Central oxygen pipeline failure

by

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DECLARATION

By submitting this research assignment electronically, I, **Lelanè Mostert**, declare that the entirety of the work contained herein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights, and that I have not previously submitted it, in its entirety or in part, for obtaining any qualification.

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SUMMARY

Case Report

A case is described of central oxygen pipeline failure that occurred at a large academic hospital and its subsequent implications for managing the situation.

Literature review

The literature review undertaken focused on the current state of affairs with regards to anaesthetic staff's knowledge of and preparedness for the management implications of central oxygen pipeline failure. The events I describe below demonstrate a significant deficiency in the staff's understanding of and training for the crisis, which should be remedied to improve patient safety. Specific measures are suggested in the literature to prevent such incidents and guidelines are available to manage central oxygen pipeline failure. These are reviewed in this study.

Recommendations

This study attempts to bring together the most critical aspects that need to be addressed to safely manage similar future incidents. Prevention should include measures to implement clearly stated disaster management plans and increased awareness with regards to the medical gas pipeline system (MGPS), simulation training, efficient alarm systems, personally conducted routine evaluations of equipment and emergency backup systems by anaesthesiologists and effective communication between hospital staff.

Careful planning and successful coordination during maintenance and modification of the medical gas pipeline system, using piston-type or air-driven, rather than oxygen-driven, ventilators and optimal design of the hospital bulk oxygen system can contribute to reduce risks.

In the event of central oxygen pipeline failure a specific sequence of actions should be taken by the anaesthesiologist and a clear institutional operational policy is described.

OPSOMMING

Gevalsbeskrywing

'n Geval van sentrale suurstoftoevoerversaking, wat plaasgevind het by 'n groot opleidingshospitaal, word bespreek. Daar word ook gekyk na die praktiese gevolge met betrekking tot die hantering van die situasie.

Literatuurstudie

'n Literatuurstudie is aangepak met die doel om te fokus op die huidige toedrag van sake betreffende narkosepersoneel se kennis en paraatheid in die hantering van sentrale suurstoftoevoerversaking. 'n Wesenlike gebrek aan begrip en opleiding aangaande hierdie onderwerp is geïdentifiseer – areas wat, met die nodige aandag, verbeter kan word ten einde die welstand van pasiënte te verseker. Spesifieke voorkomende maatreëls en hanteringsriglyne word voorgestel deur die literatuur en word gevolglik hersien in hierdie studie.

Aanbevelings

Hierdie studie poog om kernaspekte aan te raak ten einde soortgelyke toekomstige voorvalle veilig en optimaal te kan hanteer. Voorkomende maatreëls behels onder meer die daarstelling van duidelik verstaanbare noodplanne, verbeterde bewustheid aangaande die mediese gaspypsisteem, simulasie-opleiding, doeltreffende alarmstelsels, effektiewe kommunikasie tussen hospitaalpersoneel, sowel as narkotiseurs wat self roetine-evaluasies van hul narkosetoebehore en -noodtoerusting uitvoer.

Noukeurige beplanning en neweskikking tydens herstelwerk of werk aan die mediese gaspypsisteem, die gebruik van suierventilators (of dan lugaangedrewe in plaas van suurstofaangedrewe ventilators) en die optimale uitleg van 'n hospitaal se suurstoftoevoer, kan bydra om die risiko's te beperk. In die geval van sentrale suurstoftoevoerversaking

behoort die narkotiseur stapsgewyse aksie te neem. 'n Duidelike institusionele noodbeleid word ook omskryf.

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A very special thank you goes to Dieter Lahner, who provided me with much relevant information and many intricate details with regards to the technical aspects of the events described and for literally saving the day as the technologist on duty at the time they unfolded.

A vote of appreciation also goes to Anthony Pietersen and Christo Odendaal, for explaining the workings of the medical gas pipeline system of Tygerberg Hospital.

I owe a debt of gratitude to my mother, who spent endless hours looking after my baby boy while I was busy with my dissertation.

Last, but not least, I thank my beloved husband for his tireless support, motivation and for believing in me.

This dissertation is dedicated to Ruben Kriek, my son, my sun - the light of my life.

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1. BACKGROUND

i) Motivation for the study

A fully functioning oxygen supply is of the utmost importance in any intensive care unit or operating theatre. This was clearly demonstrated by the central oxygen pipeline failure that led to this study.

The aim is to investigate similar events that have occurred elsewhere by reviewing the practical implications of central oxygen pipeline failure and to suggest a clear approach to managing these occurrences, focusing on Tygerberg Hospital, but with wider application to hospitals in general.

ii) Case report

Mid-morning of 25 August 2012, a sudden, unanticipated and complete central oxygen pipeline failure occurred throughout the Tygerberg Hospital.

It transpired that a maintenance employee was welding in the presence of an unidentified oxygen leak, causing an explosion and the subsequent failure of the main oxygen valve.

This happened while I was on duty in the surgical intensive care unit (ICU), with two patients on full ventilation and four patients breathing spontaneously on 40% oxygen face masks. Given the number of patients in ICU, there was only one backup ventilator available, should any additional need for ventilatory support arise.

The hospital superintendent and the hospital's oxygen suppliers were notified immediately. However, at the time it was neither apparent what the cause or extent of the oxygen pipeline failure was, nor when the oxygen supply would be restored.

The ICU was inundated with requests for help from the various divisions of the hospital and, given the uncertainty around the cause of the failure and the restoration, there was general confusion and concern as some patients' lives were in danger.

To manage the extent and impact of the failure, the following actions were immediately taken:

a. All elective procedures were cancelled and operating theatres were placed on standby, dealing with emergencies only.
b. Mobile oxygen cylinders were deployed, with the clinical technologist ordering more oxygen cylinders [10 x 700L (0,94kg) and 7 x 350L (0,47kg)] from the medical gas stores.

At approximately 16h45, almost seven hours after the initial failure, the newly replaced main oxygen valve was slowly opened to allow pipeline pressure to build. However, the maximum rate of flow that was delivered from the wall sockets was 5L oxygen/minute, with a maximum pressure of 2,7 bar (normally 3,5 – 4,5 bar). The low rate of oxygen flow and low pressure were investigated and it was discovered that the main high pressure oxygen pipeline had ruptured. This rupture was repaired within the next hour and by 18h30 all technical problems relating to the central oxygen supply were resolved. Oxygen pressures and the flow rate were once again normal.

The failure of the central oxygen supply led to the entire hospital being without oxygen for approximately 8 hours. Fortunately there were no deaths or serious consequences for any patient as a result of the central oxygen pipeline failing.

The aim of this thesis, therefore, is to review the organisation of the central oxygen supply at Tygerberg Hospital, to undertake a literature review of similar events, to evaluate

management strategies documented in the literature and to make recommendations to better manage similar situations in future. I also hope that it will lead to a better understanding among anaesthesiologists about the management of central oxygen pipeline failure and to safer clinical practices.

(Kindly refer to Addenda A and B for detailed guidelines for medical bulk oxygen supply systems for healthcare facilities[21-23] and addendum C for detail about Afrox oxygen cylinders[24].)

iii) Current Tygerberg Hospital bulk oxygen system

The Tygerberg Hospital medical gas pipeline system (MGPS) consists of one main bulk liquid oxygen tank (with a capacity of 14 tons) and one backup bulk liquid oxygen tank (with a capacity of six tons). The two tanks are linked with automatic change over valves.

The liquid oxygen is piped from the bulk storage tanks to the vaporisers, where the liquid oxygen is transformed into oxygen gas. The gas then passes through high-pressure regulators, which regulate the system pressure down to 1 200kPa. Up to this point, the central oxygen supply system is maintained by a private company, with the rest of the system being the responsibility of the Tygerberg Hospital Engineering Department.

The oxygen pipeline system then continues into inline regulators, which further reduce the pressure to 450kPa. As a backup, these regulators are interlinked with a standby manifold consisting of 40 oxygen cylinders (10,2kg each).

Once the pressure has been reduced to 450kPa, the oxygen pipeline enters a tunnel where it links with the oxygen pipeline to the remote X-Block (see figure 1 below), from where it enters the hospital basement, splitting to the various hospital blocks as outlined below:

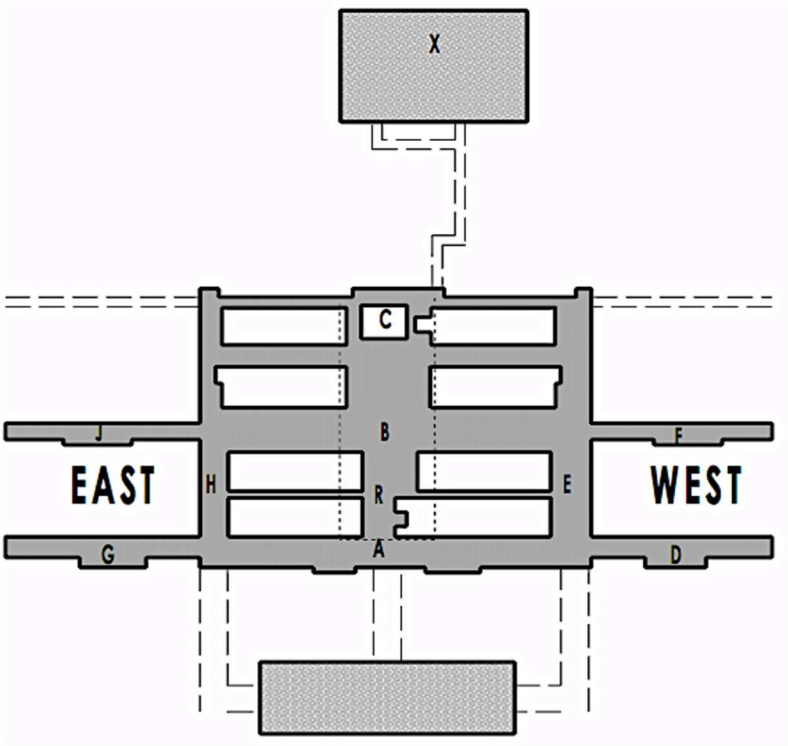


Figure 1: Schematic floor plan of Tygerberg Hospital

The oxygen pipelines run as follows: blocks D and G split into 12 floors, blocks A, C and J into 10 floors, block F into six floors, block B into four floors and block R into two floors.

In each of the blocks the oxygen pipeline system splits into shafts to each floor. The oxygen supply then runs along the passages to the valve boxes. From the valve boxes it flows to the oxygen outlets, where it is delivered to patients.

There is an average of 34 oxygen outlet points per normal ward, with up to 60 oxygen outlet points in selected paediatric wards.

All oxygen is filled by the Medical Gases Department and accompanied by a purity certificate.

The bulk oxygen tanks are fitted with both low pressure and high pressure alarm systems. When one of the alarms is triggered, it registers at both the Exchange Department of Tygerberg Hospital and at Afrox (African Oxygen Limited) in Germiston, Gauteng. As soon as an alarm is activated, the standby officer at Tygerberg Hospital is notified. The standby officer liaises with Afrox to ensure a speedy oxygen delivery.

Low pressure alarms are activated as soon as the bulk tank's content falls below three tons. At this point the standby bulk tank is filled to capacity (six tons). If there is any delay in filling the main bulk tank, the system automatically switches to the standby bulk tank with a second alarm that is triggered as soon as its level also falls below three tons. Should the standby tank also run empty, the emergency oxygen cylinder manifolds still remain as a backup system.

Tygerberg Hospital uses approximately 4,5 tons of oxygen daily. The liquid oxygen tanks are filled every second day.

iv) Ventilator models

At the time of the incident Tygerberg Hospital was making use of the following types of anaesthetic machines and ICU ventilators:

Anaesthetic machine	Ventilator drive type
Dräger Julian®	descending bellows
Dräger Fabius® CE	piston
Dräger Fabius® GS	piston
Dräger Fabius® GS Premium	piston
Dräger Primus®	piston
Dräger Zeus®	turbine

ICU ventilator	Ventilator drive type
Tbird VELA®	pressurised oxygen (2,8 – 6,0 bar)*
Dräger Savina®	generates compressed air with a blower unit, able to ventilate without any connection of medical compressed air. If compressed, oxygen is used, whether from a wall socket or cylinder, a precise concentration is measured and delivered.

(* 1bar = 100kPa)

2. LITERATURE REVIEW

Central oxygen pipeline failure is a relatively rare, but potentially disastrous phenomenon for any hospital. There are several reports dealing with central gas supply failure.[1-8] Although these were due to different causes, the impact on patients and staff remains the same. Anaesthesiology and critical care practitioners are exposed to the risk of such failures, perhaps more than other medical care practitioners and should therefore be adequately informed of and trained in the management of these emergencies.

The literature review for this study focused on:

i) the competency of anaesthesiologists to manage central oxygen pipeline failure,

ii) similar incidents of central oxygen pipeline failure and proposed management strategies,

iii) surveys and data analyses.

i) Competency of anaesthesiologists to manage central oxygen pipeline failure

Weller (2007)[9] published an article where it states that oxygen pipeline failure is a rare, but potentially catastrophic event, which can affect the care of patients throughout the hospital. The article mentions that the use of interventional protocols is often limited by the complexity of patient factors and treatment interventions, but that critical events related to equipment failure might be amenable to standardised responses and written protocols. The authors suggested that anaesthetists played a critical role in maintaining patient safety if and when these hospital equipment-related failures occurred. Anaesthetists should therefore be prepared and properly trained to support an institution-wide emergency response in the event of an oxygen supply failure.

Weller tested the preparedness of 20 anaesthetists by means of a standardised, simulated, scenario of central oxygen supply failure. The randomly selected candidates were asked to pretend that they were in a theatre, about to anaesthetise a young woman from ICU for an

emergency trauma laparotomy. They could not assume that the theatre had been used earlier that day and were given an anaesthetic assistant. The anaesthetic machine had a Ritchie whistle, oxygen-driven ventilator, standard monitors and a circle breathing circuit. The backup oxygen cylinder was empty and a full cylinder was provided as soon as participants realised this and requested it.

The patient was a victim of a motor vehicle accident with head, chest and abdominal injuries and required an inspiratory oxygen concentration of 70%. During surgery, the oxygen pipeline supply failed, triggering the Ritchie whistle. Participants were telephonically informed that the entire hospital's oxygen supply was cut off due to damage to the central bulk storage pipes by construction workers. The simulation continued for another 15 minutes before a second phone call announced that the gas flow had been restored. Participants were then given questionnaires and interviewed. Data were collected by direct observation, video recording and automated monitor printouts, including gas analysis.

Every participant maintained ventilation and used the backup oxygen cylinder when the pipeline failed, but 70% had not discovered pre-operatively that it was empty. All of them requested additional oxygen cylinders, but varied in their methods of oxygen conservation. Many of them used high-flow oxygen through non-rebreathing self-inflating bags, high rotameter flows, or the oxygen-powered ventilator. Prevention of awareness under anaesthesia during the pipeline failure also varied. Nobody disconnected the wall pipeline supply, thus everybody used the reconnected oxygen pipeline supply without testing its gas content (table 1).

Category	Description	*n* (%)
Pre-op machine check	Checks rotameters and circuit	15 (75%)
	Identifies empty oxygen cylinder before case	6 (30%)
	Checks self-inflating bag present	5 (25%)
Immediate response to pipeline failure	Turns on machine cylinder	20 (100%)
	Requests more oxygen cylinders	20 (100%)
Conserves oxygen	Voices need to conserve oxygen	3 (15%)
	Reduces gas flows	7 (35%)
Uses oxygen above essential requirements	Uses ventilator during failure	12 (60%)
	Uses self-inflating bag with high flow oxygen during failure	8 (40%)
Reconnection	Used untested pipeline gas supply	20 (100%)
Anaesthesia during pipeline failure	Volatile or TIVA	12 (60%)
	Relies on sedative infusion alone	6 (30%)
	No anaesthesia or sedation	2 (10%)

Table 1: Anaesthetists' management of oxygen failure in Weller's test

All participants would have saved the patient's life, albeit some displayed major deviations in their management of the scenario. The most important deficiencies were:

- inadequate pre-operative machine check
- failure to prevent awareness under anaesthesia
- inadequate oxygen preservation manoeuvres
- failure to test gas contents and integrity of repaired pipeline supply

The article suggests that the optimal management of oxygen pipeline failure in anaesthesia rests on the following principles:

- maintaining **oxygenation**
- maintaining **ventilation**
- maintaining **anaesthesia**
- ensuring **safety of gas supply**

Ventilation can be sufficiently maintained by turning on the backup oxygen cylinder and using manual ventilation via a circle circuit or using a self-inflating bag and room air. An

ongoing oxygen supply can be maintained by ordering additional oxygen cylinders and using conservational techniques, such as closing the adjustable pressure limiting (APL or "pop-off") valve while using low flows through a circle circuit on the anaesthetic machine.

Anaesthetists should avoid using oxygen driven ventilators. They should maintain volatile anaesthesia by continuing ventilation via the circle circuit, or switch to total intravenous anaesthesia (TIVA). When the gas supply is restored, the gas emerging from the common gas outlet should always be properly tested before it is administered to a patient.

Weller proposes the following guidelines:

1	Turn on back up oxygen cylinder on machine, close circuit APL valve* and reduce gas flows to minimum ($\sim$ 250 ml oxygen.min^{-1}).
2	Hand ventilate through the circle system.
3	Maintain anaesthesia with volatile agent if appropriate.
4	Ensure adequate inspired oxygen and agent concentration.
5	Call for additional oxygen cylinders.
6	Disconnect failed pipeline from the wall and do not re-use until formally tested at wall outlet for composition and quality.
7	If machine cylinder empties, replace it with new cylinder.
8	Call the theatre manager to assess the extent of the failure through the hospital, the reserve supplies of oxygen, and the implications for ongoing supply.
9	Ensure emergency plans are initiated.
10	Prioritise oxygen supply to patients with an oxygen requirement above room air.

*This assumes a circle breathing system and gas analysis.

Table 2: Oxygen pipeline supply failure guideline

Weller's study was limited by the small sample size. Also, a simulated scenario might not represent behaviour under real circumstances. However, what this study highlights, is the

overall lack of preparedness for a critical event that hospitals might suffer from, and the fact that anaesthetists have a responsibility to the wider hospital environment to ensure clear, accessible contingency plans for internal disaster management. Simulation training can help test clinicians' responses to a vast amount of critical equipment failure events, identify common managerial pitfalls and be useful in establishing appropriate future action protocols.

Lorraway (2006)[10] carried out a similar simulation among 20 anaesthetists in training and concluded that anaesthetists were not adequately familiar with the management of central gas supply failure. He suggested that an anaesthesia simulator would be an effective means of correcting this gap in the curriculum.

In Lorraway's study, eight second-year and twelve fourth-year anaesthesia residents were subjected to a 10 minute scenario, simulating loss of pipeline oxygen supply during cross-clamping of the carotid artery on a patient under general anaesthesia for a carotid endarterectomy.

The reserve oxygen cylinder on the anaesthetic machine was also empty and, upon request, subjects were provided with oxygen cylinders without regulators. A regulator was only provided if subsequently requested. A new oxygen cylinder was spontaneously delivered after four minutes if the subject failed to ask for it. Self-inflating resuscitation bags were placed within obvious sight of the participants. The oxygen supply failure was alleged to be a hospital-wide event; therefore, no technical support was available. Two actors played surgeon and circulating nurse, complying with requests from the candidates. All performances were videotaped and analysed.

Although most of the participants realised that the patient was receiving inadequate oxygen, they were unaware of the origin of the alarms indicating an oxygen supply failure. None of them increased airflow on their anaesthetic machine and most did not know how to change

the oxygen cylinder or open the reserve supply. The majority did not attempt to open or change the cylinder – even after being prompted by the surgeon! Most subjects maintained adequate ventilation with the self-inflating resuscitation bag and there were no significant differences between the junior and senior residents in their management of this scenario (table 3 summarises their results).

Key Action	Second Year (%) (n = 8)	Fourth Year (%) (n = 12)	Total (%) (n = 20)
Recognizes the O_2 supply and pressure alarms	37.5	41.7	40.0
Opens O_2 cylinder on machine	50.0	50.0	50.0
Recognizes O_2 cylinder is empty	37.5	50.0	45.0
Calls for a new O_2 cylinder	50.0	66.7	60.0
Changes O_2 cylinder successfully	37.5	41.7	40.0
Ventilates with Ambu® bag	100	91.7	95.0
Anticipates patient awakening	37.5	41.7	40.0

Table 3: Proportion of performed key actions

Lorraway's study suggests that oxygen supply failure is sub-optimally understood and managed by both junior and senior anaesthesiology residents. The residents' actions indicate a lack of the equipment knowledge that is required to manage an oxygen supply failure adequately. The routine checking and maintenance of anaesthetic equipment is increasingly delegated to non-physician staff, which could result in a diminished ability by anaesthetists to manage equipment related crises.

High-fidelity patient simulation is a useful tool to identify gaps in the anaesthesia curriculum. Residents' performance, skills and progress can be assessed and improved continuously without placing patients at risk.

Limitations of this study are also the small sample size, which was unequally divided between junior and senior residents (8:12 instead of 10:10). Also, there is no control group that is routinely exposed to simulation training. It would also be wrong to assume that this group of candidates would be representative of all anaesthetic registrars and that they suffer from a general lack of understanding of theatre equipment or routine anaesthetic machine checks.

ii) Reported similar incidents of oxygen pipeline failure and proposed management strategies

Schumacher (2004)[11] reported an oxygen supply tank failure and the resulting major liquid oxygen spill caused by the accidental separation of a brazed joint between the stainless steel primary tank and a brass pipe fitting (see schematic illustration below). The sudden release of approximately 8 000 gallons of liquid oxygen prevented assessment or usage of the adjacent secondary tank due to massive ice and vapour cloud formations. The hospital was fortunate enough to have its engineers on the scene at the time of the event and all oxygen flow was soon provided from the reserve oxygen supply tank at a remote location (+/- 305m away from the primary and secondary tanks). At the time of the failure, the hospital oxygen consumption was at its peak, with 30 operating theatres in use, nine busy intensive care units and several patients in the post-anaesthetic care units and wards in need of face masks or nasal cannula oxygen. There was never a total loss of pipeline supply pressure and the primary supply was restored within 10 hours.

