Report of the LPG Independent Expert Working Group

Executive Summary

This is the report of an independent Working Group (WG) established by HSE in May 2011 to advise on the prioritisation and timescale for resolution of potential corrosion problems with underground LPG vapour-carrying pipework installed at industrial and commercial premises. The remit of the WG was limited to reviewing progress with the resolution of such pipework issues and making recommendations concerning the time scales for any future steps while considering the levels of risk present in a wider context as part of normal business operations.

Following Lord Gill's report into the accident at the ICL Plastics Ltd factory in 2004, the government accepted Lord Gill's recommendation that underground metallic pipework should be replaced. HSE and the LPG supply industry then worked together during 2009 to commission a survey of commercial and industrial users of LPG. The information obtained was used in a computer model to prioritise pipework based on the risk of gas ingress into a building as a result of corrosion failure of the metallic service at a particular installation. From the available information, about 4,000 premises out of a total of 18,000 were deemed to be higher priority. The higher risk premises were further divided into three categories (A-C) and the owners were advised that at-risk pipework should be replaced (or that other appropriate risk reduction action resulting in a resolution, see examples below, should be taken) by the end of 2013. Owners of the remainder of the 18,000 premises, categorised as D-E, were advised that they should do likewise by the end of 2015.

To date over 1,000 of the around 4,000 higher priority (A-C) premises have been resolved either through replacement of underground metallic pipework, or through improved information which established that replacement was not necessary in the 2013 timeframe. The rate of resolution of such premises is currently about 350-400 per month, with a peak rate of replacements of about 200 per month (those not replaced being resolved through improved information), reflecting the limited financial and qualified personnel resources available for such work. Having reviewed progress to date and the numbers of higher priority premises still to be resolved, we conclude that it is feasible to complete the resolution of the A-C group by the end of 2013, and we recommend that this programme should continue.

As regards the remaining premises (~14,000) in the D-E categories, we conclude that, with currently available resources, it is not feasible to complete the resolution of all these installations by 2015. The ramping-up of the replacement rate that would be required is not justifiable in view of the relatively low levels of risk involved. Having reviewed the factors that determine risk in light of HSE's and the industry's current knowledge of LPG users' premises and gas installations, we recommend that these premises should be re-prioritised for action as follows:

Priority 1: Premises with medium pressure carbon steel pipework aged 10 years old or more at the time of the 2009/10 survey AND where any one or more of the factors listed below apply should be resolved by the end of 2015.

a) Regularly occupied by members of the public or

b) regularly occupied by more than 5 other persons, or
c) a cellar, basement or other significant below-floor void is present.

Priority 2: Any other premises with carbon steel pipework should be resolved by the end of 2020.

Priority 3: Any other premises with metal pipework which is not carbon steel (e.g. copper) should be resolved by the end of 2025 unless the pipework is known to be BOTH aged less than 35 years at the time of the 2009/10 survey, AND to be operating at low pressure (75 mbar or below), in which case it may remain in place for the 50 year recommended life of such pipework.

For the avoidance of doubt, in the context of this report resolution means that concerns regarding the risk of LPG leakage into buildings from corroded underground supply pipework have been satisfactorily addressed in that, for example, one or more of the following apply:

- The installation has been examined and there is no underground carbon steel pipework (for example it is found to be PE or copper or the pipework is above ground).
- Underground carbon steel pipework has been replaced by an alternative material and the installation tested.
- A risk assessment has been undertaken by a competent person and an inspection and maintenance programme has been agreed with the HSE.

We recommend that any premises whose priority is indeterminate based on the information currently held by HSE and LPG suppliers should be treated as in the highest priority category consistent with such information as is known. That is, "worst case" assumptions should be used for all parameters such as pipework material, age and pressure that are not known. We hope that this will enable HSE and LPG suppliers to provide an incentive to LPG users to put in place installation records or otherwise to provide reliable comprehensive information.

On the basis of these recommendations:

- About 2,850 premises are Priority 1 and will clearly require resolution by 2015.
- A further 4,140 premises will require resolution by 2015 if pessimistic assumptions are made in place of missing information; however we suspect the majority of these may safely be able to be deferred when and if additional information is provided by LPG users and assessed by a competent person (LPG suppliers are currently pursuing users for this information).
- Approximately 5,200 further premises are Priority 2 and will require resolution by 2020.
- Around 1,300 premises with copper pipework are Priority 3 and could be deferred to 2025 or beyond.

Our report explains the basis on which we have reached these judgments, and in particular the basis of our associated conclusions

a) that the risk associated with this hazard for the premises in question is low enough that substantial numbers of premises can safely be deferred for resolution until after 2015,
b) that carbon steel is the pipework material at particular risk, and

c) that the age of carbon steel pipework installations, operating pressure, the occupancy of the premises concerned and the presence of a basement or cellar (or other under-floor void) provide the best available basis for re-prioritisation.

We observed in the course of our work that substantial reductions in risk could be achieved by reducing the operating pressure of pipework. We recommend that, whenever pipework is to be replaced, the operating pressure of the new pipework should be as low as reasonably practicable taking into account the end use appliances and required gas throughput. For most domestic and many commercial LPG users this will result in pipework operating at Low Pressure (LP), which for the LPG industry means pressure not exceeding 75 mbar.

In conclusion we would like to acknowledge the very substantial efforts that have been made by HSE and LPG suppliers, along with LPG users, to improve the state of knowledge of LPG installations, including the promotion of installation records, and factors relevant to the risk of pipework corrosion underground since the publication of Lord Gill's Inquiry report.

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Contents

1. Introduction

On 11 May 2004 the ICL Plastics Ltd factory at Grovepark Mills, Glasgow, exploded leading to the deaths of 9 people and serious injury to 33 more. A Public Inquiry into the incident was chaired by Lord Gill, and published its report in July 2009[1] including four main groups of recommendations for commercial premises using bulk LPG supplies:

1. An urgent programme of replacement of underground metallic pipework, along with early inspection of all buildings that have an LPG supply in order to identify any hazardous features that arise from the design and layout of the building or are inherent in the layout or the condition of the service and installation pipework.
2. Creating a new safety regime.
3. Continuing development of that safety regime, particularly in the use of polyethylene pipework.
4. Establishing a permanent system by which safety questions will be reviewed and dealt with on an industry wide basis, and responsibilities will be clarified.

The government response[2] published in March 2010 accepted the first recommendation in full and the others in part. HSE, with the LPG supply industry and LPG users, worked together to obtain information on the individual installations and develop a programme of work to resolve any problems found. The majority of information was obtained using a questionnaire sent to commercial and industrial users of LPG during 2009/2010. The information on the LPG installation and the site premises obtained from the questionnaire and subsequent enquiries was fed into a computer program developed and applied by GL Noble Denton. This assessed the relative risk of gas entering and accumulating in buildings. HSE used the results of this programme to group LPG installations into priority bands (labelled A to E) for resolution of decreasing relative risk. HSE and the industry agreed a programme under which a higher priority group of just under 4,000 premises (those rated A-C based on the GL analysis) was identified for action by the end of 2013, with the remaining premises (less than 14,000, rated D-E based on the GL analysis) to be resolved by the end of 2015.

HSE in agreement with UKLPG established our Independent Expert Working Group to review progress with this first recommendation and advise on priorities and timescales for seeing it through, along with a number of related matters. Our complete terms of reference and membership are provided in Appendix 1.

The WG has communicated extensively via email and telephone and has met five times between April and July 2011, and individual members have held meetings with other relevant parties in the course of our work. Our approach, as reflected in the structure of this report, has been to

a) review the hazards associated with corrosion of LPG pipework (Section 2),
b) assess progress to date with the replacement programme (Section 3),
c) discuss and apply the factors that determine risk from this hazard (Section 4), in order to

[1] "The ICL Inquiry Report", HC 838, SG/2009/129, laid before the Scottish Parliament by the Scottish Ministers, July 2009
[2] "The Government response to the ICL Inquiry Report", Cmd 7849, March 2010

d) draw conclusions as to the feasibility of the current programme, the priorities that should apply to the remaining D-E premises and other matters relating to this risk and its control as per our terms of reference, and develop corresponding recommendations for the way forward (Section 5).

We have been supported and assisted in our work by staff at HSE (who also provided the secretariat for our group), by GL Noble Denton Ltd who developed the computer programme for prioritising the Gas in Building (GIB) risk, applying it to tens of thousands of premises, and by the officers of UKLPG and other LPG supply companies. We could not have carried out this work without them and are deeply grateful to them for their support. However, the opinions expressed in this report are our own.

A glossary of acronyms used is provided as Appendix 3.

