• Reporting programs. A formal reporting system should be
implemented that provides a path that any concerned and inquisitive
hospital plumbing professionals can follow, with no retributions
(anonymously, if necessary), to report to the committee the observ-
ance of latent failures of operations.  If properly investigated, these
inconsequential failures would become primary sources to identify
and eliminate weaknesses that could cause eventual consequential
failures.  The committee would have national influence in identify-
ing areas of improvement and recommending solutions to eliminate
these latent-failure practices on a national level.  This elimination
could take forms from simple directives, such as recommending
increased training or allocation for additional training or equipment
and creating nationally standardized installation procedures, main-
tenance procedures, and service interruptions, all the way to actual
lawful regulations.

• Lobbying programs. Formal international lobbying programs
should be commenced to influence states and municipalities on the
importance of establishing legal permit requisition and inspection
programs regarding medical gas systems.

• Publicity programs. Publicity programs encouraging a health
system-wide safety culture regarding improvement and coordi-
nation of human factors related to medical gas system installation
and maintenance are essential in providing the incentive for medical
gas safety improvements into the far future.