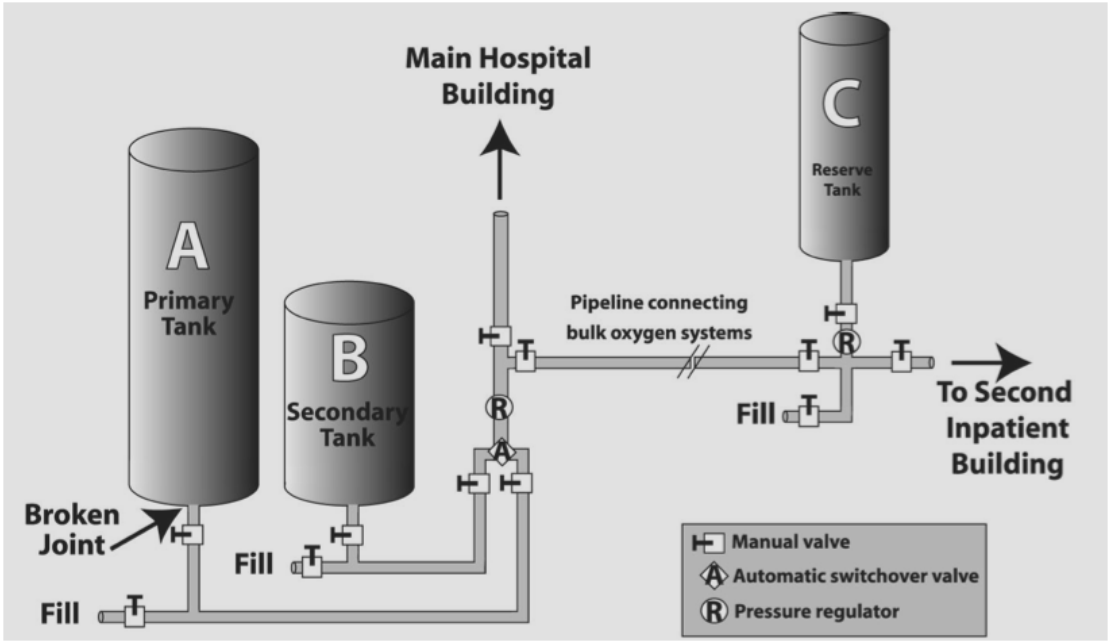


Figure 2: Schematic illustration of the bulk liquid oxygen supply system

In the operating room, the following actions were taken:

- All anaesthetists were informed about a possible bulk oxygen system failure
- Additional emergency oxygen cylinders were delivered to all theatres
- Low flow (<1L/minute) anaesthesia was administered
- Mechanical ventilation was switched to manual bag ventilation
- All elective surgical procedures were postponed

Schumacher makes the following suggestions:

- Use push-drive (piston type) ventilators rather than gas-driven ventilators
- If using gas-driven ventilators, use air-driven instead of oxygen-driven ventilators if possible
- Co-ordinate the maintenance of the MGPS and document it
- Ensure a spatial or physical barrier between the primary and secondary liquid oxygen supply tanks
- Continuously measure the quantity of cryogenic oxygen tank contents – the alarm should not only be activated by low volume, but also by an excessive rate of volume loss
- Depending on the quantity of oxygen used by the medical centre, it should consider having an additional reserve bulk liquid oxygen tank (apart from the primary and secondary supply tanks)
- Ensure adequate oxygen cylinder supplies on-site and put in place a disaster plan that includes obtaining additional supplies if necessary

Schumacher concluded by stressing the importance of a thoroughly prepared hospital-wide disaster plan, with key individuals fulfilling dedicated responsibilities. Anaesthetists play a leading role in understanding their own hospitals' oxygen delivery system and associated disaster plans and must therefore be involved in the planning of new or remodeled medical

gas pipeline systems.

Dangoisse (2010)[12] reported a case where an error in the labeling and identification of medical gas lines resulted in a cross-connection of oxygen and air, causing perioperative hypoxaemia in two cases.

Due to increased demand in their hospital five additional theatres were built in an entirely new surgical wing. A mistake in the labeling of medical gases led the technician to connect oxygen from the old installation to the compressed air valve of the new installation and vice versa.

In the first case, a healthy 23-year-old female patient presented for a laparoscopic tubal ligation and was unknowingly pre-oxygenated with room air (containing 21% oxygen). She gradually desaturated to an oxygen saturation level of 87% and was promptly intubated. Saturation increased to 94% with manual ventilation via the endotracheal tube and immediately an association was made with the engineering work done the night before. Portable oxygen was brought in and the patient transferred to another functional operating theatre without any further complications or incidences.

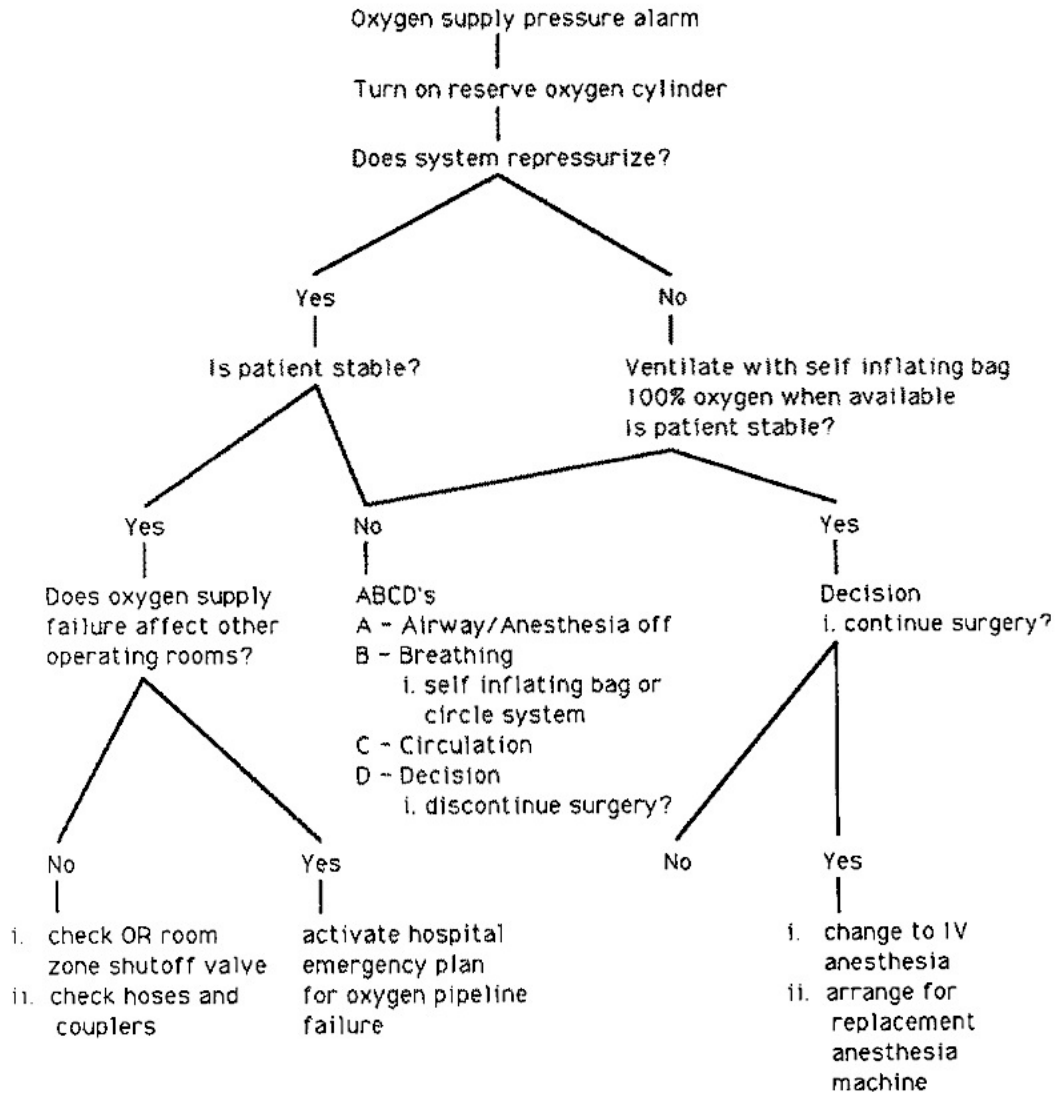
In the second case, a 6-year-old, healthy boy was scheduled for a circumcision. Inhalational induction with 50% oxygen and 50% nitrous oxide was planned, but in effect the child received a nitrous oxide/air mixture which caused him to rapidly desaturate to an oxygen saturation level of 93%. The anaesthetic was stopped immediately.

The authors remarked that no account of the oxygen analysers was taken and that oxygen was delivered in many situations without sensors, including paediatric Mapleson devices, recovery rooms and hospital wards. After any maintenance or modifications on a MGPS, the tubes must be flushed, the pressures checked and gas analysis must be performed and

certified by the company concerned and the hospital pharmacist. According to Dangoisse it remains the anaesthetic department's responsibility to ensure that oxygen concentration checks are performed in every theatre after such maintenance work.

Anderson (1991)[13] reported on a 34-year-old woman, scheduled for a total abdominal hysterectomy, where, 55 minutes into the procedure, a sudden loss of pipeline oxygen pressure and flow occurred. Emergency oxygen was administered via the reserve oxygen tanks and the patient remained unaffected. After phoning the operating room control desk and other theatres, it appeared that the problem was limited to only one theatre in the hospital. Eventually they discovered that the anaesthetic machine was standing on the oxygen supply hose and the oxygen pipeline supply was quickly restored. The reserve oxygen tanks were closed and anaesthesia continued without any complications.

Anderson stressed the importance of the routine evaluation of the medical gas supply systems in theatre, effective alarm systems on the anaesthetic machine, reserve emergency oxygen tanks on each machine (the tanks must be full and properly checked and closed prior to each anaesthetic), and the presence of self-inflating ventilation equipment. They also suggest an algorithm be used when a “low oxygen pressure supply” alarm occurs (see figure 3 below).



(*IV = intravenous; *OR = operating room)

Figure 3: Oxygen supply failure algorithm

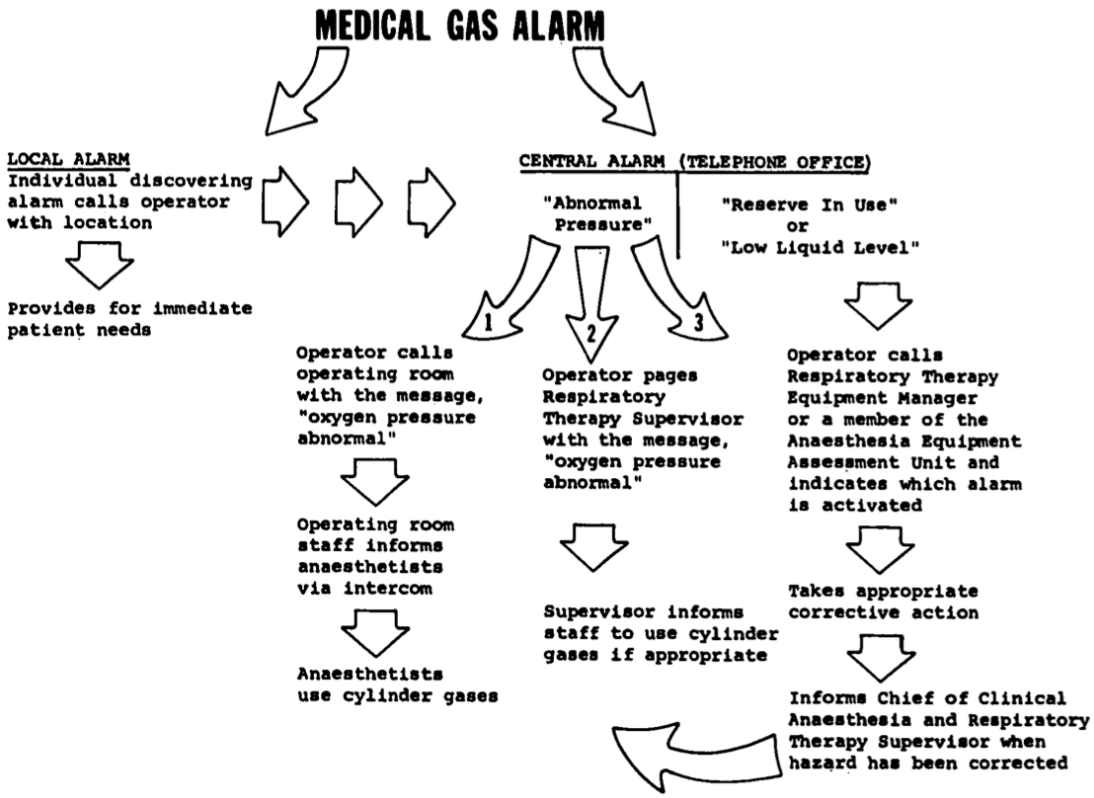
Bancroft (1980)[3] described in an article how their hospital experienced various problems with the bulk oxygen delivery system between 1978 and 1979. He ascribed these problems to a combination of the following: lack of awareness of design and function of the MGPS by hospital staff; malfunctioning alarm systems; and lack of communication between clinical, engineering and commercial supplying parties. They reported the following events:

- Inappropriate unilateral adjustment of main line pressure regulators, reducing line pressure to the hospital
- Inappropriate manipulation of main supply valve, cutting oxygen flow

- Unnoticed activation and depletion of reserve oxygen supply
- Pressure imbalance causing depletion of reserve oxygen supply (x3)
- Failure of vacuum seal causing depletion of reserve oxygen supply (x2)
- Ruptured piping between main and reserve supply causing oxygen leakage
- Defective valve on reserve tank causing oxygen leakage
- Leaking seal in main line pressure regulator
- False alarms due to calibration drift in line pressure sensors (x5)
- Foreign material (welding flux) occluding line pressure sensors
- Monitoring staff failing to notify appropriate parties during emergency

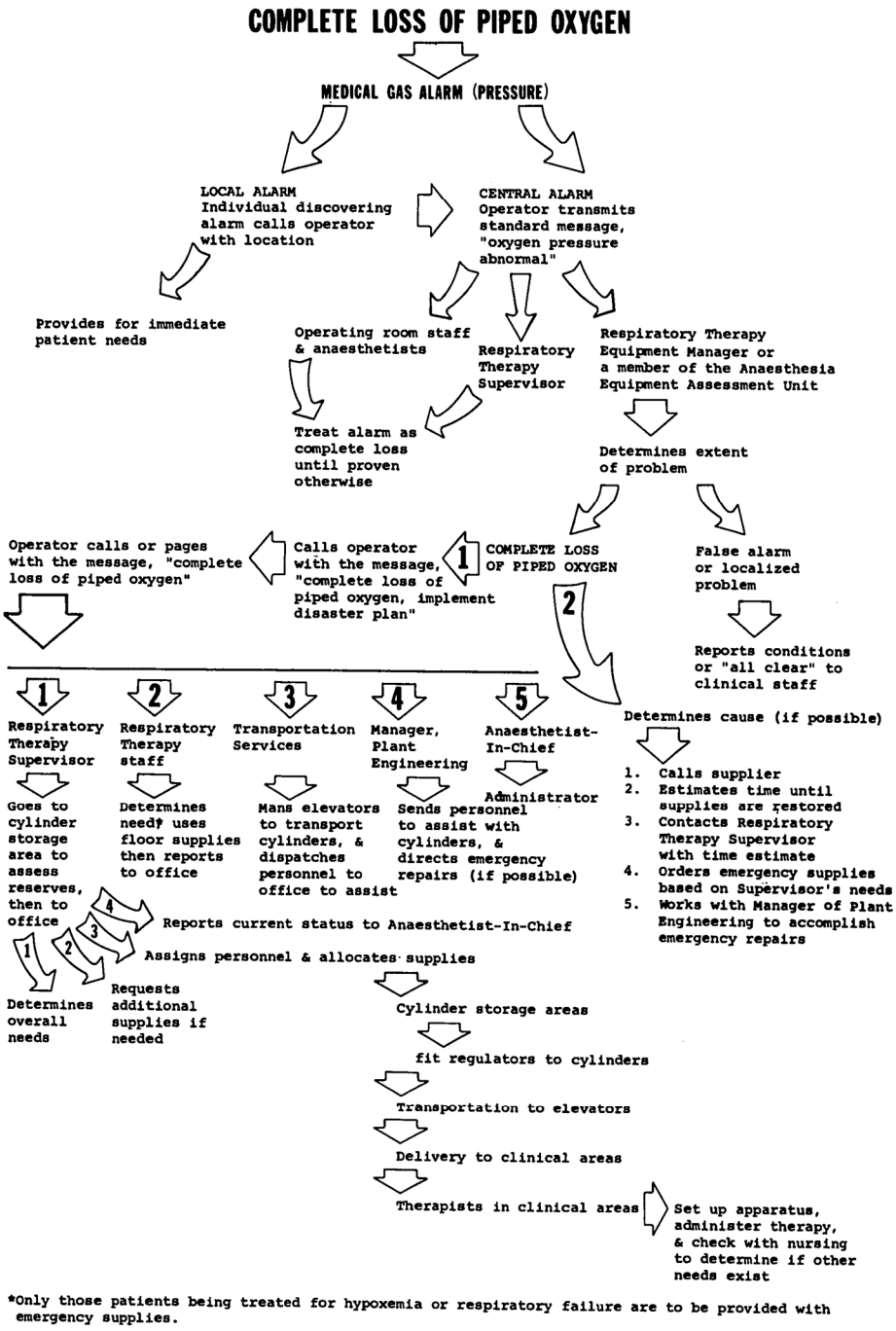
This article highlights the fact that, because liquid oxygen delivery systems are owned and maintained by commercial suppliers, hospital staff are generally unfamiliar with them and, in the event of an equipment failure crisis, may not make the necessary emergency adjustments safely. Therefore all hospital staff should be properly trained in the operation and maintenance of such equipment. Repeated false alarms also cause complacency among staff.

Their Department of Anaesthesia accepted a major role in implementing a thorough disaster management plan with regards to the medical gas pipeline system, performing regularly rehearsed mock disaster drills. Bancroft proposes the following protocols (see figures 4 and 5 below):



*Numbers indicate the order in which clinical staff are contacted.

Figure 4: Protocol for the response to any medical gas alarm



*Numbers indicate the order in which clinical staff are contacted.

Figure 5: Protocol for the response to complete loss of piped oxygen

Nolan (2012)[20] published a textbook called "Anaesthesia for emergency care" where they made the following suggestions regarding the MGPS:

Risk factors

- No machine check performed; failure to reconnect pipeline after machine check; unfamiliar pipeline connections
- Anaesthetic workstation not plugged in, or unintentionally switched off
- Recent machine or pipeline maintenance, repair or replacement
- Fault during refilling of central oxygen source
- Exhausted hospital central oxygen source

Presentation

- Alarms for oxygen failure and pressure gauge falls
- Oxygen and linked flow meters fall; emergency oxygen flush fails
- Pipeline oxygen-driven ventilators stop
- Audible escape of gas if pipeline connection is leaking

Management

- Turn on the reserve oxygen cylinder and check that the pressure gauge indicates an adequately filled cylinder; check that oxygen analyser confirms return of oxygen flow.
- Verify pressure failure on the pipeline pressure gauge.
- Check for disconnect between the oxygen pipeline and the wall, and re-attach if possible.
- Preserve cylinder oxygen: use low flows; in circle system – close the APL valve; switch to manual ventilation if oxygen-driven ventilator.
- Inform the surgeon of the event and make a plan to expedite surgery.

Once the patient is established on cylinder oxygen:

- Disconnect the pipeline supply if failure has occurred upstream from wall outlet. Re-establishment of pipeline may result in a temporary flow of gas that is contaminated, or the wrong gas may be reconnected at source.
- Inform other hospital areas where pipeline oxygen is used.
- Find out when the oxygen supply is likely to be reliably restored and arrange for an appropriate number of oxygen cylinders to safely complete the surgery.
- If the oxygen cylinder supply runs out, as a last resort, allow the patient to breathe room air or ventilate using a self-inflating reservoir bag while maintaining anaesthesia intravenously.

iii) Surveys and data analyses

Stoller (2000)[14] conducted a survey of 32 hospitals in two large cities to ascertain the status of their central oxygen supply systems by phoning hospital engineering staff to find out the following: whether any adverse conditions had ever arisen that interrupted the hospital oxygen central supply system or caused it to malfunction, whether a backup system or plan was available, and, if so, what backup measures existed. Their results suggested that mishaps regarding the central oxygen supply line have been surprisingly common.

Sixteen percent (5/32) of respondents in Stoller's survey reported that they have had at least one mishap with regards to the central oxygen supply system:

- In all five instances there was damage to the supply line from the primary reservoir or to the main line delivering gas to the hospital.
- In four cases, the main underground supply line was inadvertently cut during nearby construction and/or street repair.
- In one case, debris falling from the roof of an adjacent structure during a windstorm damaged the supply line from the primary liquid reservoir.

- In no instance of central oxygen supply interruption was an adverse patient outcome reported.

One hospital reported an inadvertent, unsuspected crossing of oxygen and nitrous oxide lines to anesthesia machines in the operating room before oxygen analysers had been routinely available, which reportedly contributed to the deaths of two patients.

Feeley (1976)[15] surveyed 200 hospital directors of anaesthesiology to ascertain the frequency of malfunction of hospital oxygen and nitrous oxide systems. Based on the 88% of responses, 31% reported 76 incidents, which caused 3 deaths. One was caused by crossed gas lines during construction work, the other two were due to the contamination of the oxygen supply with nitrogen gas. Low oxygen pipeline pressure accounted for 51% of the 76 incidents, while high pipeline pressures were reported in 9%. Low-pressure alarms failed in four instances (5%) and low oxygen flow occurred twice (3%). Contamination of the oxygen supply occurred in two instances (3%), once when the supply vessel was filled with nitrogen (causing two deaths) and once when water contaminated the line. There was one incident of an oxygen pipeline leak.

Reported causes for low oxygen pressure included: pipeline damage during construction, pipeline blockage, oxygen depletion, freezing of regulators, unannounced system shutdowns, lightning damage, regulator malfunction and the incorrect installation of wall connectors. (Additional reports of mishaps with central oxygen supply systems are summarised in table 4.)

Stoller's study was limited by several factors: the response rate to the survey was incomplete and sampling bias remains a concern. The authors fear that participants might have been reluctant to volunteer information despite assurances of confidentiality and nondisclosure of institutional identity.