2. Background to LPG Pipework Corrosion Hazard

We discuss here:

- The uses of LPG and characteristics of LPG installations (2.1).
- The susceptibility to corrosion of underground LPG pipework (2.2).
- The particular hazard of migration of LPG from such sources into buildings (2.3).

2.1 LPG and LPG Installations

LPG provides a convenient way of making a gas supply available to premises that are not connected to the natural gas network, or which use propane/butane as part of their particular processes. (Note: this report focuses on propane and propane-rich LPG mixtures; it does not address butane and the particular issues involved in making pipework robust to its liquefaction.) Its use grew substantially during the 1960's and 1970's, and has grown more steadily since then. LPG may be supplied in cylinder form or, for more substantial users, in larger tanks from which gas or liquid LPG is piped to one or more points of use around the premises. The Gill recommendations and this report cover the bulk supply, from tanks, of LPG as a gas (excluding liquid systems) at commercial and industrial premises.

The main elements of a typical bulk LPG supply installation, and who is usually responsible for them, are illustrated in Table 1 below:

Table 1: Typical LPG Supply Components and Responsibilities

System Element	Responsible Party
a) Tank and pressure regulator(s)[3] (controller). (The regulator reduces the variable gas pressure in the tank to a set pressure in the subsequent pipework. The set pressure is below the maximum working pressure of the pipework but high enough to provide sufficient flow and pressure for the consuming equipment).	LPG Supplier (except for the minority of customers who own their own tanks)
b) A length or lengths of pipework connecting from the tank and regulator to the building(s) or equipment where the LPG is to be used; this may run underground, overground or a mixture of both.	LPG user/customer
c) A second stage regulator[3] closer to the point of use (usually outside the building where the LPG is to be used) to reduce gas pressure to that needed for the relevant equipment.	LPG user/customer
d) Whatever appliances or equipment, typically inside a building, are going to use the LPG.	LPG user/customer

[3] For many domestic installations and a modest percentage of commercial installations the second stage regulator is installed at or close to the tank, so that the pressure in the pipework is substantially lower (typically 37 mbar, the supply pressure for many domestic appliances, as opposed to typically 0.75-2 bar for medium pressure pipework).

Installations will also include various safety measures such as emergency valves close to the point of use of the LPG, and protective devices closer to the tank to prevent overpressure or excess flow of gas or liquid LPG into the pipework system.

The division of responsibility for these elements of the system is as shown in the table for a large majority of installations, but may vary according to the specific LPG supply contract for particular premises. There is a range of health and safety legislation that applies to the supply and use of LPG embracing the roles of suppliers and users but in particular under DSEAR it is clear that the overall responsibility for the complete installation rests with the user.

It became clear at the ICL Inquiry that responsibility was clearly understood by most users to rest with the supplier for the tank and fittings (where owned by the supplier), and with the user for appliance and equipment. However, responsibility for pipework and connecting systems was often not so well understood. The situation contrasts with the UK natural gas system where the gas transporter owns the supply pipework and fittings up to and including the meter, with the user only being responsible for the remainder of the pipework often at low pressures. On large sites the gas supply may feed into a meter on the boundary of the site and the site pipework from the meter is then the responsibility of the user. Sometimes there are further pressure reduction stations on site which are the responsibility of the user. At the time of the ICL accident many LPG users, both domestic and commercial, were not aware of their responsibility for pipework.

Much work has been done by HSE and the LPG supply industry since the accident to rectify this situation, with HSE and Local Authorities undertaking a major programme of inspection, substantial relevant research, awareness raising initiatives with LPG users, and much industry effort to develop/improve records of installations (which many users had not maintained for long periods of time). HSE intends to evaluate the effectiveness of these initiatives later in 2011 in order to establish what progress has been made and how best to continue moving forward.

The widely distributed ownership of and responsibility for LPG pipework leads to various other contrasts with natural gas supply pipework, including:

- LPG installations are relatively few in number compared with natural gas.
- LPG pipework has been installed by a wide variety of organisations, using different protocols and procedures.
- There are no central records of LPG pipework installations; individual LPG supply companies each hold their own customer database.
- Doing anything about LPG service pipework involves engaging the individual users, rather than a small group of companies who between them own most of that service pipework.
- A significant proportion of pipework operates at medium pressure, which in the event of a leak close to buildings could result in a higher potential for a gas build up compared with pipework operating at low pressures.

During the 1960's and through to the 1980's many LPG systems were installed using carbon steel pipework both above and below ground. Below-ground pipework was often protected by the application of petroleum-based tape (often referred to by the trade name "Denso Tape").

From the 1960's to early 1990's significant numbers of copper pipework systems were installed, by one of the major LPG companies in particular.

From the l980's onward medium density polyethylene (MDPE) became the preferred pipework material, initially used for the longer lengths of buried pipework in conjunction with metal risers (to protect against heat and UV above-ground) but from the 1990's onward in conjunction with MDPE fusion fittings and risers, protected by sheathing above ground. Good practice in protecting pipework and joints (of all materials) from corrosion and other failure mechanisms has evolved over this time, but may not have been universally applied at any given time.

As premises change ownership and/or move between LPG suppliers (the supply of LPG being a competitive industry), memories and records of the pipework installations tend to get lost. As became clear in the HSE/industry survey of LPG users in 2009/10, there are thus large numbers of commercial and industrial LPG users who have little or no information on when their pipework was installed, of what material it is made, and how the installation was carried out.

We regard this paucity of information as a major deficiency and are pleased to note the substantial efforts that have been made to improve it. In particular, we are aware of:

- LPG suppliers making substantial efforts to improve the quality and completeness of the detailed information they hold on customer installations (e.g. tank details, what the gas is being used for, required pressure(s) etc).
- HSE developing a database of all installations that have been prioritised and reviewed, incorporating into this the findings of inspections they and Local Authorities have carried out, and logging the status of work to resolve individual installations.
- UKLPG and some individual gas companies have worked, with HSE input, to develop standard LPG installation record documentation and to issue this to LPG users.

Parallel initiatives to improve awareness and information available to domestic customers have been undertaken, including substantial research into the nature of the risk presented by pipework corrosion to domestic buildings, and development of an on-line safety check that home owners can use to self-assess their own pipework.

We note that it will be extremely difficult to assess the extent to which Lord Gill's recommendations on resolution of metallic pipework have been met unless some form of central record such as that currently held and being developed by HSE is maintained until the actions planned to implement those recommendations have been discharged, that is until at least 2025.

2.2 Corrosion of Underground LPG Pipework

LPG itself is non-corrosive, and to the knowledge of the WG none of the widely-used materials in LPG supply pipework suffer significantly from internal corrosion or attack by LPG. The outside of the pipework, though, may be susceptible to failure by various mechanisms including:

- Mechanical damage (e.g. by being hit with a spade or excavated by a digger).
- Corrosion at or above ground level (particularly for metal pipework in wet environments).

- Heat (e.g. from proximity to electrical cables, fire in adjacent buildings, or hot water pipework).
- Animal activity (e.g. rodents).
- Corrosion below ground level.

Different pipework materials differ greatly in terms of their susceptibility to these different mechanisms. In terms of mechanical damage, there is little to choose; thin-walled metal or MDPE pipes are not going to survive a swipe from a JCB. In terms of heat and animal activity, MDPE is somewhat more susceptible than metal pipework, and there may be some soils (e.g. with significant levels of organic contaminants) where MDPE is not suitable. But generally speaking, heat and animal activity are minor causes of pipework problems, and for the vast majority of soils, corrosion in the soil and mechanical damage are the primary potential failure mechanisms of concern – the latter generally not representing a risk to buildings as it is most often associated with excavation of or around the pipework.

In respect of corrosion in soil, there is a clear difference between pipework materials, and between different soils. HSE commissioned a Corrosion Working Group to review these matters[4]. They concluded that it was difficult to ascribe confidence to any corrosion protection without detailed knowledge of the system and its installation, and thus based their conclusions as to the survivability of pipework on unprotected steel. They concluded that typical unprotected carbon steel pipework of 3 mm wall thickness would last for the following times in different soils:

Table 2: Carbon Steel Pipework Survival in Soil

Soil Aggressiveness		Estimated Time to Failure Mean (Range)
Ia	Virtually non-aggressive	100 years (50 to 192 years)
Ib	Weakly aggressive	60 years (30 to 120 years)
II	Aggressive	15 years (7 to 30 years)
III	Strongly Aggressive	7 years (4 to 14 years)

The lifetime of steel pipework can be extended with a variety of corrosion protection systems, from wrapping with "Denso" tape, via plastic sheathing, to galvanising or cathodic protection. The effectiveness of such systems relies entirely on how well they were originally installed. We know that although the UKLPG has recommended protection measures for many years there has been wide variability in the choice of protection systems used and the effectiveness of their application. So, while carbon steel pipework may be good in some soils for 100 years plus, in the absence of detailed knowledge of the soil, of the installation history and use of the pipework system, none of the corrosion protection systems of which we are aware (including cathodic protection) can be relied upon for protection. The corollary is that it cannot safely be assumed that carbon steel pipework will last more than a few years underground before being penetrated by corrosion. Accordingly, without specific installation details, our Working Group could not reliably take into account any existing mitigation measures in the assessment of replacement priorities. Hence, we

[4] "THE CORROSION OF BURIED METALLIC LPG PIPEWORK", a report for HSE by G John, C Lee and P MacIntyre of the LPG Corrosion Working Group (undated but known to have been produced in 2010)

share the view expressed by Lord Gill that all steel pipework should be replaced while recognising that the resolution of the lower risk categories (D-E) by 2015 is not feasible.