Although the sample size of Stoller's survey was small (32 hospitals participated), a lot can be learned from the fact that mishaps with central oxygen pipeline systems and inadvertent interruptions of the bulk oxygen supply occur relatively frequently. They felt the need for improved labeling and improved protection of main oxygen supply lines and made the following suggestions to lessen the risk of mishaps involving the hospital's central oxygen supply:

- Hospitals should conduct a systematic audit of their central gas supply systems to establish the rate of daily oxygen consumption, the presence and adequacy of a backup system and the existence of a specific contingency plan in the event of an interruption.
- Prominent labeling and shielding of the oxygen feed lines that connect the main supply vessel to the hospital, so as to avert accidental interruption.
- Availability of a backup supply vessel, ideally located remotely, and with separate feed lines to the hospital.
- Ample valves along the oxygen supply line of the hospital, so that leaks can be isolated without interrupting the central supply to the entire institution.

Author	Year	Hospital	Mishap
The Toronto Star[3]	1974	NA	Crossed oxygen and nitrous oxide lines in an emergency room caused at least 9 deaths.
The Times of London[4]	1975	NA	Crossed oxygen and nitrous oxide pipes caused inhalation of hypoxic gas and brain damage in a 26-year-old.
Eichhorn et al[5]	1977	Beth Israel Hospital wing, Boston, Massachusetts	Contamination of new oxygen piping system by a hydrocarbon gas and dust containing silicon, aluminum, and titanium; filling the main hospital oxygen supply vessel to replace gas used in purging caused a high-pressure relief valve to freeze, allowing high pressure to develop (90 psi).
Smith FP[6]	1987	NA	Contamination of central oxygen supply by argon, causing the death of two patients who inspired the contaminated oxygen.
The Orange County Register[7]	1988	University of California, Irvine Medical Center	Liquid oxygen leaked from the storage vessel when the valve froze in the open position during delivery.
Gilmour et al[8]	1990	University of Minnesota Hospital	Carbon tetrachloride (used to clean the truck delivery tank) contaminated the hospital oxygen supply, causing disruption of the hospital oxygen systems for 15 hours.
Shaw et al[9]	1991	Walton Hospital, England	Air entered oxygen pipeline into operating room, lowering fraction of inspired oxygen.
Lawler and Newman[10]	1992	South Cleveland Hospital, England	Air entered oxygen pipeline, lowering fraction of inspired oxygen.
The Sacramento Bee[11]	1993	Oroville Hospital, Sacramento, California	Oxygen from liquid oxygen vessel leaked when a pipe broke, caused by delivery truck's driving away without releasing the delivery hose.
Los Angeles Times[12]	1994	Three hospitals (Olive View, Holy Cross Medical Center, Sepulveda VA Hospital)	Earthquake disrupted oxygen pipes.

NA = not available.

Table 4: Summary of selected reported mishaps with central oxygen supply systems in certain hospitals

Kacmarec (2000)[16] wrote an editorial on Stoller's article and made the following additional recommendations for central oxygen delivery systems:

- The primary and reserve systems should be physically separate from each other and enter the institution through independent pipelines.
- All hospitals should incorporate an external connection to the central oxygen piping system, to which an oxygen tanker truck could attach to provide emergency oxygen for the entire institution.
- The reserve system, whether gas or liquid, should be of sufficient size to supply oxygen long enough to allow an oxygen tanker truck to arrive at the hospital.
- Those institutions where the primary and reserve systems are located at the same site should install a gaseous reserve at a separate location, with sufficient volume to provide oxygen to all locations until an oxygen tanker truck can arrive.

Caplan (1997)[17] conducted an in-depth analysis by collecting data from the database of the American Society of Anesthesiologists Closed Claims Project, which recorded closed malpractice claims in the United States of America (USA) that had been collected in a standardised manner. There were 3 791 claims for occurrences between 1962 and 1991. All 72 (2%) claims resulting from the use of gas delivery equipment (GDE) were reviewed for patterns of recurrent injury. GDE accounted for 34 of 1 542 (2,2%) claims before 1985, but only 18 of 1 495 (1,2%) claims since 1985. The most common adverse outcomes were death and brain damage (55/72, or 76%).

There were six basic equipment categories: anaesthetic machine, breathing circuit, supplemental oxygen delivery tubing, gas supply tank or line, vaporiser, or mechanical ventilator. The "supply tank or line" category (in which we are interested) comprised storage units, gas cylinders and the medical gas pipeline system, and was involved in only 0,1% (8/72) of claims, mostly occurring between 1975 and 1983. These incidents caused 6/34

(0,17%) deaths and 2/21 (0,09%) brain damage. Adverse outcomes from GDE are relatively rare, but may have catastrophic results.

The study has a number of stated limitations, including a small number of claims, a long period of data collection and missing information of potential interest (such as equipment details with regards to age, model, design etc.). Despite these limitations the message was clear:

- Claims involving equipment misuse (human fault or error) were three times more common than pure equipment failure (and 70% of these were deemed the direct result of actions of the primary anaesthetic provider).
- Improved monitoring could have prevented injury in 78% of claims. (86% of claims resulted from anaesthesia gas delivery systems.)[18]

Deleris (2006)[19] published an article titled “Engineering risk analysis of a hospital oxygen supply system” wherein they present a model of patient risk related to the process of supplying oxygen at a single university hospital. The article illustrates how hospitals can use probabilistic risk analysis (PRA) to ascertain and diminish risks. PRA is a quantitative approach to risk assessment to support medical decision-making based on cost-effectiveness. It involves the following steps:

- Definition of the system being studied
- Identification of event combinations that lead to failures (i.e. "what can go wrong?")
- Likelihood estimation of things that can go wrong
- Severity estimation of each scenario

In Deleris’s study they assessed the threat to patient safety from the oxygen supply system by estimating the number of incidents and fatalities over a given period. They also investigated the efficacy of some risk mitigation actions in terms of the number of lives the

risk mitigations were expected to save. They structured their risk assessment using an overarching model (see figure 6 below).

The goal of this model was to answer: what can go wrong? What conjunction of events leads to failure?

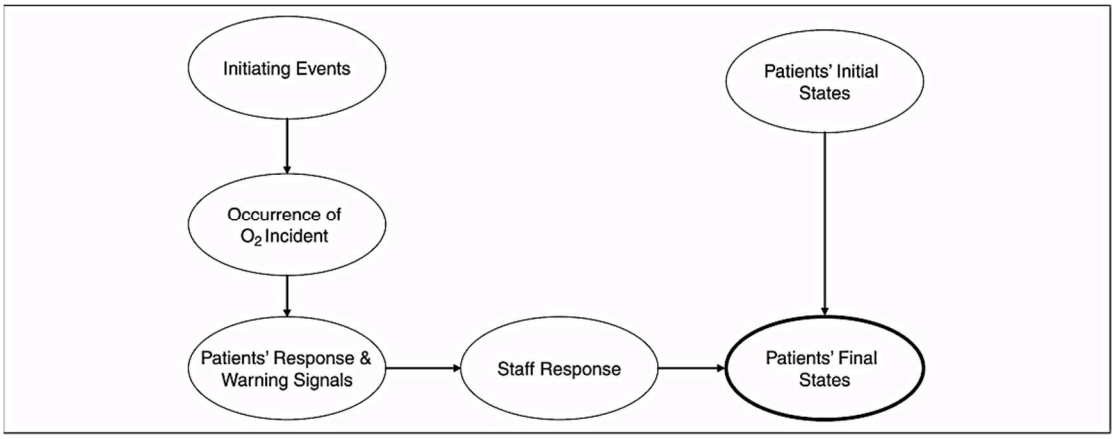


Figure 6: Diagram representing the development of an incident related to a deficiency in the oxygen supply

The "Initiating Events" node in figure 6 (above) represents events that may lead to an incident, either externally such as natural disasters, or internally such as fires or electrical outages, construction accidents, or human error.

Deleris's analysis focused on the oxygen piping system (starting from the external tank to the delivery points to patients). They identified four classes of incidents (see table 5, below) based on the location of the incident (i.e. pre- or post-outlet) and the nature of the incident (i.e. loss of continuity or contamination).

Preoutlet Contamination	Preoutlet Loss of Continuity
Absence of clear labeling on tank	Failure of the supplier alert for replenishment
Faulty cleaning of hoses used to transfer oxygen from supplier truck to tank	Access to tank blocked
Diameter safety system overridden	Tanks damaged
Faulty filling of supplier delivery truck	Pipes damaged
	Malfunction of vaporizer system
	Valves shut
Postoutlet Contamination	**Postoutlet Loss of Continuity**
Use of adjunctive gases	Failure of the ventilator
Error in the hookup on cylinder (relevant only for cases when adjunctive gases are used)	
State of the outlet safety pin (broken, removed, or operational)	

Table 5: Initiating events by classes of incidents

An initiating event does not automatically imply the occurrence of an oxygen incident, but increases its likelihood. The development of incidents is also influenced by patients' reactions and the monitoring systems' responses. Shortages might be noticed sooner than contamination.

Staff response was modeled as the total amount of time taken to put patients on backup oxygen, with four minutes (chosen arbitrarily) as the threshold parameter. The efficiency of the medical staff and the availability of backup oxygen cylinders and regulators determined the response time.

Patients were divided into two categories, requiring an inspiratory oxygen concentration either above or below 40%. The "patients' final states" variable provides the distribution of fatalities, which was the principal measure for risk in the study.

For the hospital used in Deleris's study (20 000 admissions per year), the total expected number of fatalities due to oxygen system failure was 44 over a 30-year period, with the greatest risk contribution (94%) from supply network problems. Post-outlet incidents were more frequent than pre-outlet ones, but resulted in fewer fatalities. Pre-outlet incidents carried the greatest risk (60% of total expected fatalities), followed by the contamination of the piping network (30% of total expected fatalities).

Study limitations included the following: the study model was tailored to a specific institution and cannot necessarily be extrapolated to other facilities. Some of the probability assessments are arbitrary. Some situations relied on expert opinion instead of data. The hospital admittedly assumed that the oxygen cylinder system was a failure-free backup system.

In conclusion, Deleris found that low frequency, high severity incidents affecting a hospital's oxygen pipeline systems carry significant patient risks and that it was worthwhile for every hospital to fulfill nationally standardised requirements to ensure the highest level of patient safety. Their modeling approach can be used as a framework for assessment and to evaluate benefits of risk mitigation measures, whether structural or organisational.

3. RECOMMENDATIONS

Anaesthetic and critical care staff play a governing role in the comprehension of a hospital's oxygen delivery system and associated contingency plans for internal disaster management. They should therefore be thoroughly prepared and properly trained to support an institution-wide emergency response in the event of central oxygen pipeline failure.

Although routine checking and maintenance of anaesthetic equipment is increasingly delegated to non-physician staff such as theatre technologists, the responsibility still remains with the anaesthetist to personally complete a routine equipment check and to be vigilant, able and prepared to adequately manage equipment related crises as they arise.

High-fidelity patient simulation training can help to identify gaps in the anaesthesia curriculum and test clinicians' responses to a vast amount of critical equipment failure events. It can assist in identifying common managerial pitfalls and be useful in establishing appropriate future action protocols. Residents' performance, skills and progress can be assessed and improved continuously without placing patients at risk.

i) Prevention

- Simulation training of registrars
- Routine checks of anaesthetic work stations and equipment by anaesthetists and, specifically, an awareness of the ventilator drive type that is used
- An oxygen analyser remains essential for every anaesthetic machine
- The oxygen supply pressure failure alarm systems should be checked every morning before starting with any theatre case
- Full reserve emergency oxygen tanks on each machine (properly checked and closed prior to each anaesthetic)

- Self-inflating ventilation equipment (e.g. Ambu® bag) within easy reach
- Routine evaluation of medical gas supply systems in theatre
- Continuous quantitative measurement of cryogenic oxygen tank contents – the alarm should not only be activated by low volume, but also by an excessive rate of volume loss
- Awareness of the design and function of the medical gas pipeline system by hospital staff
- Effective communication between clinical, engineering and commercial supplying parties
- Thorough disaster management plan with regards to the medical gas pipeline system, which includes regular, rehearsed mock disaster drills

ii) Planning

- The maintenance of medical gas pipeline systems should be co-ordinated between all parties involved and documented
- After maintenance of or modifications to a medical gas pipeline system, the gas company and the hospital engineering team must flush the tubes, check the pressures, and analyse and certify the gas
- Hospitals should conduct an audit of their central gas supply systems regarding the rate of daily oxygen consumption, and the existence and adequacy of a backup system and contingency plan in the event of an interruption
- Use push-drive (piston type) ventilators rather than gas-driven ventilators
- If using gas-driven ventilators, use air-driven instead of oxygen-driven ventilators

iii) Hospital design

- Ensure a spatial or physical barrier between the primary and secondary liquid oxygen supply tanks, with independent pipelines

- Large medical centres with high oxygen consumption might consider having an additional reserve bulk liquid oxygen tank (apart from the primary and secondary supply tanks) with independent pipelines
- Ensure adequate oxygen cylinder supplies on site and a contingency plan to obtain additional supplies if necessary
- Ensure prominent labelling and shielding of the oxygen feed lines that connect the main supply vessel to the hospital (so as to avert accidental interruption)
- Ensure there are ample valves along the oxygen supply line in the hospital, so that leaks can be isolated without interrupting the central supply
- Incorporate an external connection to the central oxygen piping system, to which an oxygen tanker truck could attach to provide emergency oxygen for the entire institution
- The reserve system must be of sufficient size to supply oxygen long enough for an oxygen tanker truck to arrive at the hospital

iv) Immediate action by anaesthetist in theatre

- **Confirm O_2 supply failure**
  - ✓ O_2 failure alarm sounds
  - ✓ O_2 pressure gauge falls
  - ✓ O_2 and linked flow meters fall
  - ✓ Emergency O_2 flush fails
  - ✓ O_2-driven ventilators stop
  - ✓ Audible leak in case of pipeline disconnection
- **Turn on reserve O_2 cylinder on machine**
  - ✓ Check pressure gauge - is adequately filled?
  - ✓ Check O_2 analyser and confirm return of O_2 flow
- **Close APL valve**

- **Reduce fresh gas flows to a minimum** (≈ 250 ml O_2/min)
- **Manually ventilate via circle system if ventilator is oxygen-driven**
- **Maintain anaesthesia**
  - ✓ Volatile agents (where appropriate)
  - ✓ TIVA (total intravenous anaesthesia)
- **Ensure adequate inspired O_2 concentration (FiO_2)**
- **Call for additional O_2 cylinders**
- **Disconnect failed pipeline from wall and do not re-use until gas composition and quality at wall outlet have been formally tested**
- **Inform surgeon and expedite or postpone surgery**
- **Allocate a competent person, other than anaesthetist, to manually ventilate patient if needed** (e.g. oxygen-driven ventilator on anaesthetic machine)
- **Inform other relevant hospital areas and theatre management**
- **Establish when O_2 supply is likely to be restored**
- **If O_2 cylinder supply runs out, manually ventilate patient with a self-inflating (Ambu®) bag on room air (21% O_2)**

v) Institutional operational policy in the event of central oxygen pipeline failure

- The person discovering the failure must inform the switchboard and matron on duty immediately.
- The switchboard must inform the hospital superintendent on duty, the main porter and the Authorised Person (see Glossary of terms for definition) of the problem.
- Details of the failure should be confirmed, that is: the floor level, department, room numbers, all gases involved and whether patient ventilators are in use.
- Switchboard must also notify all critical care areas.
- It is the responsibility of the matron on duty to determine which patients may have

been put at risk by the failure and to arrange immediate emergency medical action where needed.

- Depending on the reason for the failure and its possible duration, the Authorised Person must decide the most appropriate method of long-term emergency oxygen provision. This may involve establishing locally regulated cylinder supplies at ward/department entrances.
- Nursing and medical staff should attempt to reduce oxygen consumption to a minimum during the emergency.
- Portering staff must monitor/replenish cylinders at emergency stations and at plant room emergency supply manifolds.
- The hospital pharmacy must arrange emergency cylinder deliveries as necessary.
- The Authorised Person must liaise with the Competent Person (see Glossary) to complete emergency repairs to reinstate the oxygen supply, using the permit-to-work system (see Glossary).
- When the oxygen supply is fully restored, the Authorised Person must complete a critical incident form and report extensively to the hospital chief executive officer (CEO) within 24 hours of the incident.

In situations where it is envisaged that there will be a long-term loss of oxygen, the hospital superintendent on duty must liaise with clinical colleagues, including the matron on duty, the head of Anaesthesiology and Critical Care, the hospital CEO and the Authorised Person on the need to transfer critically ill patients to suitable facilities, as department closure may be warranted in extreme events.

4. CONCLUSION

In order to ensure patient safety during a central oxygen pipeline failure, a systematic approach to prevent and manage such an event is required. Hospital planning and disaster management strategies are essential. In addition, anaesthesiologists should be aware of and be adequately trained in the practicalities of managing such an event to ensure that patient safety is not compromised.

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6. GLOSSARY OF TERMS[22-23]

Area valve service unit (AVSU): A valve assembly within an enclosure provided for maintenance, for connecting a temporary supply, for shutting off the gas flow to a specific area in an emergency, or for the purging and testing of gas supplies after engineering work. Sometimes called a zone service unit.

Authorised Person: In relation to the MGPS, a person who has sufficient technical knowledge, training and experience in order to understand fully the dangers involved, and who is appointed in writing by the Executive Manager on the recommendation of an Authorising Engineer for the MGPS. The certificate of appointment should state the class of work that the person is authorised to initiate and the extent of his/her authority to issue and cancel **permits-to-work**.

Competent Person: In relation to the MGPS, a person having sufficient technical knowledge, training and experience to carry out his/her duties in a competent manner and understand fully the dangers involved, and whose name is on the register of Competent Persons (MGPS).

Line valve assembly (LVA): A pipeline-isolating valve fitted to facilitate maintenance of an MGPS. This Health Technical Memorandum recommends that all LVAs should be locked in their normal operating positions, unless it is located in a locked plant room.

Medical gas pipeline system (MGPS): The fixed medical gases pipework, the associated supply plant or pumping equipment, and the warning and alarm systems. This definition includes medical compressed air, medical vacuum installations and anaesthetic gas scavenging systems (AGSS).

Non-interchangeable screw thread (NIST) connector: A gas-specific connector used as a termination for flexible hoses and copper pipe in a ceiling plate etc. Despite the name, it is the dimensions of the male part of the connector that make it gas-specific, not the outer screw-threaded fastening ring.

Permit-to-work: A form of declaration, or certificate, in five parts, used to control work on a medical gas system. Its objective is to prevent inadvertent isolation of, or unauthorised work on, the gas system. It states the degree of hazard involved and defines all services to be worked on and the points where isolation of the affected sections are to be carried out.

Vacuum-insulated evaporator (VIE): A source of supply containing liquefied gas stored under cryogenic conditions.

7. ADDENDUM A

Guideline to Medical Bulk Oxygen Supply System for Healthcare Facilities (AIGA 049/08)[21]

Definitions

Manifold: device for connecting the outlet(s) of one or more cylinders or cylinder bundles of the same medical gas

Portable liquid cylinder: vacuum insulated cryogenic container used for the storage of liquefied gases having a maximum allowable working pressure of greater than 0,5 bar and a capacity normally not exceeding 500 litres

Primary source of supply: that portion of the supply system which supplies the pipeline distribution system

Reserve source of supply: that portion of the supply system which supplies the complete, a portion or portions of the pipeline distribution system in the event of failure or exhaustion of both the primary and secondary sources of supply

Secondary source of supply: that portion of the supply system which supplies the pipeline distribution system in the event of exhaustion or failure of the primary supply

Shall: The use of the word implies a very strong concern or instruction.

Should: The use of the word indicates a recommendation.

Sources of supply

The medical bulk supply system shall comprise of:

- Primary supply
- Secondary supply
- Reserve supply

Each supply system may be a combination of the following:

- gas in cylinders or cylinder bundles
- cylinders connected to a manifold
- portable liquid cylinder
- cryogenic liquid in stationary vessel

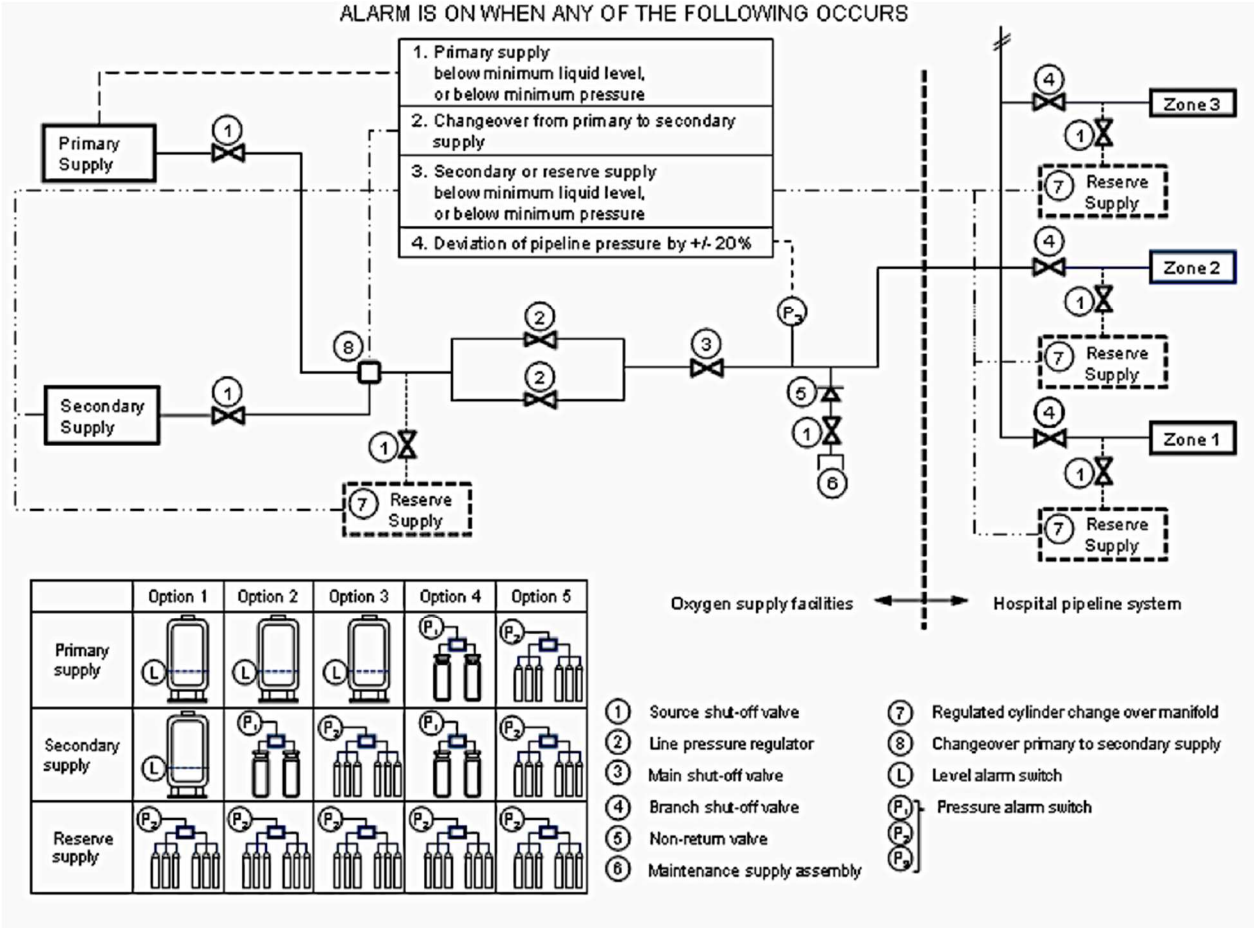

Figure 7: Schematic example of an oxygen supply system

Primary supply

The primary source of supply shall be permanently connected and shall be the main source of supply to the medical oxygen supply system. As a minimum, the primary supply should have usable quantity of product to meet expected usage between scheduled product deliveries.

Secondary supply

The secondary source of supply shall be permanently connected, automatically supply the pipeline, and be capable of providing the total oxygen flow requirement in the event of a primary supply failure. As a minimum, the secondary supply should have usable quantity of product to meet expected usage between ordering a product and the delivery of the product.

Reserve supply

The reserve supply is the final source of supply to specific sections of the pipeline. It should be capable of meeting the required demand in the event of the failure of the primary and secondary supplies, or failure of the upstream distribution pipe work. As a minimum, the reserve supply should have usable quantity of product to meet critical patient care between a request for product delivery and the delivery of the product.

Under most conditions, compressed gas cylinders are the most appropriate method of providing a reserve source of supply. The reserve supply system should include the installation of independent reserve supplies to zones on the medical gas pipeline supplying critical care areas or wards or departments that are remote or vulnerable to interruption. The positioning of these manifolds is very important to ensure that the critical supply and high-dependency areas identified in the risk management process have adequate stocks of medical oxygen available in the event of a medical oxygen supply system failure.

Storage requirements

The selection of a storage location should comply with national regulations. Avoid installing liquid storage vessels indoors or near drains or pits. The control equipment should be protected from the weather and the area fenced. Oxygen cylinder storage should be separated from vacuum and medical air compressor plants to avoid potential oil contamination. Appropriate undercover storage facilities for cylinders should be provided to ensure that the cylinders are maintained in a safe, secure and clean condition.

Capacity requirements

The capacity of any supply system shall be based on the estimated usage and frequency of delivery. The location and capacity of the hospital gas supply sources are determined by management in consultation with the gas supplier, using risk management principles.

The location and capacity of the primary, secondary and reserve sources of supply, all supply systems and the number of reserve cylinders held in storage shall be taken into account by the system manufacturer.

Review of demand

A system should be in place to regularly review healthcare facility demand patterns and to ensure that the bulk medical supply can reliably meet this demand. This review should involve the gas supplier and healthcare facility management.

The alarm system

The following alarm signals should be fitted:

- Liquid level in any cryogenic vessel below the minimum specified by the management of the healthcare facility in consultation with the gas supplier
- Changeover from primary to secondary supplies

- Secondary or reserve supply below minimum pressure
- Deviation of pipeline pressure by more than ± 20% from the nominal distribution pressure

Further requirements

- Both visual and auditory signals are required for the alarm.
- If an auditory signal can be silenced by the operator, the silencing shall not prevent the auditory signal from being activated by a new alarm condition.
- Alarm system should be tested periodically as recommended by equipment manufacturer.
- Master alarm should be located in an area where 24 hours attendance is provided.

Pressure reducing station

- The healthcare facility supply pipeline reducing station, which reduces supply pressure to the healthcare facility pipeline, must consist of a dual parallel regulator system.
- Both regulators must be online and ALL isolation valves and regulators must be in the open position.
- A design based on a single pressure regulator with a bypass is not acceptable.
- The nominal distribution pressure should be within the range of 400 kPa to 500 kPa.

Pressure relief valve

The medical oxygen pipeline system should be provided with a pressure relief device downstream of the line pressure regulator and should be connected by means of a three-way valve so that the safety device can be exchanged for a “certificated” replacement in accordance with the frequency required by the Regulations.

Material selection

- The system supplier should ensure oxygen compatible material is used for when the oxygen supply system comes into contact with the medical oxygen gas under operating conditions.
- Specific hazards, such as toxic products of combustion or decomposition from non-metallic materials (including lubricants, if used) and potential contaminants should be addressed.

Testing and commissioning

The objective of testing and commissioning is to ensure that all the necessary safety and performance requirements of the medical oxygen supply system are met. Testing and commissioning procedures are required for new installations, additions to existing installations and modifications to existing installations.

Operational management system

An operational management system should be in place to include statutory requirements, functional responsibilities, operational procedures, training and communications, cylinder and sources of supply management, preventive maintenance and repair and risk assessment, giving definitions and working practices throughout.

8. ADDENDUM B

EIGA (European Industrial Gases Association)[22, 23]

Hospital oxygen supply system design is based on the principle of single fault failure. This ensures the supply system will continue to function (even during maintenance) when any component of the system fails. It requires three sources of medical oxygen supply and a robust pipeline system that will not cause a failure of supply with a single fault.

- The main supply source must be sized to meet the predicted demand and agreed supply frequency
- A back up supply large enough to manage a loss of prime supply source
- An emergency supply of oxygen cylinders – either on a manifold or individual cylinders

MGPS security of supply is potentially improved by using a ring-main system (see figure 8) and should be located to minimise the risk of mechanical damage. Supply failure can be controlled by strategically located isolation valves. This system should be constructed to ensure a safe system even under extreme conditions (such as fire). Alarm systems should be used to provide early warnings of system faults.

Medical oxygen quality must be a medicinal grade certified product supplied into supply system storage vessels. The hospital pharmacy is responsible for the quality of medical oxygen administered to patients. The correct management of the MGPS is critical to ensure gas of the right quality.

The management of the MGPS must be under the control of an Approved Person. Modifications must be controlled, using a ‘Management of Change’ system supported by a risk assessment. A permit-to-work system is used to ensure maintenance work is correctly

planned, and that adequate prior warning is provided.

Testing is required after any work to the pipeline system to ensure end-to-end system integrity. The reinstatement of systems must be controlled to ensure they are operating correctly. All design files must be updated to reflect the changes to the system.

(Health Technical Memorandum 02-01):

MEDICAL GAS PIPELINE SYSTEMS[22]

An MGPS is installed to provide a safe, convenient and cost-effective system for the provision of medical gases to clinical and nursing staff at the point of use. It reduces the problems associated with the use of gas cylinders such as safety, porterage, storage and noise.

Existing installations should be assessed for compliance with country specific guidance documents. A plan for upgrading the existing system should be prepared, taking account of the priority for patient safety. Managers need to liaise with medical colleagues and take account of guidance published by the Department of Health in order to assess the system for technical shortcomings.

Oxygen

Oxygen is generally supplied from:

- a liquid source such as a large vacuum-insulated evaporator (VIE);
- liquid cylinders or compressed gas cylinders; or
- a combination of these to provide the necessary stand-by/backup capacity. Oxygen can also be supplied from an oxygen concentrator (pressure-swing absorber). Such systems are usually installed where liquid or cylinders are expensive, unavailable or impracticable.

Basic principles of design

Patient safety is paramount in the design, installation, commissioning and operation of medical gas pipeline systems. The basic principles of safety are achieved by ensuring quantity of supply, identity of supply, continuity of supply and quality of supply.

Quantity of supply

This is achieved by ensuring that the design of the pipeline installation and capacity of the supply plant are sufficient to provide the required flows of gases and vacuum for the intended number of patients to be treated at any one time. Adequacy of supply is established during commissioning of the systems.

Identity of supply

This is achieved by ensuring that all points to which the user can connect medical equipment (terminal units) and user-replaceable components are provided with gas-specific connectors. Such connectors are also identified by symbols, and often colour. The gas specificity is maintained by comprehensive tests and checks during installation and commissioning of, repairs to or maintenance of the systems.

Continuity of supply

This is achieved by installing, as a minimum, duplex components and providing additional means of supply in the event of failure of the primary and secondary plant or supply system. Systems are also connected to the electrical supply.

Quality of supply

Quality of supply is ensured by the use of gaseous or liquid sources that are provided to an appropriate product specification. In the case of compressor-based systems, filtration equipment to a known and agreed standard is installed. To ensure that the product is not adulterated in the distribution system, pipeline installations and components must meet agreed specifications. There are strict requirements for medical gases.

Safety

The safety of an MGPS is dependent on four basic principles:

- Identity
- Adequacy
- Continuity
- Quality of supply

Identity is assured by the use of gas-specific connections throughout the pipeline system, including terminal units, connectors etc., and by the adherence to strict testing and commissioning procedures of the system.

Adequacy of supply depends on an accurate assessment of demands and the selection of a plant appropriate to the clinical/medical demands on the system.

Continuity of supply is achieved by: the specification of a system that (with the exception of liquid oxygen systems, which may include a secondary vessel) has duplicate components; the provision of a third means of supply for all systems except vacuum; the provision of alarm systems; and connection to the emergency power supply system.

Quality of supply is achieved by using gases produced to appropriate country specific requirements or by plants performing to specific standards, by maintaining a clean system throughout its installation, and by implementing the various testing and commissioning procedures.

Modifications

Special precautions are required when existing installations are to be modified or extended, to ensure that all sections of the MGPS that remain in use are not contaminated, and that

the supply to patients is not compromised. The MGPS section to be modified should be physically isolated from the section in use. The closing of isolating valves is insufficient for this purpose. Where area valve service units (AVSUs) and/or line valve assemblies (LVAs) have been installed, blanking spades should be used. This isolation procedure is not required when work is to be carried out on individual terminal units.

The modification of existing MGPS systems may be detrimental to the overall performance of the system. In the case of older systems, there may be insufficient capacity to permit the system to operate safely with the flows typically encountered in use today.

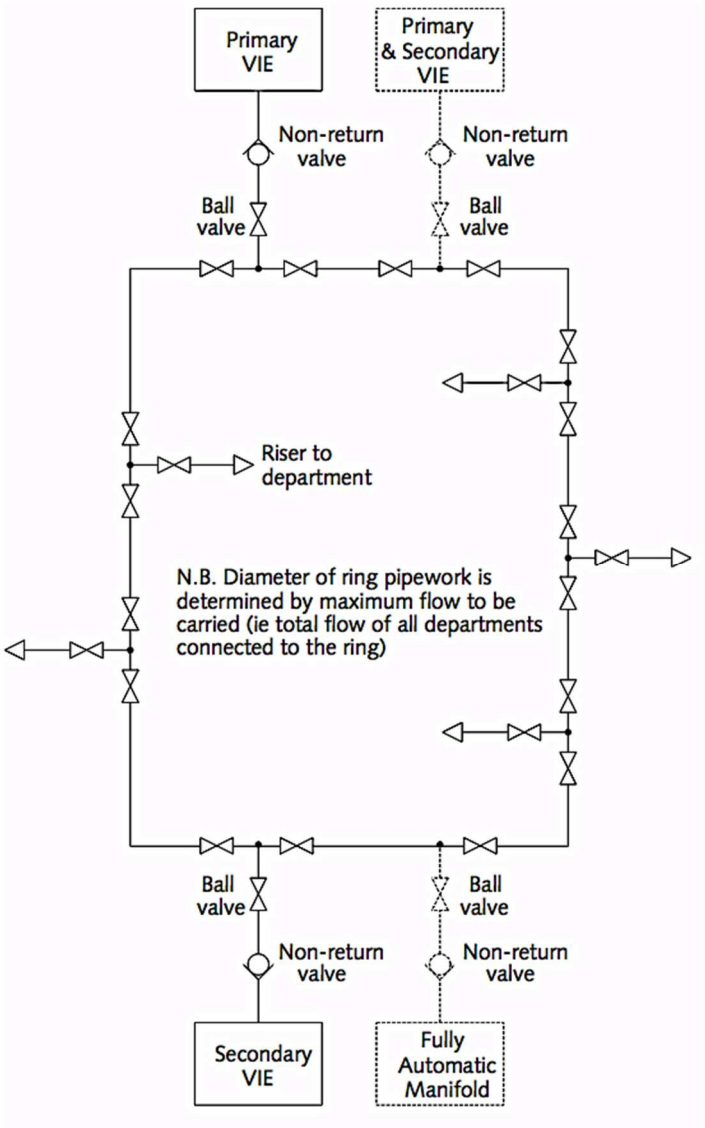

Figure 8: Typical ring-main arrangement

Primary supply	Secondary supply	Reserve supply (third source of supply)
Simplex VIE (vacuum-insulated evaporator) vessel system	Automatic manifold system. To come on-line in the event of plant failure	Automatic manifold system. May be sited to support high-dependency areas or whole site OR Locally-based integral valved cylinders with regulators/flowmeters attached
One vessel of a duplex VIE (vacuum-insulated evaporator) vessel system (on same plinth)	Second vessel of a duplex VIE system	Automatic manifold system. May be sited to support high-dependency areas or whole site
One vessel of a duplex VIE vessel system (on separate plinths)	Second vessel of a duplex VIE system (on separate plinths). NB split-site systems are intended primarily for systems where the risk assessment has identified that the site for the primary supply is limited in size or presents too high a risk having both tanks on the same site. These supply systems should be fitted with appropriate non-return valved connections to prevent gas loss in the event of one tank/system failing	Type and capacity of supply to be determined by risk assessment. May not be required when a ring main or other dual supply to a pipeline distribution system is provided

Table 6: VIE systems

OXYGEN

In-patient accommodation

Oxygen is used at a typical flow of 5–6 L/min. Each terminal unit, however, should have capacity to pass 10 L/min [at standard temperature and pressure (STP)] at a supply pressure of 400kPa, in case nebulisers or other respiratory equipment is used.

Operating departments

The diversified flow for operating departments is based on 100 L/min required for the oxygen flush. Therefore, each oxygen terminal unit in the operating room and anaesthetic room should be able to pass 100 L/min. For anaesthetic rooms, each terminal unit should have the capacity to pass 100 L/min (to provide an oxygen flush, if necessary), but the actual flow likely to be used is 6 L/min, or less. As it is unlikely that a patient would be anaesthetised at the same time that a patient in the associated operating room was continuing to be treated under an anaesthetic (and because the duration of induction is short), no additional flow is included. In recovery, it is possible that all bed spaces may be in use simultaneously; hence, no diversity is used.

Critical care, coronary care and high-dependency units

The flow for these units assumes that, although all bed spaces may be occupied, only three-quarters of them would require the use of oxygen. Each terminal unit should have the capacity to deliver 10 L/min.

Oxygen should not be used as the driving gas for gas-powered ventilators if they are capable of being powered by medical air. The minimum flow that has been shown to be adequate to drive current types of ventilators is 80 L/min at 360 kPa. For test purposes the minimum pressure is 370 kPa.

If oxygen has to be used to power ventilators and/or ventilators are operating in continuous positive airway pressure (CPAP) mode, the high flows that may be encountered should be taken into account both when designing the pipeline and when sizing the supply vessel. Ventilators use exceptional amounts of oxygen, particularly if adjusted incorrectly. If incorrectly set, they can use in excess of 120 L/min, but their therapeutic benefits are effective only at lower flows. To allow for some flexibility, and additional capacity, a diversified flow of 75 L/min for 75% of beds has been included. If significant numbers of beds are required to treat patients using CPAP ventilation, consideration should be given to running a separate pipeline from the source of supply.

Care should be taken when calculating air exchange rates in wards/rooms in which large numbers of CPAP machines may be in use simultaneously and where failure of mechanical ventilation could result in raised ambient oxygen concentrations. Consideration should be given to the installation of systems to warn of ventilation failure and oxygen concentrations above 23%.

OXYGEN SYSTEMS

Liquid oxygen systems

Risk assessment

Risk assessment is used to assist in the development of the medical oxygen installations to produce a safe and practical design and ensure that a safe supply of oxygen is available for patients at all times. Risk assessment is used for all aspects of the development process; from the initial concept designs through installation and operation to the routine assessment of the installation, once it is in service.

Risk assessment teams and the correct mix of staff should be selected to ensure that all aspects of the associated risks are considered.

Risk criteria lists should be provided to assist these teams in identifying unacceptable risks and suggesting how they might be addressed. It is recommended that annual risk assessments are carried out throughout the life of the MGPS to ensure that a safe supply system is maintained and new risks are identified.

The prime responsibility to ensure that adequate stocks of medical oxygen are available for patient use should remain firmly with the hospital's management team. However, the hospital may agree with its gas supplier or facilities management supplier that they should manage the supplies of medical oxygen and maintain adequate stock. These arrangements should be clearly documented in the MGPS operational policy and procedures document. The effectiveness of these arrangements need to be assessed as part of the risk assessment review and need to be validated to ensure they can be met.

The consequences for operational management of using different suppliers to supply medical oxygen to different supply systems on the same MGPS should be considered.

Contracts involving different suppliers should clearly stipulate the supplier's obligations and limitation of liabilities; just as facilities management agreements between the hospital and the medical gas supplier must define the responsibilities of each party.

There must be no modification to the design or any part of the medical liquid oxygen system without written authorisation from the gas supplier.

Designation of vessel contents as "operational" or "reserve" stock

The **operational stock** is the volume of product that the gas supplier uses to manage deliveries to the hospital; when this stock is exhausted, the vessel should be refilled under normal conditions.

The **reserve stock** is the volume of product that is used to provide additional stock to take account of fluctuations in demand or when the supplier fails to make a scheduled delivery.

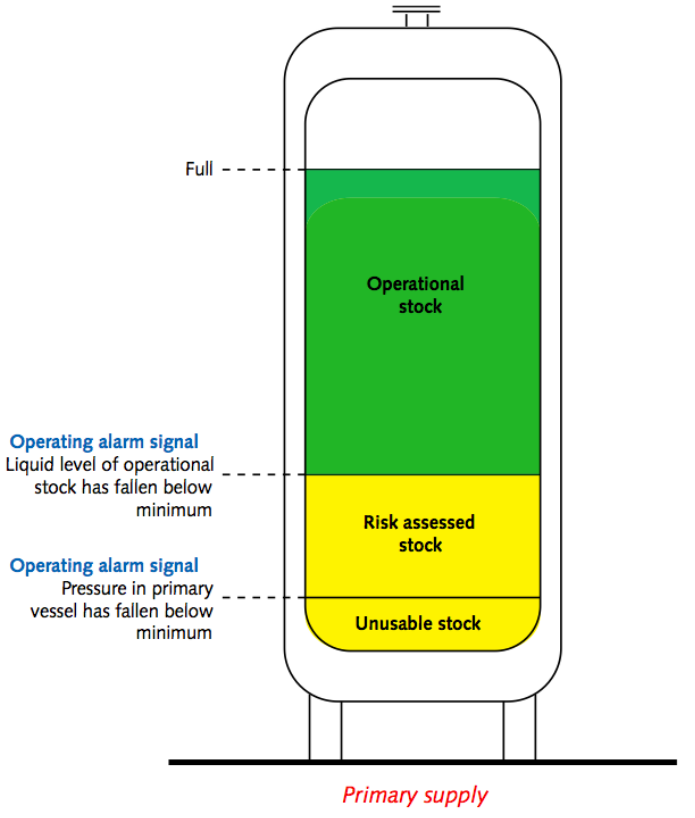

Figure 9: Primary supply (VIE)

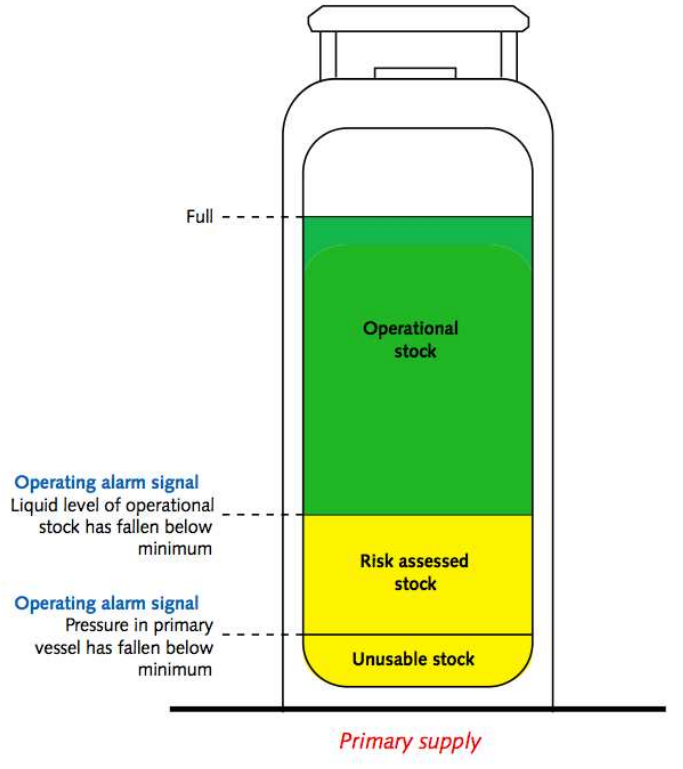

Figure 10: Primary supply (liquid cylinder)