As regards the preferential location of corrosion penetration of steel pipework, by far the most common area for this to occur is at the base of the riser adjacent to the building where the LPG is used. This is probably because of some mix of:

- Damage to any galvanising due to the jointing at the elbow.
- The difficulty of correctly applying protective wrapping around the elbow.
- Faster corrosion where metal is stressed at bends or joints.
- Higher moisture levels next to buildings because of poorer drainage or increased water deposition on windward walls.

There is relatively little data available for copper, as its corrosion and pitting rates in soils are generally very low. The WG noted the possibility of substantially accelerated copper corrosion in extremely wet and salty conditions (substantiated by one known example in a tidal salt marsh), but generally accepted that copper should survive intact for at least 50 years provided unprotected joints with dissimilar metals have not been used.

MDPE has shown no problems with corrosion to date. A life expectancy of 50 years has been demonstrated for natural gas[5] but, as for copper, there is confidence that for many installations this may safely be exceeded. HSE is undertaking work to address the life expectancy of MDPE pipe for LPG use. The work, which is ongoing at the time of writing, has not to date discovered any reason to expect MDPE durability to be any different for LPG than for natural gas.

Even in ignorance of soil properties and of how precisely the pipework was installed, there can thus be good confidence that MDPE or copper pipework in the vast majority of soils will survive for 50 years or more. In contrast, without such knowledge, there cannot be confidence that carbon steel pipework will survive more than a few years (see Table 2).

2.3 LPG Pipework Corrosion and Gas Accumulation in Buildings

The risk presented to people in buildings by gas accumulation due to corrosion of LPG pipework underground is determined by:

a) The likelihood/time for the pipework to be penetrated by corrosion,

b) the scale of the leak that can thus result,

c) the likelihood and rate at which leaking gas enters the building,

d) the volume and ventilation of the space into which it leaks (this determines whether a flammable concentration can develop),

e) the likelihood of ignition of a flammable gas mixture (before it has been detected and remedied), and

[5] "Specifications for Polyethylene pipes and fittings for natural gas and suitable manufactured gas Part 1: General and polyethylene compounds for use in polyethylene pipes and fittings", Gas Industry Standard GIS/PL2-1: 2008. BS EN 1555 series.

f) the impact of the explosion, should it occur, on the building occupants.

We are aware of only two other explosions in the UK due to underground LPG supply pipework corrosion beside the ICL accident. The first involved an underground firing range in Daventry in 1988, the second a domestic property in Lanarkshire in 2006. We are not aware of any other explosions from this cause in the UK in the past two decades. The features of these properties and accidents are compared in respect of the above risk-determining factors in the table overleaf.

Table 3: Comparison of Known Explosions due to LPG Service Pipework Corrosion

Risk Factor	Daventry 1988	ICL 2004	Lanarkshire 2006
Premises Type:	Underground Firing Range	Plastics Factory	Domestic house
a) likelihood of/time to develop leak	Plain galvanised steel pipe (no protection) installed 1980	Plain galvanised steel pipe (no protection) installed 1969	Steel pipe, installation date not known
b) scale of leak	Very rapid pressure drop on subsequent testing supply pipework, indicative of “massive leak”. Supply at MP (Medium Pressure) approx 2 bar.	Large leak; pipework corroded around 71% of circumference. MP supply pressure approx 2 bar.	Very large leak, estimated on investigation at around 4 m^3 per hour. MP supply pressure approx 2 bar
c) entry of gas to building	Underground firing range; gas access into building via penetrations for electricity, gas & water pipes. Frozen ground surface prevented escape upward.	Supply pipework ran below concrete-covered yard, entering a basement space. Building provided only outlet for leaking gas.	Supply pipework leaked direct through gaps in brickwork into void below floor. Most of leak able to enter building; outside surface paved/concreted.
d) accumulation of gas in building	Gas accumulated over weekend when ventilation minimal.	Gas accumulated in seldom-visited basement with limited ventilation.	Gas accumulated in void below floor with limited ventilation.
e) ignition before detection	Ignition on employee entering after building unoccupied for weekend.	Ignition on employee entering after basement unoccupied for days/weeks	Ignition source not known; gas had been detected by smell by residents and engineer was on way when explosion happened.
f) explosion consequences	Caused collapse of massive reinforced concrete building. Employee was on toilet and dug out of rubble with minimal injuries. No weak structure available to ‘vent’ explosion.	All (except possibly the one employee whose entry to the basement is presumed to have triggered the explosion) fatalities due to collapse of building, not by explosion blast. Structure did not ‘vent’ explosion.	Explosion below floor, blew out windows of house. 4 of 8 occupants injured, none fatally (all were hospitalised with some limb breaks but no permanent injuries).

These explosion incidents had a number of important features in common:

- Unprotected steel pipework, albeit of widely different ages.
- Large penetrations through the pipe wall due to corrosion.
- Medium pressure gas in the pipework leading to high gas escape rates.
- Combination of ground cover and building construction enabling/forcing escaped gas into building.
- Below-ground spaces where gas could a) enter and b) accumulate.
- Periods of time where that void was unoccupied, allowing gas to accumulate undetected.

We know of no explosions of LPG in buildings from this cause (corrosion failure of underground supply pipework) which did not share these features. While the population of relevant incidents is thankfully very small so that the statistical significance of these observations is limited, we note in particular the importance for risk of gas supply pressure and of underground spaces in which gas can accumulate undetected. Building construction is not easy to change retrospectively, but if service pipework is to be replaced, that pressure could, in many of the installations we have reviewed, be substantially reduced for modest marginal cost. In our view the substantial programme of pipework replacement in response to Lord Gill's recommendations thus represents a significant opportunity for risk reduction by reducing pipework pressure to the lowest practicable level, taking into account the needs of the ultimate gas using appliance or processes, and the required gas throughput.

In most situations, we would expect that, were a corrosion leak to develop in buried supply pipework, any leak large enough to threaten a building would develop from a smaller leak. The margin between gas which is detectable by smell and gas at a concentration sufficient to ignite is very large:

- The main stenching agent used (ethyl mercaptan) is detectable by smell at levels of 1 part per billion[6].
- The agent is added to LPG at a minimum concentration of 20 ppm.
- The lower flammable limit (LFL) for LPG is about 2% gas in air.
- At this LFL, the concentration of stenching agent in air would be about 400 ppb.
- Many people would be able to detect the agent at 0.1% of this level, while the vast majority of people would be able to detect it at less than 1% of the LFL.

Most corrosion leakages from a pipe buried in soil will start tiny, and grow over time. Given the above observations on LPG detectability, the scenario of "tiny leak, with gas entering building, progresses to large leak, still with gas entering building" stands a good chance of detection before a dangerous mixture of LPG and air can develop. (For the most aggressively corrosive soils – see Table 2 above – it would take over a year to grow from a pinprick to a 1 mm hole in an unprotected steel pipe). It is also relevant to note that LPG gas suppliers have to provide a 24/7 emergency

[6] Most people can detect ethyl mercaptan at concentrations 2-3x lower than this. The requirement for LPG to be odourised is laid down in BS 4250 : 1997 "Specification for Commercial butane and commercial propane"

service as laid down in the Gas Safety Regulations and would hence be expected to respond to detected leaks in a timely manner. The primary scenarios of concern are thus either:

a) A small leak[7], without gas entering a building, develops into a larger leak, after which something happens to channel gas into a building (a possibility in the 1988 Daventry incident), or

b) a small leak, with gas entering a building, goes undetected because the space it enters is unoccupied for some time, and then develops into larger leak which increases gas accumulation in the building (a possibility in the ICL incident), or

c) a significant gas flow into a building is generated relatively suddenly for example as a result of sudden fatigue failure of a badly corroded region of pipework (the cause of some cases of accumulation of natural gas in buildings), or

d) a small leak increases gradually and is detected in a building before flammable levels are reached, but the source is undiagnosed so that the concentration of gas (which tends to fluctuate greatly inside buildings as a result of weather conditions, building use etc) can increase gradually to reach flammable levels (this may have been a factor in the Lanarkshire explosion in 2006 – see Table 3).