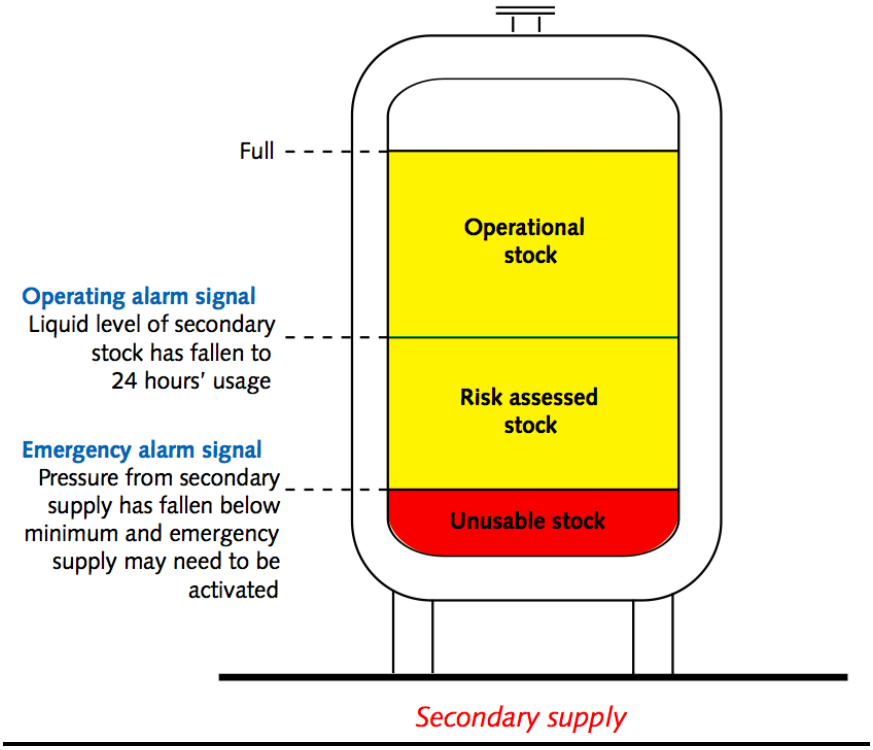

Figure 11: Secondary supply (VIE)

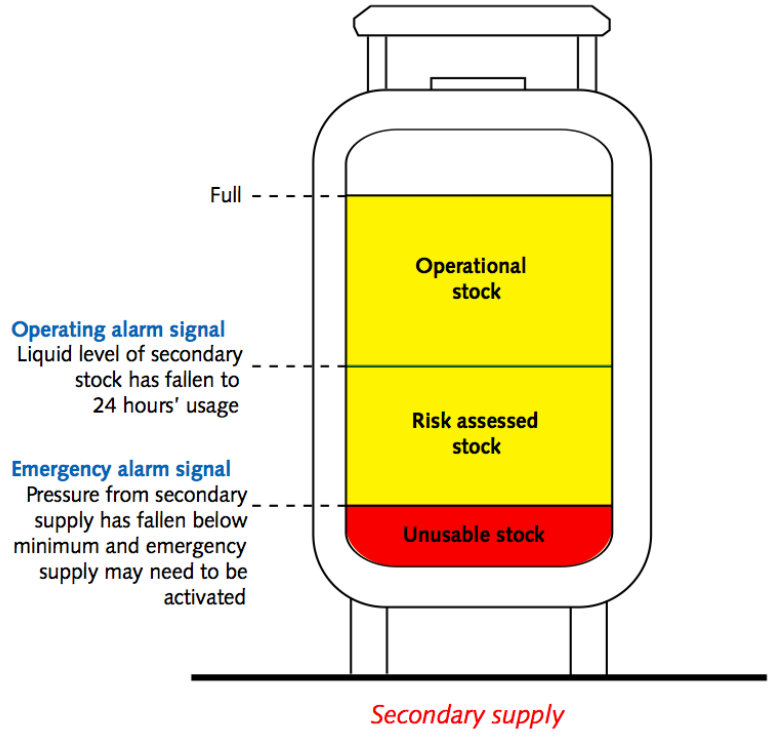

Figure 12: Secondary supply (liquid cylinder)

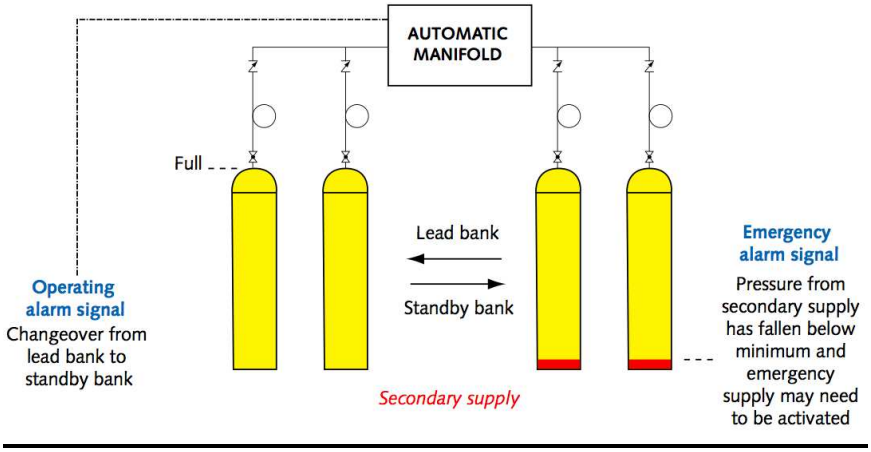

Figure 13: Secondary supply cylinder manifold

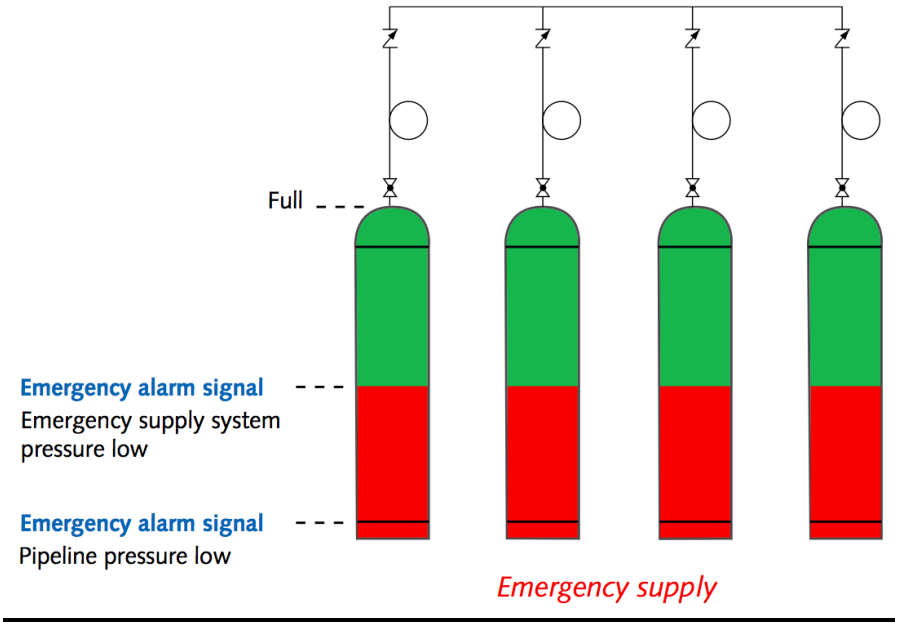

Figure 14: Secondary supply liquid manifold

Choosing an oxygen supply system

When designing or reviewing an installation to supply medical oxygen to a hospital, the most appropriate method of supplying the gas is determined by the potential size and variability of the hospital's medical oxygen demand.

To determine the most suitable and cost-effective method of supplying medical oxygen and the appropriate size of the installation, comprehensive demand figures should be provided to the designer.

These demand figures (prepared as a part of the risk assessment) should be based on:

- the current average daily gas usage based on the past twelve months' supplies;
- the maximum potential daily demand volumes based on peak flow conditions, as below;
- any planned extensions to the hospital/pipeline that may affect the demand;
- the expected natural annual growth in the use of medical oxygen.

The maximum potential daily demand should be based on the peak flow conditions measured between 8h00 and 18h00, with all operating rooms in use and with maximum demand being provided to MGPS outlets. It should not be based on the theoretical pipeline design flow conditions. Where actual flow monitoring is impracticable, daily cylinder or liquid consumption figures should be used.

Additionally, historic consumption records should be reviewed to assess the current usage and the natural growth of the medical oxygen demand. The growth predictions should take into account planned extensions to the hospital's facilities or MGPS and changes in clinical hospital practices that could affect the medical oxygen demand. Growth in usage of medical oxygen due to changes in clinical practice is about 8% to 10% per annum; however, a

hospital need to establish its own growth figure during the risk assessment process.

For new hospitals, where no historic information is available, the estimated demand should be based on the proposed size and type of the hospital and the usage figures of the facilities being replaced, if any.

It is essential to periodically review the average daily demand with the gas supplier and agree to either revise delivery frequencies to maintain the operational stock levels, or increase the size of the storage system on site. Any planned increase in demand due to hospital site developments, pipeline extensions or changes in clinical practice should be notified to the gas supplier to ensure that the changes do not jeopardize security of supply.

The medical liquid oxygen demand should be reviewed with the gas supplier at least annually (or after a significant extension to the pipeline) to re-assess the size of the installation.

As the agreed stocks of liquid oxygen are based on an average daily demand, as the demand grows so the storage volume requirements increase. With increased volume requirements for reserve stock, the volume available for operational stock will decrease. Having reviewed the average daily demand with the gas supplier, it is necessary to agree either revised delivery frequencies to maintain the operational stock levels or to increase the size of the storage system on site.

The review of the medical liquid oxygen installation should also include a risk assessment review to ensure that changed conditions on site do not jeopardize the security of the gas supply.

For smaller hospitals, where the demand is typically below 3000 m^3 per annum, the most

cost-effective method of supplying medical oxygen is from a compressed gas cylinder manifold.

As the demand increases, it becomes less practicable to use compressed gas cylinders and more cost-effective to use medical liquid oxygen. A cylinder manifold larger than 2 x 10 J cylinders is likely to prove impracticable because of the manual handling difficulties with the number of cylinders involved. Liquid cylinders, which are ideally suited to an annual consumption of between 3000 m^3 and 40 000 m^3, can be connected by a manifold to provide adequate storage capacity and flow rate.

For hospitals with larger demands, a bulk medical oxygen VIE will generally be used. There is a nominal overlap of annual consumption between 27 500 m^3 and 40 000 m^3, where either a bulk VIE or a liquid cylinder installation might be considered to satisfy a particular requirement or to accommodate possible site restrictions.

The main benefit of using gas cylinders is that installation costs of manifold systems are significantly lower than those of a liquid oxygen system. However, the cost of the medical oxygen in compressed gas cylinders is higher than the cost of medical liquid oxygen (supplied either in liquid cylinders or in a VIE). As the demand grows, so the lower unit cost of the liquid oxygen offsets the higher installation costs of the liquid oxygen system.

Cryogenic liquid systems are normally used where the demand is high enough to make bulk supplies cost-effective and where the demand makes cylinder supplies impracticable. Liquid oxygen provides a flexible approach to both the size and the choice of installation design. Its provision is determined by factors such as the size of the hospital, the availability of space for both the installation and the delivery vehicle, the proximity of the gas supplier and the demand for medical oxygen.

There are a number of operational benefits in using a medical liquid oxygen system over compressed gas cylinders, including: greater volume of medical oxygen stored on site; improved security of supply; reduced storage area for medical gas cylinders; reduced manual handling requirements for cylinder handling.

When determining the cost-effectiveness of specific proposals from suppliers, the total supply costs should be assessed, including costs for the site preparation and vessel installation, vessel rental and liquid supply over the total period of the contract.

System configurations

In order to comply with the requirements of international standards, it is necessary for all medical oxygen installations to have three independent supply sources capable of feeding medical oxygen into the pipeline:

- the primary supply – the main source of medical oxygen on site, providing gas to the pipeline
- the secondary supply – the secondary source of medical oxygen on site, providing gas to the pipeline and capable of providing the total oxygen flow requirement in the event of a primary supply failure
- the reserve supply – the final source of supply to specific sections of the pipeline, capable of meeting the required demand in the event of failure of the primary and secondary supplies, or failure of the upstream distribution pipework.

For smaller hospitals, the primary supply can be fed from compressed gas cylinders but as the demand grows, the most practicable supply source is either liquid cylinders or a VIE system. A fully automatic gas cylinder manifold is normally used as the secondary supply system for smaller VIEs and liquid cylinder systems. Where it is impracticable to maintain

supplies to the hospital using a cylinder manifold, a secondary liquid oxygen system becomes necessary.

Emergency supplies are not normally fed from a liquid oxygen supply system, as it is not possible to prevent the boil-off of the liquid oxygen over extended periods when the emergency system is not in use.

All attempts should be made to locate the primary and secondary supply systems on separate sites. They should have independent control systems and supply routes into the hospital pipeline system and be valved accordingly to ensure that the systems remain independent.

Where it is not feasible to utilise two sites, the risk assessment should evaluate the greater level of risk associated with using a single site and determine the appropriate actions to obviate the higher risks, such as using twin or ring main pipeline systems, siting of the emergency supply manifold, or installing suitable protection for the installation.

The overall system should be designed so that the primary supply is used first, with the secondary supply automatically switching in when the primary supply either runs empty or fails.

PRIMARY SUPPLY SYSTEMS

1. Cryogenic liquid systems (VIE)

These systems, commonly referred to as **vacuum-insulated evaporators** (VIEs), are used to store the medical gas as a liquid at cryogenic temperatures and to vaporise the liquid into a gas at ambient temperature for distribution throughout the MGPS.

Plant

The VIE system consists of:

- a vacuum-insulated cryogenic storage vessel to store the bulk liquid
- one or more ambient-heated vaporisers to convert the cryogenic liquid into a gas for supply to patients via a pipeline
- control equipment to control the pressure and flow of gas to the pipeline

The liquid oxygen is stored at cryogenic temperatures (down to minus 183℃) and converted to a gas at ambient temperature by passing it through an air-heated vaporiser.

The cryogenic storage vessel is normally constructed from a stainless steel inner pressure vessel that is supported in a mild steel outer shell. The space between the inner and outer vessels is filled with a high-performance insulating material, maintained under a vacuum, to minimise heat transfer to the inner vessel to reduce the rate of evaporation of the liquid oxygen.

A pressure-raising regulator that permits the flow of liquid to the pressure-raising vaporiser automatically controls the pressure in the liquid oxygen system. The vaporised liquid is fed back to the top of the vessel or liquid cylinder to maintain the pressure in the system.

Under normal operating conditions for a VIE system, the gas supply to the hospital is

maintained by feeding liquid oxygen to the main vaporiser system where it is converted to a gas and warmed towards ambient temperature. There is a tendency for the vaporiser system to “ice up” where hospital demands are high or continuous, or air flow to the vaporisers is restricted. Under these circumstances the options that should be considered are: installing additional vaporisers; installing an auto-changeover system between vaporisers; installing hot water/electrically heated vaporisers; increasing the size of the vaporiser; repositioning the vaporiser system.

Where hospital demands are low or erratic, the natural heat transfer into the vessel causes the liquid oxygen to boil and the vessel pressure to rise. When the vessel pressure rises to a set point, the hospital pipeline is fed from the top gas to prevent the vessel pressure rising above the safety-valve setting. On safety-valve operation, oxygen must be able to vent safely to the atmosphere.

In all cases, the pipeline pressure is controlled, using a system of duplex pressure regulators and valves. It is essential that all materials used in the construction of the vessels, control equipment and pipeline are compatible with oxygen at operating temperatures that could be encountered under normal operation with single fault condition. The risk assessment must determine the exact configuration.

Telemetry

The use of telemetry in the liquid storage system is recommended because it permits both the hospital and the gas supplier to monitor relevant supply conditions continuously, including storage vessel levels and pressure. In addition, it can be used to transmit other operational data from the storage vessel, pipeline and associated equipment for monitoring purposes. It may be beneficial to make this information available to the relevant person(s) in hospital management. The continuous monitoring of stock by means of the telemetric system may justify the retention of existing vessels. This solution is only acceptable

provided an appropriate risk assessment supports the decision.

Siting

The Authorised Person is responsible for determining the final location of the liquid oxygen compound(s), taking into consideration the issues raised in the risk assessment.

When considering the space requirements for the liquid oxygen compound(s), there may be operational advantages in having two compounds in different areas on the hospital site, rather than one large site utilising either a single large vessel or multiple tanks.

Each supply system should be located in a secure, fenced compound, which should be sized to allow adequate access to control equipment.

The site should essentially be level but designed to have adequate falls to prevent water accumulating beneath equipment. The location of drains in the vicinity of the site should comply with nationally specified requirements.

Only under extreme conditions should safety distances between equipment be reduced. Any relaxation of the safety distances needs to be agreed between the supply company's safety representative and the Authorised Person. Both parties must ensure that an equivalent level of safety is achieved, which should be approved and documented.

The layout of the liquid oxygen installation should provide adequate access to all the relevant components of the system and permit adequate airflow for the ambient vaporisers. The plinth should be of concrete construction. The area in front of the vessel(s) (the tanker apron) should be of non-porous concrete. Under no circumstances should tarmac be used in the vicinity of the liquid oxygen filling point, or in areas where liquid oxygen spillage may occur.

The location of the liquid oxygen compound should permit the supplier to gain safe access with the appropriately sized tanker. It is the supplier's responsibility to assess the space requirements for vehicular access.

The design of the liquid oxygen installation should take into account the gas supplier's requirements for discharging the liquid oxygen from the cryogenic tanker. The area directly in front of the vessel should be kept clear to provide access for the delivery vehicle at any time. Under no circumstances should cars be permitted to park in front of the compound, nor should the compound be used for the storage of other equipment.

Where the secondary or emergency supply system is fed from a cylinder manifold, it should be accommodated in a separate enclosure/manifold room and have adequate space to permit safe cylinder changeover. Spare cylinders should not be stored in the VIE compound or liquid cylinder compound, but in the nearest medical cylinder store.

A pipework and installation diagram (P&ID) of the plant should be displayed clearly to indicate the appropriate valves that are necessary to operate the plant safely.

2. Liquid cylinder systems

Plant

Liquid cylinder systems can also be used to store the medical gas as a liquid at cryogenic temperatures and to vaporise it into a gas for patient use. These systems are used where the demand is too high for compressed gas cylinders to be a practicable option but where it is neither economic nor possible to supply bulk medical liquid oxygen in a VIE system.

Liquid cylinders are constructed in a similar way to vacuum-insulated cryogenic storage units; that is as double-walled vessels. However, unlike the VIE, the liquid cylinder has an

internal vaporiser coil to convert the liquid into a gas.

The size of the liquid cylinder can vary between 200 L and 1 000 L water capacity. To obtain sufficient storage capacity and to meet the hospital's flow requirements, a number of liquid cylinders can be connected together via a manifold.

The liquid cylinder system consists of: a number of vacuum-insulated liquid cylinders; a system to manifold the liquid cylinders together to store sufficient liquid on site to meet the hospital's demand; control equipment to regulate the pressure and flow of gas to the pipeline.

Although liquid cylinders are suitable for transportation when full, they are normally installed as a fixed installation and remotely filled while in situ.

Liquid cylinders are designed and supplied with gas-specific liquid-fill and gas-use connections (including the connection on the remote liquid-fill connection where the liquid cylinders are filled in situ).

Where there is no alternative, a liquid cylinder manifold may be installed in a building or confined area, but only if the vent header (to which all liquid cylinder vents will be connected) is piped to a safe area via a back-pressure control valve. This valve should be set at a pressure below that of the liquid cylinder relief-valve setting, thus ensuring that any excess pressure is safely vented.

3. Compressed gas cylinder manifolds

The simplest supply system to provide medical oxygen to a hospital pipeline system utilises compressed gas cylinders, connected to an auto-changeover manifold. As the demand increases, the number of cylinders fitted to the manifold can be increased to meet the

hospital's requirements. The secondary supply for this system is usually a manual changeover compressed gas cylinder manifold, which comes on line automatically (via a non-return valve) in the event of primary manifold failure.

SECONDARY SUPPLY SYSTEMS

Where the primary supply system is a VIE, the secondary supply system can be either:

- another VIE
- a liquid cylinder manifold
- a fully-automatic compressed gas cylinder manifold

Where the primary supply system is a liquid cylinder system, the secondary supply system should be a fully automatic changeover gas cylinder manifold that comes into operation automatically. There should be a system of backflow prevention to protect either system venting into the other in the event of a single fault in either system.

Where the secondary supply is fed from compressed gas cylinders, the size of the changeover manifold and the number of cylinders stored on site should be based on the gas supplier's ability to guarantee a delivery service within a defined period.

Where a liquid oxygen system is used for the secondary supply, the system design should allow the liquid oxygen that has boiled off, if any, to be fed to the MGPS to utilise product.

Where the feed from the VIE compound to the hospital extends over a long distance, or is exposed to potential mechanical damage, particular importance should be given to siting the secondary supply system remotely from the main VIE compound with a separate supply to the hospital MGPS.

Where the secondary supply is sited remotely, consideration should also be given to the set point of its output regulator to ensure that pipeline pressure is maintained at a minimum level of 4,1 bar. When the vessels are located on separate sites, a back flow prevention device must be fitted on each leg feeding into the MGPS. This prevents loss of product, either from

the other vessel or from the MGPS in the event of the failure of or damage to a VIE unit or its feed into the MGPS. The backflow protection should be sited at a secure location where it is not liable to mechanical damage and be as close to the hospital curtilage as possible.

EMERGENCY SUPPLY PROVISION

In the event of total plant and/or main pipeline failure, an emergency supply of oxygen should be available for patient use. The emergency supply system should be activated automatically when the primary and secondary system is empty or fails to supply or when the hospital pipeline pressure falls below 3,8 bar. It must automatically prevent the backflow of medical oxygen into the remainder of the MGPS should the pipeline fail upstream of the connection.

Under most conditions, compressed gas cylinders are the appropriate method of providing an emergency supply source. The size and design of the emergency supply system should allow for cylinders to be changed whilst in operation. The set point of the regulator of any emergency supply system should also be considered, to ensure that pipeline pressure remains above the minimum level of 3,8 bar.

Fixed automatic/manual manifold systems

Where two VIE units on the same plinth are in use, the emergency supply system should comprise a fully automatic cylinder manifold permanently connected to (one of) the main oxygen riser(s) in the hospital, or directly to a ring-main system. It must be able to feed a riser automatically (without back-feeding to any damaged upstream section) on failure of both the primary and secondary plants, or the MGPS upstream of the entry point into the hospital. Such an arrangement is particularly suited to situations in which the main feed from the VIE installation to the hospital pipeline is vulnerable to mechanical damage, for example when buried under a road. The location and size of the manifold should be determined by means of risk assessment and according to the dependency of the patients.

When two separately sited VIE units are used to provide the hospital supply, the need for an emergency manifold should be assessed against the likelihood of failure of both VIE

systems and their respective feeds into the hospital pipeline.

Where it can be shown that one or both units feed into the hospital pipeline in a manner that minimally disrupts one or both of the feeds, the option to waive the fitting of further (manifold) supplies may be considered.