The risk factors and their relevance to actual premises are discussed further in Section 4.

[7] "Small" and "Large" are used here in terms of gas flow rate out of the pipe, not size of hole (a very small hole can lead to rapid gas escape and accumulation, particularly for MP pipework). The TTAC report found that a large majority of underground corrosion leaks which led to an engineer being called out to a reported gas escape involved slow rates of pressure drop in the service pipework. For LP systems, over 90% were estimated to involve LPG leakage rates less than 0.01 m^3/hour (at NTP), while around 85% of MP pipework systems subject to corrosion failure were estimated to have been leaking at less than 0.1 m^3/hour. The known incidents of explosions in buildings from this cause (see Table 3 above) all involved larger leak rates, of the order of 1m^3/hour or more.

3. Progress to Date

The key steps taken by HSE, LPG users and the LPG supply industry to meet the recommendations of the Gill Report to date have been:

- A survey of LPG users to identify risk-relevant features of their installation, and develop a database of such users.
- Use of a computer model to prioritise pipework for replacement/resolution based on likelihood of achieving a flammable accumulation, and notification of LPG users accordingly.
- A substantial programme of inspection and enforcement activity by HSE and Local Authorities.
- Replacement or other resolution of underground metal pipework by LPG users and in some cases suppliers.

These are discussed in turn below.

3.1 Survey of LPG Users

During the summer of 2009 HSE and the LPG suppliers developed a survey questionnaire which was sent to all commercial LPG customers. It covered key features of the premises and gas supply relevant to risk, including:

- Supply pipework material, protection, pressure and age.
- Ground cover outside the building(s) supplier, around the riser.
- Presence of a cellar or basement.
- Building use and occupancy.

The questionnaire was issued and collected by LPG suppliers, who went to considerable lengths to get questionnaires completed and returned. HSE have also gone to considerable lengths to follow up non-responders. Numerous questionnaires were incomplete in one or more respects, and in such cases HSE made conservative assumptions (e.g. if a questionnaire did not mention whether it had a cellar or basement it would be assumed to have one, as this would increase the risk).

The absence of information on installations is a serious issue for our Working Group, as it limits the degree to which we can, with confidence, judge whether pipework replacement may safely be deferred for substantial numbers (many thousands) of properties. Our view, consistent with the approach taken by HSE to date, is that where information is missing, worst case assumption should be made in prioritising the relevant installation. We would recommend making it clear to the duty holders for such installations that an opportunity to defer resolution of their underground metal pipework may be available if they can provide further relevant information. The burden of collecting such information needs to be switched from HSE and LPG suppliers onto duty holders (LPG users) as the levels of effort dedicated to this issue by both HSE and the LPG suppliers over the past 18-24 months are not sustainable and would in our view be disproportionate to the risk remaining once the A-C premises have been resolved.

3.2 Initial Prioritisation of Premises

HSE commissioned GL Noble Denton Ltd to apply a computer model initially developed for prioritisation of cast iron natural gas service pipework replacement to the survey results, along with research from the Health & Safety Laboratory (HSL) into the migration of LPG in soils[8]. The GL model was based on the following methodology:

- The corrosivity of the soil at the premises was obtained from a national database using the postcode.
- The corrosion rate of the pipework and time to penetration was estimated from this basis.
- The escape rate of gas was estimated taking into account the operating pressure and hole size.
- Assumptions linked to survey responses were used to allocate a proportion of escaped gas entering the building.
- From the above basis, the % of the lower flammable limit (LFL) for LPG that might be achievable inside the building was calculated, taking account of the type of building and the presence or otherwise of a cellar/basement.

The premises were then allocated a priority code from A to E by HSE as follows:

A	10-100%+ of LFL	(246 premises)[9]
B	1-10% of LFL	(2,205 premises)
C	0.1 to 1% of LFL	(1,497 premises)
D	0.01 to 0.1% of LFL	(8,698 premises)
E	< 0.01% of LFL.	(4,702 premises)

HSE agreed with the industry that it should be feasible to tackle the first three categories (A-C) by the end of 2013 and the remainder by 2015, and Suppliers wrote to their customers accordingly.

3.3 Inspection and Enforcement Activity

To reinforce the information being provided to LPG users by their suppliers, HSE agreed in association with Local Authorities to undertake a substantial programme of inspections of LPG users' gas supply systems, and to enforce accordingly. An overview of the programme to date and the inspection findings is provided in HSE's recently published Annual Report. We concluded that this had provided a very effective, if somewhat resource-intensive, way of communicating this issue to duty holders and of promoting/requiring action to resolve buried pipework corrosion hazards. Key points we noted included:

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[8] "Comparing subsurface migration of LPG with natural gas", R J Bettis and J Fletcher, HSL Research Report RR736, 2009

[9] Numbers of premises provided by HSE and are the latest available at the time of writing in July 2011; a small proportion of premises (around 270) remain unranked because of late questionnaire returns and for other reasons. The information is derived from suppliers representing over 90% of LPG use in the UK.

- Since commencement of the programme in October 2009 to the end of March 2011, HSE has undertaken 2965 of a planned 3000 visits, (2732 of which were delivered in 2010/11). Over 650 additional sites have been addressed through central management interventions with larger duty holders[10].
- A significant proportion (about half) of premises inspected turned out on inspection or provision of further information NOT to have any relevant pipework (thus resolving the need for action without requiring pipework replacement). Given the large number of incomplete questionnaires, the conservative assumptions for missing data resulted in many installations being ranked in a higher category than appropriate.
- The programme identified numerous examples of minor gas safety issues in addition to underground metal service pipework, and a smaller number (a few % of installations) with more major issues requiring prompt correction or a Prohibition Notice.
- The HSE inspections have resulted in over 1500 Improvement Notices being served to secure satisfactory control of risk. Of these, about 54% relate to buried metal service pipework requiring resolution. Most of the remainder relate to tanks and the associated fittings, with about 3% relating to above-ground pipework.
- For the vast majority of users, replacement of buried metal pipework with MDPE is the obvious solution expected to be pursued. Some users have argued that the required improvements are not necessary, but such arguments have not generally been supported by informed assessment of risks and controls by a competent person. The current HSE position is to offer the duty holder alternative strategies for meeting the legal obligation of maintaining an installation in a safe condition.

3.4 Resolution of Underground Metal Supply Pipework

Although service pipework is in a large majority of cases the clear responsibility of the LPG user rather than the supplier, some suppliers made their own decision, in advance of the survey and GL prioritisation findings, to start working with LPG users to replace underground MP steel pipework. HSE is collating information provided by the suppliers with the outputs of the GL programme and of its own and Local Authorities' inspection programme into a database which, it is intended, will hold details of each LPG users' premises and supply installation, and will allow progress on replacement/resolution of buried metal service pipework to be tracked.

The Working Group strongly supports the development of improved information on the status of LPG installations, and we note that it will not be possible to evaluate the progress made against the implementation of Lord Gill's and our own recommendations unless such a database or equivalent arrangement is maintained until those recommendations have been seen through. We recognise that it may not be sustainable to continue such a database in perpetuity, but are hopeful that by the time these recommendations have been seen through, LPG suppliers will have significantly improved knowledge of customers' installations, and LPG users themselves will recognise the need to maintain their own records of LPG installations, and the benefit of being able to demonstrate those installations' integrity.

[10] HSE Annual Report 2010-11, available online at www.hse.gov.uk/aboutus/reports/1011/ar1011.pdf

The estimates of service pipework systems replaced to date are based on information derived largely from the four major suppliers and from HSE's inspection programme. The current rate of resolution of relevant premises is about 350-400 per month, made up of approximately equal numbers of

a) replacements of metal service pipework, and
b) premises discovered on inspection or further consultation with suppliers not to require action (typically because they do not have underground metal pipework currently in use).

We do not currently know how many LPG users have taken their own action to replace their service pipework. Users have no obligation to use or even to consult their supplier before embarking on a change to pipework systems that they own. While we expect that many users will have spoken to their supplier before embarking on such a project, it is entirely possible that some will not have done so. These rates of resolution estimated from the HSE database may thus systematically under-estimate the true figures.

4. Prioritisation of Remaining Pipework

The current rate of resolution of premises at risk from corrosion of underground steel pipework is about 350-400 (see above). Our assessment is that this should be sufficient to see through the resolution of all installations classified as A-C based on the GL work by 2013. However, there will remain around 14,000 installations classified D-E for which HSE, after consultation with LPG suppliers, has a current deadline for completion by the end of 2015. These clearly cannot all be resolved in an additional 2 years after 2013 without greatly expanding the rate of resolution, which is not justifiable given the relatively low average risk levels involved. In our view, it would be very much preferable to re-prioritise the D-E premises, allowing those for which resolution can be safely deferred to be so deferred, rather than to escalate the already substantial resources being devoted to this issue by HSE and LPG suppliers.

We discuss here:

- The key risk factors revealed in the initial prioritisation exercise (survey and GL analysis, 4.1).
- Other important risk factors (4.2).
- What we actually know and do not know about LPG users' premises and gas installations, and its implications for our prioritisation (4.3).
- The absolute and relative risks involved in the D-E premises remaining to be prioritised (4.4).
- Risks and control approaches being adopted for other premises (domestic and caravan parks in particular) that use LPG (4.5).

4.1 Risk Factors Identifiable from the GL Study

Our primary concern is to establish whether the category D and E premises identified in the original survey and GL study carried out in 2009-10 can safely be prioritised so as to defer resolution of some premises' pipework beyond 2015. Our first observation in this respect is that, by virtue of their D-E categorisation, ALL of these premises have been assessed by the GL model as generating 0.1% or less of the flammable concentration of LPG in the relevant buildings at the time of the analysis. As we are aware of a number of simplifying assumptions in the model of a generally very cautious nature (e.g. relating to building construction, volumes and ventilation), we accept that the risk associated with D-E premises is likely generally to be low.

Our starting point is to review the implications of different LPG installation and premises attributes which determined whether premises were ranked in the higher (A-C) or lower (D-E) priority category in the original GL study. Appendix 2 provides some charts illustrating the numbers of relevant (i.e. with metal underground service pipework) premises with different attributes, and the proportion of premises with those attributes that emerged as priority D-E as opposed to A-C. Our key observations from this exercise are:

1. Pipework material is the single biggest factor determining the proportion of premises that are ranked D-E, with all copper pipework systems in this D-E category.

2. Pipework age is a very important factor, with all pipework under 10 years old and 99% of pipework aged 10-19 years falling into categories D-E.
3. Pressure is also a very important factor, with most LP installations falling into band E. A substantial proportion (over 75% of the D-E premises which answered the "pressure" question in the HSE/UKLPG survey) of commercial LPG installations are currently MP, though suppliers and users are reducing the pressure wherever practicable in the current programme of replacement/resolution.
4. Presence of cellars/basements, and of a hard ground covering around the riser outside a building, made less difference to the model results than did the above factors. In our view this more likely reflects the swamping of these factors by other assumptions in the model, particularly those pessimistic assumptions made for premises for which information was not available. Presence of cellars, basements or other voids below floor level has been a common factor in all three of the UK explosions due to LPG service pipework corrosion of which we are aware, and is in our view an extremely important risk factor. This is because low level accumulations from initially small leaks may not be detected early thus enabling flammable gas concentrations to develop undetected. Moreover, an explosion in a confined space below a building will generate high overpressures causing major structural damage and injury to people in other parts of the building.
5. Soil type is crucially important for the GL results, but this information was not available to the WG for any of the premises and is in any case subject to significant local uncertainty[11].
6. Substantial proportions of premises are "unknown" in relation to one or more of the factors relevant to the GL model. Because conservative assumptions were made for these premises (e.g. material = steel, age = 35 years, pressure = MP, cellar = present), a significant proportion of premises rated A-C will have been those with incomplete survey responses.

Our conclusion from this is that the factors on which we can rely to make a major difference to the risk of metal service pipework corrosion underground are:

1. Pipework material – carbon steel is the only significant risk.
2. Pipework age – less than 20 years is low risk, less than 10 years very low risk.
3. Pipework pressure – makes a significant difference in the event of corrosion, but is unlikely on its own to be very useful as a discriminator for the replacement strategy as the majority of commercial properties use the higher risk MP pipework.

4.2 Other Risk Factors

The other substantial piece of research in this area commissioned by HSE since the ICL Inquiry report was issued was an assessment of the relevant risk for domestic premises, of which one of our

[11] The assumed soil type in the model is that looked up from a national database. The actual backfill used around service pipework is not known for individual premises, though GL have assured us there is a strong correlation between soil type looked up from the database and the proportion of pipes found to have been corroded in a large programme of excavation of users' pipework undertaken by Calor (described in their ICL Inquiry evidence). The basis of this correlation is proprietary so has not been available to us.

members was the lead researcher[12]. This research did not have access to the substantial (proprietary) evidence base on pipework leaks which underpins the GL model, but developed and validated independent models for each of the risk factors described in Section 2.3, using evidence collected from LPG suppliers and HSE.

Significant differences between this research and the GL model are that it used

a) simpler, generic estimates of the frequency with which LPG leaks from underground pipework could be expected and of the probability of experiencing leaks of different sizes (both based on information elicited from suppliers' gas engineers and databases of emergency calls responded to for suspected gas leaks), along with

b) explicit models of gas migration through soils and into buildings, taking into account building floor construction and other factors.

The key risk factors this work identified which we consider transferrable from the domestic to the commercial installations which are our primary concern are:

1. **Floor construction**: for buildings with solid or suspended concrete floors the individual fatality risk in "worst case" buildings was estimated to be below 10^{-6} per year (a level below which risks are widely regarded as "broadly acceptable", including by HSE[13]).
2. **Supply pressure**: MP pipework typically generated risk levels an order of magnitude (i.e. a factor of about 10) higher than those for LP pipework, because of the higher associated gas escape rates for a given degree of pipework corrosion.
3. **Presence of cellars, basements or other voids below floors**: suspended timber floors involved an order of magnitude higher risk than concrete floors, and the presence of a basement or cellar involved a further order of magnitude increase in risk.
4. **Riser location**: incorporation of the riser into a building (whether through incorrect installation or through extension of a building out to cover a pre-existing riser) is a particular risk factor, especially if the riser is in a room or space not normally occupied where gas could accumulate undetected.

Even when making conservative assumptions about leak rates and building ventilation, this research found that a large proportion of more modern buildings (post 1970's) would, if correctly built and maintained to modern building standards, be effectively immune to this hazard. This is because their floor construction will either

a) prevent gas ingress from soil in the first place (via membranes, solid floors and the screeds laid over them), or

b) where there are suspended floors with a void capable of admitting gas, modern ventilation standards reflect the desire to avoid ground gas contamination in buildings, and should generally prevent gas accumulation in such voids up to flammable concentrations.

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[12] "Risk Assessment of Corrosion Leakage of LPG from Domestic Underground Service Pipework", M Hunt, K Somaiya and T Taig, TTAC Ltd report for HSE, March 2010

[13] "Reducing Risks, Protecting People – HSE's Decision Making Process", HSE 2001, http://www.hse.gov.uk/risk/theory/r2p2.pdf

4.3 Knowledge and Uncertainty about the D-E Premises

The current HSE database of commercial LPG users has significant numbers of blanks for large numbers of properties, and does not include some of the important risk factors (e.g. floor construction) which were identified in the domestic research carried out after the survey of users had already been completed.

The database does, though, include some information which we would expect to be reasonably reliable (and certainly would be easy to establish at a particular premises) as to the use of the buildings and the number of people using them. In particular, it is relatively straightforward to distinguish between premises that are used more or less by members of the public (e.g. retail premises, hospitals, schools etc in the "more" and agricultural or factory premises in the "less" category).

We are confident that, if the service pipework material below ground is known to be a material OTHER THAN carbon steel (and not to incorporate carbon steel components), it can safely be considered to be very much lower risk than any pipework which is carbon steel, or contains carbon steel components underground.

In view of the uncertainties as to the effectiveness of any corrosion protection applied to carbon steel pipework, and the general uncertainty as to what material was used as backfill around service pipework, we see a need to make pessimistic assumptions as to the survivability of carbon steel pipework in soil. However, based on the GL results (which use a model derived from a substantial evidence base on relevant pipework corrosion rates) we are confident that carbon steel pipework of less than 10 years old should be at substantially lower risk than older such pipework.

Supply pressure is an extremely important risk factor, although we note that only a relatively small proportion of commercial premises (of order 20%) use low pressure pipework, which in our view does enable them to be prioritised behind premises with medium pressure pipework.

Were it available, we would have considered using information on floor construction as a potentially important prioritisation factor. The key risk factor here is "presence of a void near or below ground level into which gas could relatively easily migrate from soil and within which it could accumulate undetected". A corresponding clear de-risking factor is "presence of a well built concrete slab floor in good condition and without significant penetrations close to the LPG riser", but this was not ascertained in the survey. The best available information for discrimination between properties is thus the survey response as to the presence or absence of a cellar or basement. This is a key risk factor reflected in our prioritisation criteria.