Local manifold provision (critical care areas)

To offer additional protection against the possibility of a pipeline failure within the hospital, further (manual or automatic) manifolds can be permanently connected, via non-return valves, downstream of the area valve service units (AVSU) controlling high-dependency areas. Such units should come on line automatically upon the main supply to an AVSU failing. Another non-return valve must be added upstream of the AVSU to prevent back-feeding into a failed main supply system.

The positioning of these manifolds is very important to ensure that the critical supply/high-dependency areas identified in the risk assessment process have adequate stocks of medical oxygen available in the event of a system failure. However, the risk analysis for the complete system may indicate that the probability of use of such a manifold system is negligible, or that the circumstances causing the system failure would in any event require the evacuation of the area.

Availability of accommodation, staff and manual handling issues also need to be considered during risk assessment. Where space limitations prevent the installation of such manifolds, the implications of providing discrete cylinder/regulator combinations must be considered.

Gas feed via an AVSU (or terminal unit)

Oxygen supply to the downstream side of an AVSU (with the valve closed) can be achieved using an “emergency supply kit” consisting of two cylinder regulators and associated supply

hoses with gas-specific connectors.

Such an arrangement may be used to support high-dependency departments, albeit the unit usually has limited capacity compared to a fixed automatic manifold system.

Storage, maintenance, testing, security and deployment arrangements for the emergency supply kits must be documented in the MGPS operational policy.

Discrete cylinder supplies

For non-critical care areas where there are no high-dependency patients, it may be appropriate to use individual cylinders as the reserve source of supply. Cylinders fitted with integral valves and having a product-specific terminal unit outlet are suitable for this purpose. The difficulties associated with storing, testing, maintaining, distributing and connecting large numbers of such equipment must not be underestimated. (Such protocols should be referenced in the MGPS operational policy.)

Alarm systems

Installations of the following type should be fitted with alarm systems to provide visual and audible warnings for the following conditions. For: dual VIE vessels feeding into a single control panel; or a single VIE vessel supported by a liquid cylinder secondary supply; or a single VIE vessel supported by a fully automatic compressed gas cylinder manifold, the following displays should be presented at the plant and in a 24-hour staffed position.

Status/fault condition	Indication	Legend
Normal operation System available for use	Green	Normal
Primary supply system's operational stock empty Primary supply system's reserve stock in use	Yellow	Refill liquid
Primary supply system's reserve stock empty Secondary supply system in use	Yellow	Refill liquid immediately
Secondary supply system empty Emergency system in use	Yellow	Emergency supply in use
Pipeline pressure high or low	Red	Pressure fault

Table 7: Alarm system 1

For: two discrete VIE vessels feeding into separate parts of the pipeline system; or a single VIE vessel supported by a liquid cylinder secondary supply that feeds separate parts of the pipeline system; or a single VIE vessel supported by a fully-automatic compressed gas cylinder manifold secondary supply that feeds separate parts of the pipeline system, the following displays should be presented at the plant and in a 24-hour staffed position.

At the primary vessel and a 24-hour-manned position		
Status/fault condition	**Indication**	**Legend**
Normal operation System available for use	**Green**	Normal
Primary supply system's operational stock empty Primary supply system reserve stock in use	**Yellow**	Refill liquid
Primary supply system's reserve stock empty Secondary supply system in use	**Yellow**	Refill liquid immediately
Secondary supply system low	**Yellow**	Secondary stock low
Pipeline pressure high or low	**Red**	Pressure fault

Table 8: Alarm system 2

When the primary system operational stock has been exhausted and the vessel contents reach the reserve stock level, the first alarm condition is indicated by a yellow alarm and an illuminated "refill liquid" legend.

When the primary system reserve stock is empty and the secondary supply system is in operation, the second alarm condition is indicated by a yellow alarm and illuminated "refill liquid immediately" legend. The alarm continues until the primary supply system is refilled.

When the secondary supply system is low, the third alarm is indicated by a yellow alarm and an illuminated "secondary stock low" legend. This alarm continues until the secondary supply system is refilled or the cylinders are replaced.

Should the primary supply of medical oxygen to the hospital pipeline fail due to lack of contents or mechanical failure of any of the components, or should a serious leak occur, the pipeline pressure will fall. When the plant output pipeline pressure falls below 3,75 bar, the condition will be indicated by the “pressure fault” alarm.

If the regulator controlling the pipeline pressure should fail to “open”, the pipeline pressure rises. This condition is indicated by the “pressure fault” alarm when the pressure rises above 4,9 bar.

At the secondary vessel/liquid cylinder supply/cylinder manifold and a 24-hour-staffed position		
Status/fault condition	**Indication**	**Legend**
Normal operation System available for use	**Green**	Normal
Secondary supply system’s operational stock empty Secondary supply system’s reserve stock in use	**Yellow**	Refill liquid/ change cylinders
Secondary supply system’s reserve stock empty Emergency supply system in use	**Yellow**	Emergency supply in use
Pipeline pressure high or low	**Red**	Pressure fault

Table 9: Alarm system 3

When the secondary system operational stock has been exhausted and the vessel contents reach the secondary reserve stock level, the first alarm condition is indicated by a yellow

alarm and an illuminated “refill liquid” legend. This alarm condition continues until the secondary supply system is refilled.

When the secondary supply system is empty, the second alarm condition is indicated by a yellow alarm and an illuminated “emergency supply in use” legend. This alarm condition continues until the secondary supply system is refilled or the secondary supply manifold cylinders are replaced.

Should the secondary supply of medical oxygen to the MGPS fail due to lack of contents or the mechanical failure of any of the components, or should a serious leak occur, the pipeline pressure falls. When the plant output pipeline pressure falls below 3,75 bar, the condition is indicated by the “pressure fault” alarm.

With a correctly installed and commissioned emergency system, the hospital pipeline pressure is maintained downstream of the primary and secondary supply connections (by means of non-return valves) at a minimum pressure of 3,9 bar. Pressure on the plant side of the non-return valves will, however, remain below 3,75 bar until the plant is refilled, or any fault remedied. Therefore, the plant and 24-hour monitored alarms continue to indicate both the “pressure fault” and “emergency supply system in use” legends until the vessel is refilled or the fault is repaired.

If the regulator controlling the pipeline pressure should fail in the “open” position, pipeline pressure rises. This condition is indicated by the “pressure fault” alarm when the pressure rises above 4,9 bar.

Where the emergency supply is installed on individual zones of the pipeline system, the “emergency supply in use” alarm must be displayed within the pipeline zone area. A separate “emergency supply low” alarm should also be installed on each zone.

Where more than one VIE is used and the operational and reserve stock is distributed between multiple vessels, an illuminated “normal” display indicates that the vessel is available for use.

In the event that the primary (or secondary) vessel should run empty (or suffer from any other fault condition), the “normal” display should be extinguished, indicating that the vessel is not available for use.

Alarm conditions should be transmitted to the central alarm system.

If relays are used, they should be energised relays, which de-energise under fault conditions, with contacts having a minimum rating of 50 V dc and 50 mA. Alternatively, volt-free, normally closed contacts rated at 50 V dc and 50 mA should be provided for transmitting conditions to the alarm system. Typical alarm trigger points are shown in Figures 9–14.

Determining system size by means of risk assessment

Risk assessment should take into account all issues concerning the safety and continuity of medical oxygen supply. It is suggested that identified risk factors and criteria should be evaluated, using both qualitative and quantitative measures. All results should be recorded in a manner that supports decisions made. The record of the risk assessment also acts as a reference document when the MGPS is reviewed.

Additional local factors and requirements identified by the project team also need to be considered when carrying out the risk assessment to take account of site-specific issues concerning the storage, distribution and use of the product.

Procedures identified by the risk assessment process that are designed to minimise identified risks must be recorded and incorporated into the relevant hospital standard operating procedures (SOP) or work instructions (WI).

When sizing vessels and cylinder manifolds to provide adequate storage of medical oxygen on site, stock should be distributed among the three sources of supply. The capacity of the primary and secondary supply system will consist of operational stock and reserve stock.

The operational stock is the volume of product that the gas supplier uses to manage deliveries to the hospital. Its exhaustion signals the point at which the vessel should be refilled under normal conditions. The reserve stock is the volume of product that is used to provide additional stock, to take account of fluctuations in demand, or when the supplier fails to make a scheduled delivery. The MGPS should be designed so that the primary and secondary supply system stocks are kept separate from each other. Under no circumstances can the primary supply system operational stock be stored in the secondary supply system vessel.

However, where it is not possible to install a single large VIE vessel for the primary supply (such as where planning permission restrictions prevent the use of a single large vessel), it may be appropriate to hold all or some of the primary supply system reserve stock in the secondary supply vessel. Under these circumstances the primary supply vessel should retain a minimum level when changing over to the secondary supply system. The volume retained in the primary supply vessel should equate to the secondary supply system reserve stock. This should provide adequate stock on site to enable the gas supplier to resupply product to the primary vessel in the event of failure of the secondary supply. This level should be determined by the risk assessment process but should comprise at least one day's usable stock.

Review of risk assessment

The documented risk assessment should be reviewed after installation is complete and prior to commissioning, to assess whether parameters or circumstances have changed since the initial assessment. The risk assessment must also be reviewed at least annually (or when there is any significant change to the medical oxygen supply system or usage pattern) to ensure that details remain current. At this review, all changes should be considered that might have an effect on the safety of the system or the security of supply.

VIE installations

The operational and reserve stock for each supply system should normally be held in the same vessel. Where planning restrictions prevent the use of a single large vessel on site, it may be appropriate to utilise multiple vessels to provide adequate stocks. When sizing VIE systems for primary or secondary supply, the vessel size is determined by adding up the operational and reserve stock and making an allowance for the level of unusable stock left in the vessel when the designed flow rate cannot be maintained.

Liquid cylinder installations

For liquid cylinder installations, the primary system should be made up of a number of liquid cylinders connected to a manifold. The secondary system comprises an automatic or manual compressed gas cylinder manifold system. Each liquid cylinder has a maximum design flow rate for continuous use. The number of liquid cylinders required for an installation may be governed by either the maximum storage capacity required on site or the flow rate required to meet the hospital's maximum demand.

When determining the number and size of liquid cylinders required for either a primary or a secondary supply to a VIE, an allowance has to be made for the unusable capacity of each cylinder when connected to the manifold system.

Compressed gas cylinder manifold systems

For auto-changeover cylinder manifolds, one bank of cylinders should be considered the operational stock and the other the reserve stock. The size of each source of supply should be determined by considering the operational and reserve stock requirements for each source.

The secondary supply normally comprises a manually operated manifold system, connected such that it comes on line automatically (via a non-return valve) in the event of primary supply failure.

The size of the compressed gas cylinder systems manifold normally is determined by the hospital's ability to provide adequately trained staff to switch cylinders quickly enough to meet the demand. The number of cylinders required to support the manifold can be determined by dividing the relevant stock figure by the usable volume of each cylinder (that is the volume at full cylinder pressure less the volume at the pressure of the cylinder when the manifold changes over).

Risk assessment process

Risk assessment for management responsibilities

The risk assessment criteria, when considering management responsibilities for the medical liquid oxygen system, need to include the following:

- documented and agreed responsibilities for the monitoring of the medical liquid oxygen VIE, and established backup procedure with the gas supplier to ensure that adequate stocks are maintained in the event of a failure of the fitted telemetry system;
- the hospital should set up procedures to ensure that the VIE system is monitored at regular intervals for any deviation from normal operation (such as safety valves lifting, leaks, or failure of either the telemetry or the alarm system);

- the implications of decisions to not fit telemetry or to utilise a vessel or vessels that do not provide adequate operational and reserve stocks. These decisions should be taken at an appropriate level of management and should be documented. Their implications should be considered as part of the risk assessment;
- consideration of the resources needed to maintain adequate supplies of medical oxygen under normal or emergency conditions. When evaluating these requirements, consideration should be given to the risks that the trust would face in the event of supply failure causing disruption of clinical services;
- consideration of the operational management consequences of using different suppliers to supply medical oxygen to different supply systems supporting the same pipeline installation. Contracts involving different suppliers should clearly state the parties' obligations and limitations of liabilities.

Where manifolds are used either as the secondary or emergency supply, adequately trained staff should be available whenever necessary to ensure continuity of supply. Consideration also needs to be given to manual handling issues such as changing cylinders on the manifold and arrangements to store adequate stocks to meet demands.

Consideration needs to be given to the type of clinical activities carried out in each area of the hospital and the ability to provide emergency back-up to individual areas used for critical care, or within high-dependency units.

Initial risk assessment for siting of plant

The initial risk assessment should consider requirements to ensure a continuous supply of medical gas to each patient who needs it. Criteria related to the complete installation should include:

- the size and location of each source of supply (for example the volume operational

and reserve stock for each source of supply, located on one site or at two independent sites);

- the risks associated with siting operational and reserve tanks at the same or separate locations (for example the physical space available, accessibility for product delivery and site maintenance, accessibility to the hospital MGPS [access to tie-in points, etc.], alarm systems and cabling, pipeline routing and protection);
- the need to site reserve sources of supply local to the point of use to protect against pipeline failure where high-dependency patients are located;
- safety requirements for the storage of oxygen on site, including compliance with approved safety distances;
- the location and extent of the medical oxygen pipeline system;
- the vulnerability of the MGPS to mechanical damage and whether underground sections of the pipeline system comply with the requirements of this Health Technical Memorandum; and whether the pipeline is can be inspected throughout, or pressure tested (whilst maintaining the supply), or otherwise tested;
- the space available for the liquid oxygen installation, or cylinder manifold, and the available access for the delivery vehicle;
- the vulnerability of the site to external damage;
- the possibility of interference with the supply system or other security issues.

Risk assessment for sizing of operational stock

The risk assessment criteria for the sizing of operational stock should include:

- the average daily demand at the end of the contract period. Changes to the predicted growth need to be considered, as do changes to the vessel size or delivery frequency. It may be beneficial to set a daily demand rate at which changes to vessel size or delivery frequency are considered;
- a review of vehicular access to the VIE, the timing of the deliveries, restrictions due

to local planning requirements, and the effect these factors on delivery frequency;

- an environmental impact assessment.

Risk assessment for sizing reserve stock

The risk assessment criteria for sizing reserve stock should include:

- the average daily demand at the end of the contract period. Changes to the predicted demand growth need to be considered, as do changes to the vessel size or delivery frequency. It may be beneficial to set a predetermined daily demand rate at which changes to vessel size or delivery frequency are considered;
- the short-notice delivery frequency guaranteed by the gas supplier should the primary supply system fail;
- the minimum response time by the supplier from the time when the primary supply system fails to when the delivery vehicle is on site to refill the secondary supply VIE, or to provide replacement compressed gas cylinders for the manifold.

Risk assessment for emergency supply systems

The risk assessment criteria concerning emergency supply systems should include:

- the need for the installation of independent emergency supplies to zones on the medical gas pipeline supplying critical care areas or wards or departments that are remote or vulnerable to interruption;
- the positioning of the manifold to ensure easy access and manual handling in the event of a changeover of cylinders;
- the storage of cylinders associated with the emergency manifold must comply with the appropriate codes of practice and local hospital requirements;
- training requirements for the relevant clinical and operational staff to ensure correct operation of the emergency supply system.

Stock calculations

Calculation of operational stock for primary and secondary supplies

The operational stock capacity of primary and secondary supply systems should be agreed with the gas supplier based on the following parameters:

- the current average medical oxygen daily demand, plus any natural growth over the contract period;
- additional, planned growth (over and above natural growth) within the contract period;
- the agreed delivery frequency.

The current average daily demand can be calculated by dividing the current annual consumption by 365 days. The operational stock should be based on an average daily demand predicted for the end of the contract period calculated as follows:

- Average daily demand = current daily demand + planned growth + natural growth
- Operational stock is calculated as: Operational stock = average daily demand X agreed delivery period

If there is significant growth in average daily demand over the contract period, either the vessel should be resized or the agreed delivery frequency should be reviewed to reduce the delivery period and maintain the operational stock level. The delivery period for the primary supply is based on the gas supplier's normal delivery frequency, while the delivery period for the secondary supply is based on emergency conditions when the primary supply is not available. Under these circumstances, special delivery response times must be agreed with the gas supplier.

The supply agreement should commit the supplier to manage the operational stock, based on an agreed delivery frequency and the minimum stock level to be maintained in the vessel.

Calculation of primary reserve stock

The table below provides a matrix for the calculation of primary reserve stock based upon distance from gas supplier and fitting of telemetry.

Kilometres from gas supply depot	No telemetry (no of days' stock)	Telemetry fitted (no of days' stock)
Up to 75	5	3
75–150	6	4
150–300	7	5
Over 300	8	6

Table 10: Calculation of primary reserve stock

Calculation of secondary reserve stock

The minimum level for reserve stock for secondary supply should allow for circumstances in which the primary supply system is not available for use. The secondary supply system reserve stock level depends on:

- the proximity of the supplier's distribution depot;
- the response time the gas supplier needs to make a delivery;
- the delivery frequency that can be sustained when the primary supply is unavailable for use.

Calculation of capacity of emergency supply systems (cylinder manifolds)

The number of cylinders to be stored by a hospital for the emergency supply system manifold and the number of connections on the manifold(s) should be determined by risk assessment. When determining these requirements, the risk assessment needs to consider:

- the maximum demand from the high-dependency patients who may be supplied from

the pipeline zone that the emergency supply system protects;

- the maximum duration for which an emergency is likely to last;
- the proximity of the compressed gas supplier to the hospital;
- the ability of the hospital to connect cylinders to the manifold.

Consideration needs to be given to the logistics of storing and handling the number of cylinders needed to provide adequate supplies until the primary/secondary supply systems or the hospital pipeline can be re-established.

FUNCTIONAL RESPONSIBILITIES[23]

Management – definition

Management is defined as the owner, occupier, employer, general manager, chief executive, or another person who is ultimately accountable for the safe operation of the premises. Appointment of an Authorised Person to manage the MGPS is necessary.

Key staff

The following are the key staff who have specific responsibilities within the MGPS operational policy:

- Executive Manager
- Estates/Operations Manager
- Authorising Engineer
- Authorised Person
- Competent Person
- Quality Controller
- Designated Medical Officer or Designated Nursing Officer

Executive Manager

The Executive Manager is defined as the person with ultimate management responsibility, including the allocation of resources and the appointment of staff, for the organisation in which the MGPS is installed. Depending on the nature of the organisation, this role may be filled by the general manager, CEO, laboratory director or another person of similar authority.

The formal responsibility for the MGPS rests with the Executive Manager, although the Authorised Person retains effective responsibility for day-to-day management.

The Executive Manager is responsible for the implementation of an operational policy for the MGPS. He or she should ensure that the MGPS operational policy clearly defines the roles and responsibilities of all staff who may be involved in the use, installation and maintenance of the MGPS. The Executive Manager is also responsible for monitoring the implementation of the MGPS operational policy.

The Executive Manager may delegate specific MGPS responsibilities to key staff to the extent circumscribed in the MGPS operational policy, together with the arrangements for liaison and monitoring. In most organisations, the Authorised Person takes responsibility for the preparation, implementation and monitoring of the MGPS operational policy, and works closely with senior medical and nursing staff.

Estates/Operations Manager

The Estates/Operations Manager holds responsibility for the integrity of the MGPS and should also monitor the implementation of the MGPS operational policy.

Authorising Engineer

This person has specialist knowledge of the MGPS. He or she acts, and is employed, independently of organisations submitting potential Authorised Persons for assessment. The Authorising Engineer, subsequent to assessing a potential Authorised Person, recommend to the Executive Manager of the submitting organisation either that the person can proceed to formal appointment or requires further training.

Authorised Person

The Authorised Person is defined as that person designated by the Executive Manager to be responsible for the day-to-day management of the MGPS at a particular site or sites and also has specific duties with regard to VIE installations. All Authorised Persons should be

appointed in writing by the Executive Manager on the recommendation of an Authorising Engineer. An individual assessment of the suitability of a potential Authorised Person is required before such a recommendation can be made.

The Authorised Person is responsible for ensuring that:

- all Designated Nursing Officers (DNOs) likely to be affected by work to or interruptions in the MGPS are advised within a reasonable time of the estimated duration of the work or interruption
- all terminal units that are affected or out of service are appropriately labelled with “danger do not use” notices
- work is carried out only by approved, specialist contractors registered within the scope of the design, installation, commissioning, validation, verification and maintenance of MGPS as appropriate. Evidence of registration should be obtained by means of sight of the certificate of registration

Arrangements should be made to ensure that cover for an Authorised Person is always available, particularly during holidays and other absences.

The Authorised Person must liaise closely with other professionals in various disciplines. Consequently the appointment should be made known in writing to all interested parties.

The Authorised Person should have direct contact with the Quality Controller, users and other key staff. He or she is responsible for assessing the competency of all Competent Persons employed by the estates/operations department and for maintaining a list of Competent Persons. He or she should also be consulted before the purchase of any medical equipment that is connected to the MGPS.

Authorised Persons are appointed on the recommendation of the Authorising Engineer.

Competent Person

The Competent Person is the person who carries out the installation of and/or maintenance on the MGPS, and should receive appropriate training. He or she should be included on a list of Competent Persons.

Quality Controller

The Quality Controller is the person designated as the quality controller for MGPS. He or she is responsible for controlling the quality of the medical gases at terminal units and equipment such as medical air compressors, oxygen concentrators and synthetic air systems.

The Quality Controller accepts professional responsibility for the last independent check of an MGPS that, if faulty, could cause critical clinical consequences to patients. The Authorised Person, in conjunction with the chief pharmacist, should contact the Quality Controller when testing of the MGPS is required. Authorised Persons, when contracting Quality Controller services, should obtain documentary evidence of the Quality Controller's continuing and recent experience in MGPS testing before a contract is finalised.

The Authorised Person needs to liaise with the Quality Controller before an MGPS is taken into use, as quality tests may be required before gases are passed to patients.

Designated Medical Officer or Designated Nursing Officer

The Designated Medical Officer (DMO) or the DNO (hereon further referred to as the Designated Officer) is the person in each department with whom the Authorised Person liaises on matters affecting the MGPS and who gives permission for a planned interruption

to the supply.

Liaison between the medical and nursing staff that use the MGPS is essential and the Authorised Person must ensure that the MGPS is appropriate to their needs. The Designated Officer should sign the appropriate parts of the permit-to-work. The MGPS operational policy should clearly stipulate the requirements for such permission, including the circumstances that demand the Designated Officer's signature.