Other attributes of buildings which we consider relevant and useful in prioritisation, are their use and their occupancy. In particular we consider that

a) premises used by members of the public warrant a higher priority than those used only by staff/employees, and

b) premises occupied by larger numbers of people warrant higher priority than those occupied by smaller numbers.

The key factors we therefore propose taking forward to incorporate into our recommendations for prioritisation are:

- Pipework material.
- Pipework pressure.
- Pipework age.
- Floor construction (presence of cellar or basement).
- Building occupancy.

4.4 LPG Service Pipework Corrosion Risks in Perspective

HSE included in our terms of reference a request to provide perspective where possible on the nature and magnitude of risk associated with this particular hazard, in relation to other hazards involving the use of gas. We can glean relevant information from a number of sources:

- HSE gas safety statistics (as referred to in the ICL Inquiry report).
- The GL study.
- The risk levels for domestic premises estimated in the TTAC report.
- RIDDOR and COIN information provided to TTAC Ltd by HSE.
- Gas escape information provided to TTAC Ltd by LPG suppliers.

The latest available RIDDOR statistics obtainable from the HSE gas safety web site show total annual fatalities associated with ALL gas use (predominantly natural gas) ranging between 10 and 20 per year, as shown in the table below:

Table 4: Gas Fatalities in the UK – HSE Data

Year	Explosion/Fire Fatalities	Carbon monoxide fatalities	Other exposure fatalities	TOTAL fatalities
2005/06	4	16	0	20
2006/07	2	10	0	12
2007/08	2	13	3	18
2008/09	2	15	1	18
2009/10*	1	9	0	10

* Provisional figures.

There were 11 natural gas related explosion/fire fatalities in the five year period covered in Table 4, in comparison with a total of 8 fatalities resulting from the ICL explosion (the only bulk LPG fire/explosion fatalities of which we are aware in the UK in the past 20+ years). Both numbers are significantly less than the 63 fatalities attributed to CO poisoning in the 2005-2010 timeframe.

The average over the first four years in Table 4 (for which final statistics are available) is 17 per year. The average UK population over this period was about 61.2 million[14], implying that the average annual individual fatality risk for UK residents was about 0.28 per million per year, of which 0.04 derive from fire/explosion and the remainder from CO poisoning or asphyxiation/other hazard. Hence the average individual risk of fatality in a gas explosion is very small, of order $4x10^{-8}$ per year (25x lower than the 10^{-6} level widely regarded as broadly acceptable[14]).

The GL study, as discussed above, provided a deterministic calculation of the concentration of flammable LPG gas that might develop in building air, based on an assessment of gas leak rate, proportion of gas entering building, and assumed building/room volumes and ventilation rates. The resulting concentrations derived for categories D and E premises (those of most concern here) were

a) 0.01 to 0.1 % of LFL (category D), and
b) < 0.01% of LFL (category E).

While the GL calculations are subject to considerable uncertainty, it is our view that the assumptions they used were likely to be pessimistic for many premises. We therefore interpret these results as implying that in general, the likelihood of flammable mixtures developing in D & E premises as a result of corrosion in service pipework outside the building is small at the time (2009-10) to which the survey data relates; it will increase with time.

The TTAC report estimated annual individual fatality risks per million due to this hazard within broad ranges as shown in the table below for properties with MP pipework:

Table 5: TTAC Estimates of Individual Risk (per million, per year)

Context	Range – MP (0.75-2bar) pipework
Slab floored buildings	<0.0001 to <1
Suspended timber floored buildings	<0.001 to 10
Suspended timber floor, with cellar	<0.01 to <100
Property with riser leaking into occupied space	~1 to ~30

The corresponding values for properties with LP pipework were an order of magnitude (i.e. a factor of 10) or more lower. Even with all the uncertainties associated with these estimates, a person resident at almost any property with an LP installation was estimated to be at fatality risk of less than 1 in a million (10^{-6}) per year, whereas for some properties with MP installations (see bottom 2 rows of Table 5) the risk could be as high as 10-100x above this level (extending into the range where further action is generally desirable to reduce risk[13]).

The wide ranges in these estimates reflect not only the large uncertainties in such calculations, but also the important differences between different buildings. Generally, more modern buildings will

[14] http://www.statistics.gov.uk/downloads/theme_health/Pop-change-components16.xls

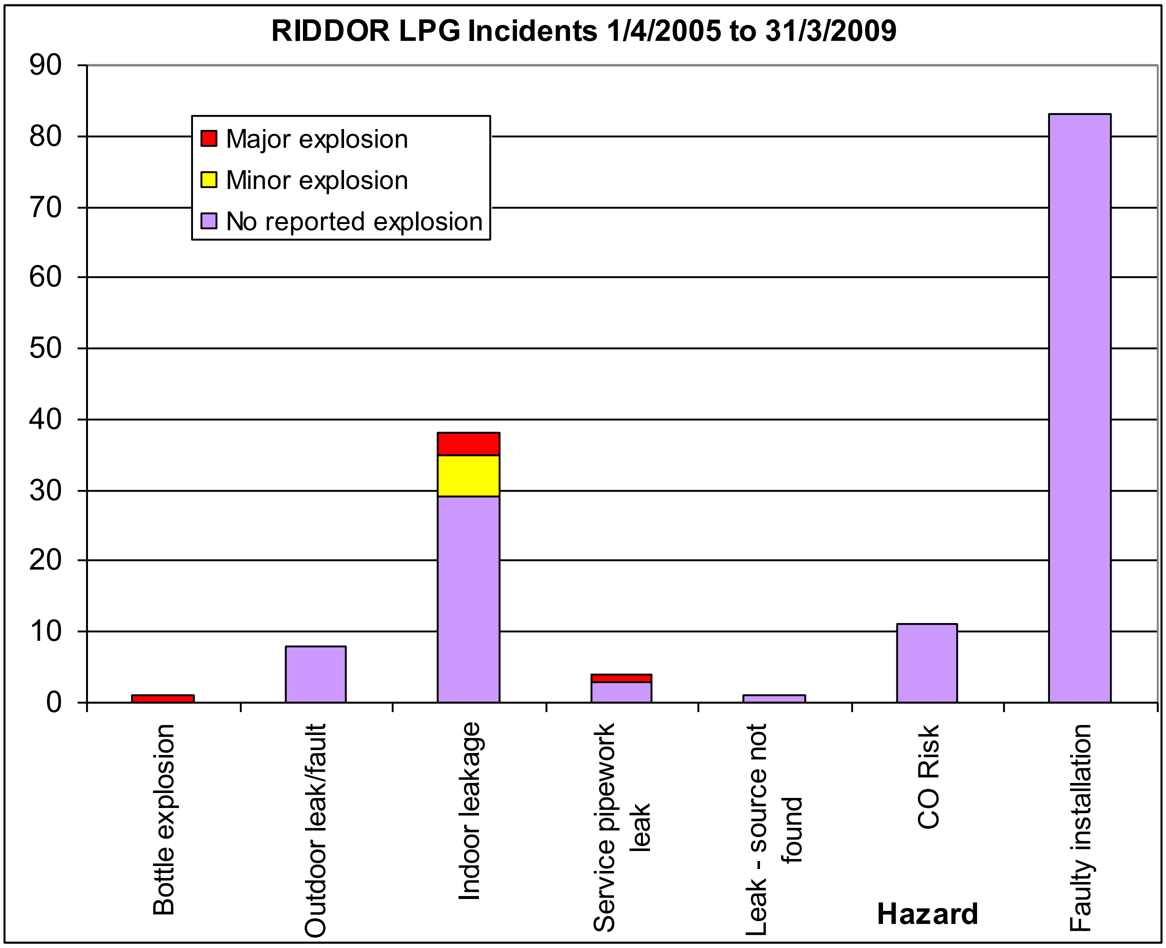
have foundations which are less permeable to gas, and better ventilation so that if gas does enter the building it is less likely to accumulate to a flammable level.

We would not expect the risk values for commercial premises with a given service pipework pressure to be significantly higher than those for domestic premises with the same pressure, though it may be possible for significantly more people to be at risk. All else being equal, larger volume spaces where the gas enters the building, and better ventilation (the upper ends of the TTAC risk ranges assume extremely limited ventilation) would reduce risk from the TTAC levels.

As part of the TTAC study, HSE provided TTAC Ltd with raw data from RIDDOR on over 15,000 reported gas incidents from April 2005 to March 2009. These were re-analysed to select incidents involving LPG (based on text searches for “LPG”, “propane” and “butane” in the incident descriptions). These 202 LPG incidents have been further re-analysed to produce Figure 1 below showing the location and severity of the various issues involved.

The “minor explosions” shown in Figure 1 involved small leaks igniting, often repeatedly, in or around a particular appliance. The “major explosions” caused significant structural damage to the properties involved, though fortunately none was fatal. The figure includes the one explosion we know of in domestic premises due to a corrosion leak in service pipework outside the building (Lanarkshire 2006 – see 2.3 above). The point we particularly note here, though, is the relatively large numbers of incidents involving LPG leaks inside the properties (nearly 10 per year). In addition, there are even larger numbers of “faulty installations” (typically a natural gas appliance being connected without modification to an LPG supply), many of which involve both a leakage/explosion and a carbon monoxide hazard. The absolute rates of incidents implied in the chart are almost certainly substantial underestimates, as there is no reason in many of these cases why a RIDDOR report should have been filed. But observing the relative numbers of incidents, a reasonable conclusion from this analysis might be that external service pipework accounts for perhaps 1-10% of the overall risk of LPG developing at flammable concentrations inside buildings.

Figure 1: RIDDOR LPG Incidents



Finally, three LPG suppliers who provided information on reported gas escapes to TTAC Ltd included substantial information on reports of other external (i.e. outdoors) and internal (i.e. inside building) gas escapes. These reports will generally understate the actual incidence of internal escapes, since the pipework and appliances concerned are the customer's responsibility, and customers may simply fix such problems without contacting their supplier. Nonetheless, the reported numbers of incidents provide a helpful perspective on the incidence of service pipework corrosion leaks in comparison with other external leaks (from tanks, pipework and fittings), and with other contributors to gas leakage into buildings (i.e. all internal leaks):

Table 6: Reported Gas Escapes per 1000 Customers per Year

Escape Type	Escapes per 1000 customers per year	Basis
All External leaks	39	All customers
All Internal leaks	3	All customers
Buried service pipework corrosion leaks	0.2 to 2	Range from min to max (per 1000 customers with buried steel service pipework)

We note that ALL of the Internal leaks will involve LPG entering a building. In contrast, only a tiny proportion of buried service pipework corrosion leaks lead to detectable gas in a building (perhaps as high as 1-10%; the TTAC research would suggest a lower figure).

These figures support a simple description of the scale of risk to people from different leak sources:

- External leaks are relatively frequent but rarely lead to harm to people.
- Internal leaks are less common but potentially much more harmful to people, as they lead in all cases to gas leakage into the building.
- Corrosion of buried service pipework makes up only a small fraction of the instances of external leaks, but those leaks may be more harmful because of their potential to track into voids below buildings. Moreover, they may lead to larger gas escapes than internal leaks because the service pipework pressure may be many times higher than that of pipework inside the building.

Overall, corrosion leaks in service pipework for LPG are a significantly smaller contributor to the risk of gas in buildings than are internal leaks (somewhere between about 0.1% and 10% based on being 0.1 to 1x less frequent, and 1% to 10% as likely to lead to significant gas inside a building).

Our key conclusion based on all of the above considerations is that the average risk to commercial LPG users from premises classified by HSE as D or E based on the GL analysis is low, in both absolute terms and relative to other gas risks. Whilst wishing to see good practice introduced and potentially corrodible underground service pipework replaced in a timely way wherever practicable, we would not wish, given the relatively small nature of this risk, to insist that, following resolution of all A-C premises by 2013, all D-E premises should be resolved by 2015.

4.5 Other LPG Users

As regards domestic users, having received the results of the TTAC research, HSE and UKLPG have developed a web-based “safety check” tool which individual users or property owners can use to decide whether they should consider action to tackle corrosion of their service pipework. This involves the user answering a series of simple questions about their gas supply, pipework material, presence of a cellar or basement, and floor. Depending on the response, a message is generated either to reassure the user that all is well, or to advise them to contact their LPG supplier. An important feature of the safety check is that at the outset it checks for a key risk factor – whether there is an Emergency Control Valve on the outside of the building (if not, it is likely that the riser has been incorporated inside the building, which would make leakage from it particularly dangerous). It also discriminates substantially between low and medium pressure service pipework.

We understand that LPG suppliers have in various ways contacted their customers to advise them of the potential issue of corroding service pipework, and to point them towards the safety check web page[15]. We are not aware at present of any alternative, paper or telephone-based system that has been made available for use by LPG users who do not have internet access. Nor are we aware of the extent of uptake of the safety check tool, of the results that have emerged, or of the action taken by users in response to those results. We are, on the other hand, aware that a number of suppliers have been proactive in contacting customers with medium pressure LPG supplies and steel service pipework, and that many such services have been replaced with a LP MDPE supply.

As regards caravan parks, we understand that HSE's policy position on these is still evolving, with information still being collected on the features of relevant gas installations. A questionnaire has been distributed to 1700 or so members of the British Holiday & Home Park Association, and Local Authorities (LAs) have been asked for lists of any other caravan parks (which must have a LA license in order to operate). The planned approach is to treat any communal buildings on caravan parks in exactly the same way as other commercial installations (use the GL analysis to assess risk of flammable gas being generated and prioritise replacement accordingly). Where there is a central gas tank and distributed pipework system it is generally the case that the site owner is responsible for the pipework, providing a single point of contact with whom to liaise.

For individual vans or mobile homes HSE has decided to adopt a more "domestic-like" approach, i.e. to provide owners with information and let them make their own decisions in relation to ventilation and pipework.

Our general view is that the risk associated with most caravans and mobile homes is likely to be small in relation to its counterpart for domestic properties, because a) ventilation underneath caravans and mobile homes is generally very good, and b) occupancy is generally lower than for domestic premises. There is an important possible exception if skirts or other enclosing structures are built around the space below a caravan or mobile home without provision for adequate ventilation, but should be a straightforward risk factor to communicate to owners or users of such caravans or mobile homes.

Given the generally low level of individual risk concerned at domestic and caravan premises, we support the HSE and UKLPG position of allowing users to make their own, informed decision about whether and when to replace or upgrade their service pipework. We note, though,

a) the possibility of small numbers of "special risk" properties[16] (domestic or caravan) which could be at much higher risk, and

[15] www.uklpg.org/advice-and-information/safety-check/

[16] In particular domestic properties where the riser has been incorporated inside the building or where there is a MP supply and a cellar, basement or other void below the floor, and caravans or mobile homes where a skirt has been built around the underside of the van, the riser is inside that skirt, and there is no provision for ventilation of the enclosed space thus created below the van.

b) that a policy of “provide information and enable users to make their own decisions” relies for its effectiveness on reaching all, or a very large proportion, of those potentially at risk.

In light of these observations we recommend that particular efforts should be made a) to help users and their suppliers identify the small number of particular risk properties, and b) to extend awareness of and ability to participate in the “safety check” exercise to households which do not have, or may not use, internet access.

5. Conclusions & Recommendations

Our conclusions and corresponding recommendations are tabulated below.

Table 7: Conclusions and Recommendations

No.	Conclusion	Recommendation
1	Resolution of all premises ranked A-C based on the GL analysis should be achievable by the end of 2013	Resolution of A-C premises should be seen through as planned by the end of 2013.
2	Pipework material, age, pressure and building characteristics and use are key risk determining factors.	a) Carbon steel should be avoided as a material for underground service pipework. b) Other widely used materials require their integrity to be proven if their life is to be extended beyond 50 years. c) Service pipework should be operated at a pressure which is as low as reasonably practicable, usually below 75mbar, although in some cases a higher pressure may be required for particular LPG end use equipment and/or needs for gas throughput.
3	Risks generally are likely to be small for premises ranked D-E, both in absolute terms and in relation to other relevant risks. Our information on the risk-critical attributes of premises is incomplete but is sufficient to enable us to prioritise them reliably with confidence that the greatest risks are reduced first.	Lower risk D-E premises may safely be deferred beyond 2015 without incurring risks which are significant either in absolute terms or relative to other risks associated with gas use. We recommend that resolution of remaining metal pipework commercial premises should be prioritised as follows: • H (by 2015): any premises which has medium pressure (>75mbar) carbon steel service pipework 10 yrs old or greater at the time of the 2009 UKLPG/HSE survey, and any one or more of the following risk factors a) is regularly used/visited by members of the public, b) is regularly occupied by more than 5 people at a time, c) has a cellar, basement or other significant void space below ground level. • M (by 2020): Any other premises with carbon steel underground service pipework • L (by 2025): Any other premises with metal pipework which is not carbon steel (e.g. copper) should be resolved by the end of 2025 unless the pipework is known to be BOTH aged less than 35 years at the time of the 2009/10 survey, AND to be operating at low pressure (75 mbar or below), in which case it may remain in place for the 50 year recommended life of such pipework.