The Designated Officer and the Authorised Person are responsible for ensuring that all clinical/nursing staff are aware of the interruption to the MGPS and the location of terminal units that may not be used.

Ideally, a Designated Officer should be appointed for every department; the MGPS operational policy should list Designated Officers and the arrangements for cover in case of a Designated Officer's absence.

The Designated Officer acts as the focal point for communications related to the MGPS and advises on any special requirements for his or her department relating to MGPS, such as providing emergency cylinders and vacuum pumps. The Designated Officer normally carries out the appropriate action in the event of an emergency (for example the isolation of a ward supply). Such actions should be set out in the MGPS operational policy. All Designated Officers should have received training on the MGPS relevant to their departments and on the action to be taken in the event of an emergency.

OPERATIONAL POLICY

Many of the difficulties arising from the failure of medical gas supplies can be avoided if operational protocols are in place before emergencies arise. It is recommended that an operational policy should be prepared. This should be based on a fully documented compliance survey in which the MGPS is examined in the light of current requirements.

Deficiencies are highlighted and become the subject of risk assessments; current risks are analysed and solutions recommended along with re-assessed risk levels. Each risk is then attributed a priority level, and high-priority risks are summarised and used to develop a remedial action plan.

The operational policy is based on the system at the time of the survey. Many of the procedures it contains are aimed at minimising identified risks. Some of the risks disappear as the system is brought up to specification. For this reason the operational policy must not be seen as a "static" document; rather, it changes constantly to reflect the needs of staff managing and using the MGPS.

Responsibilities for policy preparation and updating

The Executive Manager is responsible for the operational policy, although responsibility for policy preparation and implementation is usually delegated to the Authorised Person. To ensure that the policy is regularly updated, it contains a protocol for the review process. Fundamental to this is the establishment of a medical gas committee, comprising, as a minimum, the Authorised Person, the Quality Controller and representatives from clinical and nursing specialties. Other members (for example health and safety officers) may be co-opted as necessary.

The medical gas committee should meet at least once a year to review the policy, but a

procedure for immediate updating of, for example, contact details must operate regardless of the meeting frequency. Usually, the Authorised Person chairs the meetings and reports their minutes to the CEO.

The Executive Manager is responsible for ensuring that the operational policy is properly updated. This should be carried out regularly, and the procedure for updating should be set out in the policy.

The responsibility for monitoring specific aspects is often delegated to appropriate key staff. For example, the responsibility for monitoring the implementation of the permit-to-work procedure would normally be delegated to the Estate Manager/Authorised Person. The details of such delegation should be set out in the operational policy.

Emergencies

The operational policy should set out procedures to be followed in the event of an emergency. This should include the following:

- reporting an incident
- actions to be taken (for example turning off isolation valves, using portable emergency cylinders)
- liaising with other staff and departments
- calling out contractors

All alarm systems should be clearly labelled and all staff should be trained in the appropriate actions to be taken in the event that an alarm is initiated. Staff responsible for the MGPS plant operation should be aware of the action that should be taken in an emergency and the activities necessary to ensure the continued safe operation of the MGPS. The Authorised Person in particular should take the lead to explain to users the function of the MGPS. He or

she has to be adequately trained and informed about the system. They should be similarly familiar with the purpose of AVSUs and how to use them in emergencies.

Power supply failure, changeover to emergency gas supply and reinstatement of normal gas supply may cause control systems on plant items such as compressors and manifolds to change to a default condition. When such resetting occurs, staff should ensure that, for example, manifold cylinder contents accord with the alarm signal status.

Gas quality requirements

Medical gases supplied from cylinder or liquid sources should comply with national standards. Pharmacy staff are responsible for monitoring the quality of all gases delivered. It may be appropriate to include warning systems within the pharmacy department.

Control of work

Any work involving alterations, extensions or maintenance work on the system should be subject to the permit-to-work procedure, which should be under the control of the Authorised Person.

Responsibility for gas cylinders

The responsibility for gas cylinders should be clearly defined in the operational policy. This would include the training of staff in the correct procedures for cylinder handling, storage and transportation.

Record drawings

The estates department should have accurate and up-to-date drawings of the MGPS showing main sections and branches, departments served, control valves, terminal units and alarm systems for each medical gas service. These drawings should be readily available on site for use by any Authorised Person and all Authorised Persons should know their location.

Each isolating valve should be individually identified by a unique reference number. The appropriate reference number, corresponding to the number shown on the drawings, should be displayed at or on each isolating valve. The drawing should indicate the type and make of terminal units. A schematic diagram of the installation should be provided.

When a contractor makes additions or alterations to existing installations, the Authorised Person should provide an adequate number of prints from the master drawing as agreed with the contractor. On completion of the work, the contractor should return to the Authorised Person at least one copy of an amended print, indicating pipework alterations etc. The Authorised Person should arrange for the master MGPS drawing to be updated. In some cases it may be part of the contract agreement that an amended as-fitted drawing is provided by the contractor to then replace the original master drawing.

Locking of valves and plantrooms for MGPS

All valves on the MGPS, except those in plant rooms, should be secured in such a way that they can normally be locked in the closed or open position. In the case of valves that may have to be operated in an emergency (for example AVSUs), the locking system should allow override.

Medical gas plant rooms should be kept locked, except when work is in progress in them, with a prominently displayed notice indicating the location of the spare key. The valves in the liquid oxygen installation need not be locked away. The gate to the liquid oxygen installation should be locked, and an indestructible and clear notice stating the location of the key should be securely fixed to each gate. The fire brigade should be informed of the location of the key.

GENERAL SAFETY

The safety of MGPS depends on four basic principles:

- identity
- adequacy
- continuity
- quality of supply

Identity is assured by the use of non-detachable gas-specific connections throughout the pipeline system, including terminal units, connectors etc., and by adherence to the strict testing and commissioning procedures of the system.

Adequacy of supply depends on an accurate assessment of demands and the selection of a gas supply plant with capacity appropriate to the clinical/medical demands on the MGPS.

Continuity of supply is achieved by the specification of systems that have primary, secondary and tertiary means of supply. Alarm systems are provided to ensure that staff are aware of the status of the medical gas systems; additionally, medical gas systems are connected to the emergency power supply system.

Quality of supply is achieved by:

- the use of gases purchased to the appropriate national requirements, or produced by plants performing to specified standards;
- the maintenance of a clean system throughout the installation; and
- the implementation of various testing and commissioning procedures.

Modifications

Special precautions are required when existing installations are modified or extended, in

order to ensure that the supply to patients is not compromised or that any section of the pipeline system that remains in use is not contaminated. The section to be modified should be physically isolated from the section in use.

The modification of existing systems may be detrimental to the overall performance of the system. In the case of older systems, there may be insufficient capacity to permit the flows encountered today. Before contemplating the extension of an existing system, an assessment should be made of the existing system to ascertain whether it has sufficient capacity to support the proposed additional flows that will result from the changes.

SAFETY STATEMENT FOR USERS OF OXYGEN EQUIPMENT

In the liquid state, oxygen is pale blue with a boiling point of –183℃ at atmospheric pressure. In the gaseous state, oxygen is colourless, odourless, tasteless, non-toxic, non-irritant and non-flammable. It will, however, strongly support combustion, and is highly dangerous when in contact with oils, greases, tar-like substances and many plastics.

When oxygen therapy equipment is in use, fire and safety warning signs/labels should be conspicuously displayed at the site of administration to alert the patient, healthcare staff and visitors that oxygen is being used and that appropriate precautions need to be taken. When oxygen is being administered in paediatric departments, the text should include the precaution: “Only toys approved by the hospital fire officer may be given to the child.” Putting up similar signs in other languages should be considered.

All users of oxygen and associated equipment should know and understand the properties of oxygen and should be trained in the use of the equipment. This applies to all hospital staff.

Health hazards associated with liquid oxygen

Cold burns and frostbite. Localised pain usually gives a warning of freezing, but sometimes no pain is felt or it is short-lived. Frozen tissues are painless and appear waxy, with a pale yellowish colour. When the frozen tissue thaws, it can result in intense pain, with associated shock. Loosen any clothing that may restrict blood circulation and seek immediate hospital attention for all but the most superficial injuries. Do not apply direct heat to the affected part, but if possible place the affected part in lukewarm water. Sterile, dry dressings should be used to protect damaged tissues from infection or further injury. However, dressings should not restrict the blood circulation. Alcohol and cigarettes should not be given to the patient.

The effect of cold on lungs. Prolonged breathing of extremely cold atmospheres may

damage the lung tissue.

Hypothermia. A risk of hypothermia arises when liquefied atmospheric gases are released. All persons at risk should be warmly clad. Hypothermia is possible in any environment below –10℃. Susceptibility depends on the length of expo sure, the atmospheric temperature and the individual; older people are more likely to be affected.

The formation of mist. When liquefied gases are released and evaporation takes place, a white mist is formed by the condensation of moisture in the atmosphere. The mist formation may introduce potential hazards because of poor visibility. In the event of mist forming, extreme caution should be exercised when evacuating the area.

Material compatibility. Gaseous oxygen vigorously supports the combustion of many materials that do not normally burn in air, and is highly dangerous when in contact with oils, greases, tarry substances and many plastics. Only materials approved for oxygen service may be used.

Fire precautions

The general guidance on fire precautions provided in 'Firecode' should be followed. Guidance is also available from the gas supplier; any specific recommendations should be followed.

Fire can occur when the following three conditions are present:

- flammable materials
- oxidising atmosphere
- ignition

Flammable materials should not be present in cylinder stores, manifold rooms or liquid

oxygen compounds. It may not, however, be possible to avoid the presence of flammable materials in the vicinity of the patient when medical gases are being used.

An oxygen-enriched atmosphere may be present when medical oxygen or nitrous oxide/oxygen mixtures are used. Nitrous oxide also supports combustion. Further guidance should be obtained from the fire prevention officer, the fire safety officer and the local fire brigade.

MAINTENANCE

An MGPS should be subjected to a planned preventive maintenance (PPM) schedule, which should be the responsibility of the Authorised Person, irrespective of whether or not a full preventive maintenance scheme has been implemented for the hospital as a whole. All work on an MGPS, irrespective of whether the medical gas supply is or is likely to be interrupted, should only be carried out under the instructions of and with the permission of the Authorised Person.

All work on the MGPS should be subject to the permit-to-work system and approved by the Authorised Person before the contractor leaves the site. Maintenance work on an MGPS should only be carried out by specialist registered contractors.

Patient safety is paramount when carrying out any work on the MGPS and should be given priority over cost, even though contracts are managed to be as cost-effective as possible.

Emergency call-out procedures

In addition to the planned maintenance tasks as specified in the contract, the contractor should provide an efficient call-out service in the event of a breakdown or another incident between planned maintenance visits.

The call-out service should be available 24 hours per day, all year round.

For emergencies where the supply has been, or will likely be, interrupted or where patient safety is affected, the contractor should attend the site within a maximum time from receipt of the initial call as specified in the maintenance contract by the hospital. The geographical location of the hospital, contact number for the hospital's Authorised and Competent Persons and the availability of technical guidance are all considerations when defining the emergency response time. For normal circumstances, a response time of two hours is recommended.

Daily – general tasks
Check all alarm panels, manifolds and plant visual indicators for correct function, absent displays or damage.
If any manifold is observed to be in operation on its "emergency reserve" bank, replacements for the empty cylinders should be made available immediately.
Check all plant and manifold pressure gauges for abnormal conditions.
Check all plant and manifolds for unusual noises, signs of overheating, vibration etc.
Check plant oil levels.
Weekly – general tasks
Safety notices – check that appropriate notices are clearly displayed in all plantrooms and cylinder stores.
"No smoking" notices – check that they are clearly displayed.
Discharge points/vents/vacuum/AGS – check that warning notices are clearly displayed.
Check that motor guards are in position and in good repair.
Notices warning of automatic start/stop – check that they are in position and legible.
Check that plantrooms are free from combustible material and with adequate access for maintenance.
Check that all cylinders are properly stored/secured and all batch labels are correct and in date.
Specific daily tasks for VIE plant
Check and record the vessel pressure and contents.
Check and record the pressure of the pipeline.
Check and record the pressures of the cylinders on the secondary manifold (should be above 68/100 bar – full cylinders will read 137/200 bar, depending on the type of manifold). If the pressure of either bank is below 68/100 bar and no "reserve low" alarm is indicated, inform the Authorised Person (MGPS).
Ensure that the compound is secured when leaving and that lights have been turned off.
Specific weekly tasks for VIE plant
a. Check mechanical joints for obvious signs of leaks.
b. Check for mechanical damage.
c. Check that the vessel(s) is (are) operating at normal working pressures, and record these.
d. Check that the plant output (pipeline) pressure is at normal, and record this.
e. Where a compressed gas cylinder manifold is used as a secondary supply, check that the cylinder pressures are above 50% of "full" pressure and record the actual pressures.
f. Record content level(s) of vessel(s).
g. Ensure that there is no build-up of rubbish/flammable material within the vessel compound.
h. Report all faults to the Authorised Person (MGPS)/gas supplier as necessary.
Where staff are available, (c) (d), (e) and (f) should be carried out on a daily basis.

Table 11: Example of maintenance task list

PREPAIRING AN OPERATIONAL POLICY

Signatories

It is essential that the operational policy is acceptable to the Executive Manager, and he/she should signify this on the policy document. Other signatories that are required are staff involved in the preparation of the policy, or at least members of the medical gas committee.

Circulation

The medical gas committee should agree to the circulation of the operational policy. Circulation depends to a certain extent on the content of the document, and some thought should be given to how the document relates to the work of specific staff specialties; for example, separate sections could be included for nursing and portering staff but separately issued to these disciplines.

Site plans

A small (A3/A4 paper size) site plan should be drawn up, showing the location of VIE, plant rooms, cylinder stores, main buildings, roads etc. No details of pipework need be shown, as the plan only facilitates actions in the event of an emergency. Relevant pipework drawings can be referenced on the operational plan but need not be included in the policy, as this will lead to a very bulky document.

Other guidance

There is little point in the MGPS policy reiterating guidance issued by other departments or staff (for example fire practice). However, where appropriate, this documentation should be referenced accordingly and any relevant contacts listed. Many policies fail to achieve operational usefulness simply because basic information, such as names and telephone numbers, is not updated.

It is important to keep lists of staff/telephone numbers up to date and, preferably, together in one easily accessible section of the policy (for example as a separate appendix).

Emergencies

This is probably the most important section of the operational policy, and it is crucial that information here is accurate, clear, concise, up to date and, above all, written with safety in mind. It will help if this section is immediately accessible and identifiable, for example by colour-coding it and referring to it on or inside the front cover of the policy. This section should be compulsory reading for all staff working with the MGPS.

Description of the MGPS

This is usually for Estates Department use. Very detailed information on the MGPS can be included in a master copy of the operations policy. However, in an emergency such data is often of little use, and the bulk of the document only contributes towards a reluctance to use it.

Details such as equipment lists, for example terminal unit types, locations and numbers, are best kept separately in an equipment schedule, allowing the policy to be a smaller, easily accessible publication. For the main policy document, each of the major system components (that is, manifolds, compressors etc.) needs to be treated in separate sections under the following headings:

- Security
- Communications/documentation
- Emergency actions
- Routine operations
- Location
- Safety

- Staff/responsibilities

The following checklist is offered as a prompt for typical operations policy inclusions, and should not be considered definitive or exhaustive:

- key control procedures (routine and emergency)
- actions in the event of an alarm
- posting of safety instructions/notices
- use of personal protective equipment
- procedures for ensuring continuity of supply
- manifolds/cylinder ordering/stock control/VIE filling and monitoring etc.
- general fault reporting procedures, including cylinder defect reporting
- manifold room practice/procedures
- policy statement for use of lasers/surgical diathermy with dedicated vacuum systems
- permit-to-work system/variations/responsibilities etc.
- MGPS testing procedures/responsibilities
- cylinder supply and control procedures
- responsibility statements for record-keeping (drawings/maintenance logs/modifications)
- references to other safety policies, for example fire
- policy statement for users of oxygen equipment (approved toys, cosmetics, substances etc., and the associated fire risk)
- statements detailing consultancy arrangements with the Authorised Person before purchase/connection of medical equipment for/to the MGPS (especially CPAP units)
- statements related to the use of contractors
- lists of staff and arrangements for departmental cover in the event of absence
- statements for users giving awareness of capacity/limitations of the MGPS
- locations of special gas connectors, emergency regulators, hoses, brazing equipment

etc.

- normal and emergency procedures for the interruption of a gas supply

Emergency actions

Actions in the event of MGPS emergencies should be summarised. The final number of defined emergencies would vary according to each system, but as a minimum should include:

- major gas leaks
- interruption of the gas supply
- electricity failure
- low/high gas pressure
- pollution of the gas supply
- fire

The following should also be given consideration:

- location and type of emergency supplies
- responsibility for maintaining and providing emergency supplies
- training of staff in the use of emergency equipment
- training of staff in equipment failure procedures

Communication channels in the event of an emergency:

- Fire officer/brigade
- Estates Department
- Pharmacy
- Portering staff
- Administration/press officer
- Nursing/clinical

A SAMPLE OPERATIONAL POLICY:

Preparation date .....

Review date .....

Issue no .....

This copy no .....

Hospital publication reference no .....

This copy belongs to .....

Distribution list

Contents

[To be completed on completion of body of document.]

GENERAL POLICY STATEMENTS

This policy addresses the provision of a piped medical gas pipeline system (MGPS) in *[name of site]*. The MGPS provides a safe, convenient and cost-effective supply of medical gases to points where these gases can be used by clinical and nursing staff for patient care. *[Premises]* management recognises its commitment to maintaining the MGPS to required standards and the training of all staff associated with its operation.

SCOPE OF POLICY

This policy is intended for use by all staff involved with the MGPS in *[name of site]*.

It applies throughout the *[premises]* to all fixed MGPS and *[list of MGPS plant and areas, for example dental, where MGPS may be installed]*.

MGPS terminal units define the limits of the Estates Department *[or other organisation]* responsibility in this policy. Equipment connected to the terminal units is not covered by this policy other than where its mode of use may affect system operation or safety.

Medical equipment is the responsibility of the *[name of department/organisation]*.

Medical gases should not be used for non-medical purposes other than as test gas for medical equipment.

Medical air should be used as the power source for ventilators; the routine use of oxygen as a driving gas should be avoided.

MGPS management responsibility for *[premises]* resides with the *[usually Estates]* department. It is *[premises]* policy that, before work on the MGPS can commence, a permit-to-work form signed by an Authorised Person must be completed.

RESPONSIBILITIES

Chief executive *[or general manager]*

Ultimate management responsibility for the MGPS rests with the *[premises]*'s chief executive *[or general manager]*. The chief executive *[name. . .]* delegates the written appointment of Authorised Persons to *[name]*. *[Mr name of chief executive]* delegates day-to-day management responsibility for the MGPS to *[name – usually Senior Authorised Person]*.

Authorising Engineer

The duties and responsibilities of the Authorising Engineer are to:

- recommend to the *[usually estates]* manager those persons who, through individual assessment, are suitable to be Authorised Persons
- ensure that all Authorised Persons have satisfactorily completed an appropriate training course
- ensure that all Authorised Persons are re-assessed every three years and attended a refresher or other training course before such re-assessment
- review the management systems of the MGPS, including the permit-to-work system

- monitor the implementation of the operational policy and procedures.

Authorised Person

[Number] Authorised Person(s) are required for *[premises]* and will be based in *[premises]*. The Authorised Persons assume effective responsibility for the day-to-day management and maintenance of the MGPS. The duties and responsibilities of Authorised Persons are to:

- ensure that the MGPS is operated safely and efficiently in accordance with the statutory requirements and guidelines
- manage the permit-to-work system, including the issue of permits to Competent Persons for all servicing, repair, alteration and extension work carried out on the existing MGPS
- supervise the work carried out by Competent Persons and monitor the standard of that work (a register of Competent Persons must be kept)
- ensure that the *[premises]* MGPS maintenance specification and schedule of equipment (including all plant, manifolds, pipework, valves, terminal units and alarm systems) are kept up to date
- liaise closely with Designated Nursing/Medical Officers, the Quality Controller and others who need to be informed of any interruption or testing of the MGPS
- provide technical advice to those responsible for the purchase of any medical equipment that will be connected to the MGPS in order to avoid insufficient capacity and inadequate flow rates
- in accordance with the *[premises]* policy on provision of services, provide advice on the provision and/or replacement of MGPS central plant and associated systems (the *[name]* department holds overall responsibility for the provision and maintenance of MGPS services within the *[premises]*)
- organise such training of *[estates]* staff (and other staff if requested) and/or transfer MGPS information as is needed for the efficient and safe operation of the MGPS.

Competent Person

All Competent Persons are craft persons, employed by *[employer]*. The duties and responsibilities of Competent Persons are to:

- carry out work on the MGPS in accordance with the *[premises]*'s maintenance specification
- carry out repair, alteration or extension work as directed by an Authorised Person in accordance with the permit-to-work system and the National Health Technical Memorandum
- perform engineering tests appropriate to all work carried out and inform the Authorised Person of all test results
- carry out all work in accordance with the *[premises]* health and safety policy

Quality Controller

It is the responsibility of the *[name]* to appoint, in writing, on the recommendation of the chief pharmacist, a quality control pharmacist with MGPS responsibilities. The Authorised Person will be responsible for liaising with the Quality Controller and organising attendance as required. The duties and responsibilities of the Quality Controller are to:

- assume responsibility for the quality control of the medical gases at the terminal units (that is the wall or pendant medical gas outlets)
- liaise with the Authorised Person in carrying out specific quality and identity tests on the MGPS in accordance with the permit-to-work system and relevant national standards
- organise MGPS training of pharmacy staff who may deputise for the Quality Controller

The Quality Controller should receive training on the verification and validation of MGPS and be familiar with the requirements of this MGPS operational policy. The pharmacy department at the *[premises]* must:

- receive delivery notes for compressed gas cylinders, check them against invoices received and pass invoices for payment
- order and supply (via *[name of department, for example portering]*) cylinders of medical gases and special gas mixtures for the following areas: *[Define wards and departments.] [Define manifolds, as others may have responsibility for cylinder supply to specific units.]*
- maintain a record of cylinder rental charges and pass rental invoices for payment
- ensure that cylinder gases comply with national requirements
- ensure that other gases and gas mixtures comply with manufacturers' product licences

Designated Medical Officer (DMO) and/or Designated Nursing Officer (DNO)

[A major decision is required here. Does the responsibility for granting permission for all levels of hazardous work lie solely with the nursing staff or a combination of medical and nursing staff, that is the DMO or DNO? If the DNO is selected, a statement such as the following should be included: "It is the policy of the [premises] that all MGPS work in wards and departments carried out under the MGPS permit-to-work system is controlled by the nursing staff. The term Designated Medical Officer or its abbreviation may not be used." If both the DMO and the DNO positions are considered necessary, the duties and responsibilities of both should be defined below.]

The duties and responsibilities of the DMO/DNO are to:

[This section should contain information on:

- *who the defined person is and a statement of their responsibility to liaise with the*

Authorised Person

- *the scope of responsibility for giving permission to interrupt supplies*
- *any requirement to employ a nurse manager/senior medical officer for high hazard work or work involving more than one department*
- *restrictions on working hours and arrangement for out-of-hours cover*
- *responsibilities during emergency situations*
- *training arrangements.]*

Designated Porter

A Designated Porter is a *[usually a porter but may be different in the private sector]* with particular responsibilities for medical gases. He/she would have undergone specialist training in the identification and safe handling and storage of medical gas cylinders, including relevant training in manual handling. Designated Porters in the *[premises]* undertake the following duties:

- assist with the delivery of gas cylinders by *[gas supplier]*
- deliver full gas cylinders from the *[usually cylinder stores]* (as appropriate) to *[areas]* and return empty cylinders to *[cylinder store]*
- transfer gas delivery notes from the delivery driver to the *[usually pharmacy]*
- attach to and remove from cylinders, medical equipment regulators (or regulator/flow meter combinations) and manifold tail-pipes
- identify, and remove from service, faulty (e.g. leaking) cylinders and subsequently notify *[usually pharmacy]* of the location of such cylinders
- perform a weekly check on cylinder stocks and report any deficiencies to *[usually pharmacy]*;
- ensure that all cylinder contents are used within the three-year fill/refill time scale specified by the gas supplier.

The Designated Porter must work safely at all times, using the appropriate personal protective and manual handling equipment, damage to which must be reported immediately to *[name]*.

Medical gas committee

A medical gas committee shall consist of the Senior Authorised Person, the *[premises]* matron (or a nominated *DNO/DMO),* the portering manager, the Quality Controller *[etc]*.

MGPS operational policy review

The MGPS operational policy should be reviewed *[frequency]*; the Authorised Person *[or other nominated chair]* shall convene the review meeting and be responsible for writing and distributing the minutes of the meeting. The committee shall report to the chief executive/general manager.

MGPS record drawings and documentation

The Authorised Person must maintain copies of the following *[delete/add as applicable]*:

- up-to-date and accurate as-fitted record drawings (including valve/key numbers/TU identification) for all MGPS
- any necessary MGPS insurance/statutory documentation
- MGPS safety valve replacement schedule (on a five-yearly basis)
- new and completed permit-to-work books for work on the MGPS
- plant history/maintenance records
- manufacturer's technical data sheets/manuals for all MGPS components
- National Health Technical Memorandum, all latest editions of any associated supplements and National Engineering Specifications
- MGPS contractors' service contracts certificates, staff training records, equipment

calibration certificates (copies)

- a list of all staff associated with the MGPS, especially the permit-to-work system
- emergency and other useful telephone numbers
- MGPS staff training records
- calibration certificates of *[premises]*-held test equipment
- the MGPS operational policy.

Pharmacy will maintain copies of the following *[delete/add as applicable]*:

- delivery notes for medical gas cylinders
- sales invoices for medical gas cylinders
- delivery summary form (tracks cylinder stock information)
- cylinder rental invoices
- cylinder rental reconciliation form (monitors trends in cylinder use over six months)
- delivery notes for special gas and industrial gas cylinders
- sales invoices for special gas and industrial gas cylinders
- rental invoices for special gas and industrial gas cylinders
- calibration records of Quality Control (QC) test equipment and records of all QC tests performed.

Training

It is essential for the safety of patients that no person should operate, or work on, any part of an MGPS unless adequately trained or supervised. MGPS training at the *[premises]* for all *[usually estates]* staff is administered by *[name/department]*. A record of those trained is kept in the *[department]*. It is the duty of departmental managers to ensure that all staff working with the MGPS are appropriately trained.

The Authorised Person may request training records of contractors' staff. Training on MGPS

will be provided as follows: *[Insert a table showing various grades of staff, who is to provide training, and how often the training is provided. This includes refresher training.]*

The MGPS structure

[This section should be devoted to a short description of the plant and other components of the MGPS. It is usual to include cylinder management in this section. Each item is presented in terms of a description of the plant/component/system, its location, emergency reserve provision, access arrangements (including key control) and safety and signage requirements.]

Cylinder storage

[Each storage area (main, ready-to-use etc.) must be addressed separately in terms of location, access and emergency use. General information common to all store types, for example signage and storage conditions, can be added to this section.

Area valve service units

Summary

Locked boxes containing isolating valves in enclosures with breakable glass fronts called area valve service units (AVSUs), are provided at the entrances to wards and departments. AVSUs provide facilities for both routine and emergency isolation of gas supplies. They contain an emergency inlet port, which is gas-specific. This may be used to supply gas to a ward when the main supply fails or is shut down for essential engineering work.

General rules and conditions for control of line valve assemblies

Pipeline valves, called line valve assemblies (LVAs), in ducts, risers, ceiling spaces etc shall be locked in the normal operating position. Pipeline valves will normally be left unlocked if they are sited in a locked plantroom. *[Usually Estates]* holds keys for these valves.

Access

Under normal events, only the Authorised Persons using the appropriate key from the *[usually Estates']* medical gases key cabinet should access AVSUs and any other locked LVAs under control of a permit-to-work. The key cabinet contains a list identifying all AVSUs and locked LVAs with corresponding key numbers.

Key-holders

[List all of them in an annexure.] In the event of an emergency, access to the AVSUs may be gained by smashing the breakable glass fronts. **A member of the nursing staff must perform this action after steps have been taken to ensure that no patient is compromised by the isolation of the gas supply.**

ROUTINE PROCEDURES

The MGPS permit-to-work system

The aim of the MGPS permit-to-work system is to safeguard the integrity of the MGPS and, therefore, the safety of patients. It is the policy of *[hospital/premises/organisation]* that – with the knowledge and permission of the Authorised Person – a permit must be raised before any work (except the changing of manifold cylinders *[add VIE refilling, QC testing of medical/surgical air etc here if relevant]* or emergency isolation by a member of the nursing staff) can be undertaken on any part of the *[premises]* medical gas system.

Granting of a permit-to-work and the way in which the work is carried out must follow the directions of national regulations unless otherwise defined in this policy. Responsibility for signing a permit-to-work lies with the DMO/DNO in each department. The DMO/DNO should ensure that colleagues are advised of the interruption to the gas supply and its estimated duration and, via *[usually Estates]*. that all affected terminal units are appropriately labelled.

Planned interruption

A planned interruption is needed to repair, extend or modify the existing MGPS. An Authorised Person shall supervise any planned interruption in strict adherence to the permit-to-work system in the national Health Technical Memorandum. The Quality Controller shall be involved in any planned interruption from the planning stage.

The Authorised Person shall assess the hazard level of the work to be carried out in accordance with the definitions that are provided in the following sections.

High hazard work

Any work on the MGPS, such as cutting or brazing, that introduces hazards of cross-connection and pollution is classified as high hazard. Cross-connection, performance,

identity and quality tests shall be required before the MGPS is again taken into use. High hazard work might require, at the least, a planned interruption to a single ward or department or, at worst, a major shut-down of an MGPS as a whole at *[premises]*.

In such an event, the Authorised Person must ensure that key staff for each ward or department are informed; if necessary, he/she could call a site meeting. The Quality Controller should be included in discussions that may lead to an interruption of the MGPS.

Two weeks before the planned interruption, the Authorised Person shall liaise in person with the *DMO(s)/DNO(s)* of the ward(s) or department(s) concerned. The *DMO(s)/DNO(s)* of the ward(s) or department(s) involved should be made aware that their signatures are required on the date on which the work is due to take place. The requirement for portable cylinders or vacuum units is determined and confirmed, with details of the interruption, by a memorandum from *[usually Estates]* to the *DMO(s)/DNO(s).* .

A copy of this memorandum is sent to the ward(s) or department(s) concerned. A further memorandum, requesting the services of a Quality Controller and detailing the requirements for portable cylinders, shall be sent to the pharmacy department *[or other QC organisation]*.

It is the responsibility of the Authorised Person to arrange, through the portering and pharmacy departments or an appropriate hire firm if necessary *[delete as applicable]*, for portable cylinders and regulators (stocks of regulators are held by *[department]*).

The Authorised Person must provide all details of the work to be carried out. Work shall only commence when the senior duty nurse(s)/DMO(s) for the ward(s) or department(s) is (are) satisfied that no patients will be put at risk by the shut-down of the MGPS and has (have) signed the permit- to-work form.

The Authorised Person supervises the isolation of the AVSU(s) by the Competent Person after: confirming isolation details by consultation with the Competent Person; and examining the sketch on the permit and any additional drawings (if available).

Once the system(s) has(have) been isolated and depressurised, the Competent Person must sign the permit-to-work form, and then work may commence. The Competent Person must sign the permit to certify that work has been completed and contact the Authorised Person so that the installation may be examined and tested.

Depending on the extent of high hazard work, the Authorised Person must determine and carry out, with the assistance of the Competent Person, the necessary tests and examination of the system(s) in accordance with national standards and regulations. When the tests have been completed satisfactorily, the Authorised Person must initial the relevant spaces and sign the permit.

The Quality Controller, with the assistance of the Authorised Person, must carry out identity and quality tests on the system(s). When the tests have been completed with satisfactory results, both must sign the permit. Unsatisfactory results may lead to the cancellation of the permit.

Low hazard work

Any work on the MGPS which does not introduce any hazard of cross-connection or pollution is classified as low hazard work. A performance test is required before the MGPS is again taken into use.

If there is any doubt as to the hazard level classification of a permit-to-work, advice should be sought from the Senior Authorised Person. Low hazard work on terminal units is normally the result of a leak on anterminal unit due to a faulty valve or seal, but may also include work

on the plant that does not interrupt gas supply.

This type of work is usually carried out at short notice because of the need for minimum disruption to patient care. The Authorised Person may have to arrange a portable cylinder or vacuum unit so that the terminal unit can be taken out of service.

The Authorised Person liaises with, and fully brief, the senior DNO/DMO of the ward/department and provides all the detail of the work to be carried out. The Competent Person, with the assistance of the Authorised Person, if necessary, carries out flow, pressure drop, mechanical function and gas-specificity tests on the serviced terminal unit(s).

Actions in the event of a medical gas alarm

[One proven method of approaching this topic is to actually include a simple sketch of the relevant alarm display, adding text to describe the actions appropriate to each indication.]

The diagrams below show the actions that should be taken at each level of alarm. On detection of a local alarm indication, for example in a ward area, the senior duty nurse *[or other nominated person]* should contact the switchboard to confirm that a fault has been signalled and that *[usually Estates]* has been informed. In the event of an alarm condition on the central alarm panel, it is the responsibility of the duty telephonist *[or other nominated person]* to inform the appropriate staff as shown in example below.

Alarm indication	Action (telephonist to inform)
Normal	No action to be taken
Plant fault	NWH – Estates ONWH – Estates (on-call rota)
Plant emergency	NWH – Estates ONWH – Estates (on-call rota)
Reserve low	NWH – Porters ONWH – Porters
Pressure fault	NWH – Estates ONWH – Estates (on-call rota)
Panel indication (all alarm panels)	
Alarm indication	**Action (telephonist to inform)**
Power on	No action to be taken
System fault	NWH – Estates ONWH – Estates (on-call rota)
Abbreviations: NWH = Normal working hours ONWH = Outside normal working hours	

Table 12: Actions in the event of a medical gas alarm

Disabling the alarm system, other than upon due authorisation by an Authorised Person, is absolutely forbidden, as it may compromise patient safety. There should always be a "normal" light displayed on the alarm panel. If the "normal" light is not on, there is a fault of some kind, possibly only with the alarm panel. However, *[usually Estates]* should investigate this fault. Alarms should be tested weekly by a Competent Person *[or other nominated person]*. The successful operation of the test button confirms all audible/visual indicators are in working order. Nursing/medical staff should be advised of this test.

Cylinder management

[The topic should cover the preparation of cylinders for use, cylinder storage, handling and transport, cylinder switching on manifolds and medical equipment, special instructions for manual emergency reserve manifolds (for example leaving one cylinder valve open and one closed), the delivery of gases to wards, stores etc, delivery of liquid oxygen.

Reference should be made to training in manual handling of cylinders and include a statement that only Designated Porters are allowed to work with cylinders.

Restrictions on the work of the Designated Porters, if any, should be inserted here. An example would be that only estates staff are allowed to change oxygen cylinders within a cryogenic liquid storage system compound.]

Shut-down of the MGPS for maintenance, extension etc.

Pre-planned work on the MGPS requiring the isolation of a plant, or part of the system, is covered by the MGPS permit-to-work system. No isolation should take place without full liaison between the Authorised Person and all other disciplines.

All necessary emergency/additional gas supplies should be in place before the work starts. This may involve the provision of portable emergency supply systems and/or the additional provision of cylinder regulators from *[usually Estates]*. Minimal gas should be consumed for the duration of the work.

EMERGENCY PROCEDURES

Use of emergency reserve manifolds

[The sample text below will probably require considerable amendment to suit particular circumstances. The title also refers to emergency reserve manifolds such as those attached to a plant.

Additional manifolds may be supporting the MGPS (for example a local manifold sited nearby) and used to supply oxygen to a critical care area in the event of a main system failure. These manifolds are referred to as emergency supply manifolds in order to distinguish them from those attached to plant and other manifolds.

It is necessary to describe the location and emergency operating procedures for all the types of manifold on the premises.]

General statement

Emergency supply manifolds are attached to all medical gas systems.

Oxygen system

In the event of failure of the primary oxygen supply, the secondary (cylinder manifold) supply automatically provides the *[premises]* with gas. The manifold supply will automatically switch to the alternative banks of cylinders as one bank runs empty, but requires cylinder replacement as a bank empties.

Important: Cylinder manifolds have limited capacity compared to the normal *[premises]* demand supplied from a VIE, so additional manpower may be required in an emergency situation, both to switch the cylinders on the manifold and to bring the replacement cylinders to the manifold. Measures to reduce gas consumption may also need to be taken.

It is the duty of *[usually portering]* to ensure that sufficient J-size cylinders are available to maintain the gas supply and that there is an emergency procedure in place for handling these cylinders.

Emergency cylinder ordering procedure

[This tends to be site-specific, hence a sample is included without further comment.]

Note: The pharmacy department routinely orders cylinder based on required stock levels and weekly use. Portering checks stocks weekly and report deficiencies to the pharmacy. For emergency ordering, the following procedure should be followed:

- Pharmacy must telephone the emergency number of the medical gas supplier
- Pharmacy must inform the medical gas supplier that “new issues” are needed, if no empties are to be returned
- Upon delivery by the medical gas supplier, the duty porter checks the delivery

against the request and sign the driver's delivery note

- The note is passed to the pharmacy

A serious leak of medical gases

- The telephonist/duty nurse must contact the duty porter and Authorised Person
- Details of the leak should be confirmed; that is the floor level, department, room number, gas or gases involved, and whether patient ventilators are in use
- If the leak is detected outside normal working hours, the on-call engineer must notify the Authorised Person
- The duty nurse must isolate the medical gases to the area(s) after ascertaining that no patients will be put at risk
- The duty nurse must issue appropriate instructions to make the situation safe, such as to open windows in the affected area(s) and close doors, in accordance with the *[premises]* fire policy
- The duty porter must remain on stand by to provide extra gas cylinders as required
- The Authorised Person must arrange for repairs to the affected system(s) under the permit-to-work system

Total or partial failure of a medical gas supply

- The person discovering the failure must inform the telephonist and duty nurse immediately
- The telephonist must inform the senior duty manager, the duty porter and the duty Authorised Person of the leak
- Details of the failure should be confirmed; that is the floor level, department, room number(s), gas or gases involved, and whether patient ventilators are in use
- As a precautionary measure, the telephonist must also notify critical care areas that a failure has occurred on part of the system so that they can prepare for evacuation in

the event of the fault extending to their departments

- The duty nurse must check which patients may have been put at risk by the failure and, if necessary, arrange immediate emergency medical action
- Depending on the reason for the failure and its possible duration, the Authorised Person must decide the most appropriate method of long-term emergency gas provision. This may involve establishing locally regulated cylinder supplies at ward/department entrances
- Nursing and medical staff should reduce gas consumption to a minimum during the emergency
- Portering staff must monitor/replenish cylinders at emergency stations and at the plant room emergency supply manifolds
- The pharmacy must arrange emergency cylinder deliveries
- The Authorised Person must liaise with the Competent Person to complete emergency repairs to reinstate the gas supply, using the permit-to-work system
- When the supply is fully restored, the Authorised Person must complete a critical incident form and produce a full report, which must be given to the *[usually chief executive/general manager]* within 24 hours of the incident.

In situations where the long-term loss of oxygen or medical air service is identified, the duty senior manager must liaise with clinical colleagues, including the senior nurse manager, the medical director and the Authorised Person on the need to transfer critically ill patients to *[premises]*, as department closure may be warranted in extreme events.

Contamination of a medical gas supply

It is not unusual for a smell to be noticed when using “plastic” equipment hoses to deliver gas to a patient. This smell usually disappears rapidly after first use of the hose, and will generally be familiar to operatives.

However, if either an operative or a patient complains of an unusual or strong smell from equipment, the situation must be treated as serious and immediate action must taken to ascertain the cause.

Where it is obvious that the smell is coming from the gas pipeline rather than a piece of connected equipment, the gas supply must not be used. In such an event, the fault should be treated as a complete gas failure to the area concerned and the actions described above must taken immediately.

It is very important that, when such an incident occurs, the telephonist shall advise all departments of the problem, especially critical care areas.

Over- or underpressurisation of one or more gas systems

Local alarms are designed to indicate when system pressure(s) is/are outside the normal operating range. Excessively high or low pressures may cause medical equipment to malfunction. The duty nurse should report all instances of local alarms to the telephonist.

Fire

Procedures in accordance with the *[premises]* fire policy should be followed in the event of a fire involving, or likely to involve, the MGPS. During a fire, the senior brigade officer assumes full control of the area(s) affected.

Under no circumstances should medical gas supplies be isolated until the DNO has confirmed that all patients likely to be affected have been evacuated and/or have been supplied with alternative gas sources.

VIE INSTALLATIONS

There are specific duties associated with the management of cryogenic oxygen supplies. These are summarised below (it is not an exhaustive list).

- Liaising with the gas supplier to ensure the most cost-effective solution to the hospital's oxygen supply requirements. This involves the Authorised Person, the hospital's risk manager, the chief pharmacist (or Quality Controller representative), an appropriate clinical representative, and a representative of the potential medical gas supplier in the risk assessment process detailed in this guidance. Consideration need to be given to items such as the siting of the installation, the environmental impact of vehicular deliveries, the provision of high power electricity supplies to the compound (if required by the gas supplier), compound lighting and safety, and roadway modifications that may be required if larger delivery vehicles are to be used.
- Following the risk assessment protocols in this guidance closely, including considerations relevant to a particular site that are not mentioned here.
- Assimilating telemetric data and responding to abnormal levels of liquid consumption, vessel pressure etc.
- Assigning responsibility for agreeing the final location of the liquid oxygen compound(s), taking into consideration issues raised in the initial risk assessment. This involves confirming compliance with the relevant health and safety issues, and agreeing (in writing) with the hospital's health and safety officer and the gas supplier's safety representative any relaxation of the requirements (for example safe separation distances). The hospital and the medical gas supplier must ensure that they achieve a commensurate level of safety, which must be approved and documented.
- Providing technical information and training to staff who may be involved with the installation and who have not already been trained by the gas supplier in the safe

operation of the plant.

- Providing advice to hospital management on the operational consequences of using different suppliers for the different supply systems on the same pipeline system. Contracts involving different suppliers should clearly state each party's obligations and limitations of liabilities. There may also be consequences for management in situations where one VIE system supplies more than one hospital. In particular, the management responsibilities of Authorised Persons for each site and its insurance implications require clarification. The gas supplier must provide a clear description of its insurance liability for the supply equipment, and each hospital must define liability in the event of an incident arising from gas supply failure or contamination.
- Responding safely to emergency conditions on plant or pipeline systems, such as avoiding undue or inadvertent interruption to supplies, product wastage, or dangerous situations.
- Clearly displaying a piping and instrumentation diagram of the plant indicate the appropriate valves to operate the plant safely.
- Ensuring that the VIE compound(s)/manifold room(s) remain(s) locked, unless maintenance is performed or product is delivered. Key or lock combinations should be made available to appropriate staff for maintenance and routine or emergency product deliveries, even outside office hours. The key control system should be documented in the MGPS operational policy.
- Ensuring that, in addition to the routine maintenance and testing performed by the gas supplier, basic maintenance is carried out and recorded.

9. ADDENDUM C[24]

Gas Type	Contents (kg)	Valve Type	New SAP Item Number	Contents (L gas @ 1 atm. & 20°C)	Cylinder Height (mm)	Cylinder Diameter (mm)	Cylinder Material	Item Number
Medical Oxygen 	0,25	PI	P101-AD-P125	187	262	90	Aluminium	W340411
	0,47	PI	101-CB-P1	352	415	100	Steel	W340279
		BN	101-CB	352	415	100	Steel	W340280
	0,49	PI	P101-BD-P1	367	405	102	Aluminium	W340413
	0,64	IVR	101-BF	480	400	100	Fibre Wrap	W342131
	0,94	BN	101-EB	705	755	100	Steel	W340281
		PI	101-EB-P1	705	755	100	Steel	W340282
	1,40	IVR	101-FE-IVR	1 050	880	100	Steel	W342123
	1,84	BN	101-HB	1 380	770	140	Steel	W340283
		PI	101-HB-P1	1 380	770	140	Steel	W340284
		P1 (Homecare)	101-HH-P1	1 380	470	176	Steel	W340679
	4,60	BN	101-KB	3 450	1 197	176	Steel	W340288
		PI	101-KB-P1	3 450	1 197	176	Steel	W340290
	10,20	BN	101-RC	7 650	1 422	230	Steel	W340286

Table 13: Medical oxygen cylinders available from Afrox