4	Many commercial LPG service pipework installations do not appear to incorporate modern good practice, a) because of the variety of people and organisations who installed LPG service pipework, and b) because in a small percentage of cases, building works have effectively incorporated existing service pipework into buildings. Records of installations are poor but LPG suppliers are working hard to improve this situation.	a) Any LPG user being advised of the need to resolve the issue of potentially corroded service pipework should be advised of other aspects of good practice in order to avoid the perpetuation of sub-optimal pipework configurations into a new generation of service pipework. b) Users and suppliers should regularly review the fitness for purpose of service pipework in light of building works and other changes of use of users' premises. c) The central databases of installations under development by HSE should be maintained at least until the recommendations of this report have been discharged. d) LPG suppliers should maintain their efforts to update their own customer databases with the high level features of customer installations, and to promote the adoption and use of standard template gas installation records by relevant customers.
5	Resolution of this hazard will generally be via replacement of buried metal pipework with MDPE in line with our proposed timetable, but alternatives may be possible or desirable in specific cases.	a) MDPE should generally be the first choice material for LPG service pipework, though alternatives may be considered subject to a suitable assessment of soil, operating pressure etc and may be preferred in some cases (e.g. where organic contaminants are present in soil) b) Any proposal not to replace carbon steel pipework in line with our proposals should require alternative risk controls, supported by an evidence-based assessment of risks carried out by a competent person. c) Suppliers, HSE & LA Inspectors should be consistently well briefed on factors that greatly increase or decrease risk and should reflect these in any communication with duty holders and others. HSE's topic pack for Inspectors should be updated in line with these recommendations and UKLPG codes of practice.
6	We endorse the HSE/UKLPG strategy of enabling domestic and caravan/ mobile home LPG users to assess their own risks and take appropriate action, subject to ensuring a) that such enablement is extended to users who do not have or do not use the internet, and b) particular focus on the relatively rare circumstances that create particular risk.	The current activities of HSE, the LPG and partners in these areas should continue, with particular emphasis on a) the relatively rare circumstances which will place a home, static caravan or park home at particular risk, and b) extending the programme of informing and enabling users to make their own assessment of risk and appropriate decisions to LPG users who do not have access to, or who do not or cannot use, the internet.

We have evaluated the impact these proposals would have on the current advice from HSE to duty holders that D-E premises should resolve underground metal pipework risks by the end of 2015. Based on the latest version of HSE's spreadsheet database of premises, our best estimates of the numbers of properties that would fall into the various categories created by Recommendation 4 above are as follows:

Table 8: Numbers of Installations in Different Priority Bands

Priority	Resolution by	Installation/Property Characteristics	No.
1	2015	Installations with MP underground carbon steel pipework or components age 10 years or more at the time of the survey[17] with one or more of the risk factors (a) regularly used/visited by members of the public, (b) regularly occupied by more than 5 people at a time, (c) has a cellar, basement or other significant void space below ground level	2828
1*	2015*	As (1) but including any installations with incomplete survey information that COULD fall into priority 1	4140
2	2020	All other installations with underground carbon steel pipework	5172
3	2025	Installations with copper underground pipework EITHER aged >34 years at the time of the survey OR operating at medium pressure (>75mbar), OR both	1060
4	On life expiry	Copper pipework aged 34 years or less at the time of the survey	257

We are confident that a substantial majority of the installations which make up the second row of Table 8 (the 1* installations) will, when full information is available, be capable of relegation to priority 2 or lower, and that the total of replacements of D-E pipework to be carried out during 2014 and 2015 should be achievable without significantly increasing the current rate of replacements of around 200 per month.

A similar relegation process can be applied to any installations which fall into priority 2 by virtue of absence of information, rather than knowing definitively that they possess underground carbon steel pipework. That is, if such installations are discovered when further information is available as falling into a lower category, they may be moved into that category.

The incomplete information collected via the survey has led to large numbers of installations being given a priority higher than was warranted, based on premises resolved to date, and this situation will be repeated for D-E premises. In extending an opportunity to service pipework owners (i.e. the LPG users/customers) to defer their service pipework

[17] "The survey" refers throughout to the 2009-10 survey carried out via LPG suppliers in collaboration with HSE.

replacement or other risk reduction action in accordance with our recommendations, we consider it entirely reasonable that the burden of providing information that would support such deferral should fall on those owners, rather than on LPG suppliers who have already taken on a large burden of responsibility for the remediation of assets which are not their direct responsibility, or on HSE who have many other areas of work competing for resources with this one, and which present larger risks to workforces and the public.

Given the previously existing and current paucity of information about commercial and industrial LPG installations it is inevitable that the resolution of Lord Gill's recommendations has to involve a substantial information collection and updating task, in addition to any physical work done to replace or otherwise assure the integrity of underground metallic pipework.

Peter Lindstedt (chair)
Barbara Lowesmith
Tony Taig
Richard Wigfull

The HSE LPG Independent Expert Working Group

November 2011

Appendix 1: The Working Group and Terms of Reference

A1.1 Working Group Membership

The members of the Independent Expert Working Group are:

- Peter Lindstedt (chair)
- Barbara Lowesmith
- Tony Taig
- Richard Wigfull

Peter Lindstedt is Director of Research and Deputy Head of the Mechanical Engineering Department at Imperial College. He has worked in explosion related research for 30 years. His Ph.D. thesis on "Deflagration to Detonation Transition in Mixtures with LNG/LPG Constituents" was awarded the Dudley – Newitt Prize for exceptional merit. He served on the CEC appointed Model Evaluation Group for Gas Explosions from 1994 – 1998, as Chair from 1996, and retains a strong research interest in the area. He also served on the International Board of Directors of the Institute for Dynamics of Explosions and Reactive Systems from 2002-2006 and, from 2006 onwards, holds the UK position on the International Board of Directors of the Combustion Institute.

Barbara Lowesmith has worked in the oil and gas industry for 30 years, specialising in the study of major hazards, in particular through the conduct of large experiments of gas build up, fire and explosions. Her work has included the study of explosions in buildings and the investigation of gas related incidents in buildings.

Tony Taig is an independent consultant specialising in risk and uncertainty. He has worked extensively with HSE and other regulators and regulated organisations in the UK and New Zealand, and was the lead author of the TTAC research referred to in this report. He has acted as special adviser to the House of Commons Transport and other select committees.

Richard Wigfull is a European and Chartered Engineer who has been actively involved in the liquefied petroleum gas industry for over 30 years. After working for major international companies both in the UK and overseas as a specialist engineer he returned to be a member of a small family run company which specialises in contracting for the LPG industry. As a member of the UKLPG working groups since 1979, including the Technical Management Team, plus being the LPG technical advisor to several organisations including APEA, PEIMF and PELG, he has a wide knowledge of the LPG industry. He is a tutor for a variety of courses relating to LPG and coordinator for several working groups including the recent revision of the LPG section of APEA/EI “Blue Book” revision. He is also a Member of the Expert Witness Institute.

A1.2 Working Group Terms of Reference

The Group's terms of reference were to:

- Review the work already undertaken to replace industrial/commercial and domestic buried metallic LPG service pipework
- Consider the replacement of lower risk buried metallic pipework at industrial and commercial sites contextualised in terms of the residual risk presented by this aging infrastructure and GB approaches to the management of risk associated with other types of pipework (e.g. natural gas mains supply).
- Make recommendations about future next steps and timescales in relation to the remaining buried metallic pipework in industrial/commercial premises and the level of risk it presents in the context of a wider consideration of risk and normal business operations. This should explicitly address the question as to whether the current replacement timescale should be maintained, or varied, in the light of the totality of factors identified in the report.
- Produce a written report for publication summarising the findings of the group.

Without prejudice to the remit set out above, the group was also asked to include in its consideration the following points:

1. What is the scale and nature of the residual risk after the replacement of pipework at higher risk premises?
2. How does this compare to other risks within society (e.g. mains gas, oil pipes)?
3. How could users and industry tackle the residual risk as part of the routine maintenance and replacement of pipework?
4. Are there other significant factors in relation to the replacement of LPG pipework that the group consider should be identified for consideration/action?

[end of Appendix 1]

Appendix 2: Prioritisation Factors from GL Analysis

This appendix provides a number of charts illustrating the difference made by various attributes of gas installations and premises to the prioritisation from A to E which emerged via the GL analysis. The first chart for each attribute shows how premises with each attribute split between higher (A-C) and lower (D-E) priority based on the GL/HSE analysis. The second chart shows the absolute number of D-E premises with each attribute (including blanks and unknowns). The attributes considered in turn are pipework material, age, operating pressure, presence of a cellar or basement, and ground cover outside the building.

A3.1 Pipework Material

Figure A2.1: GL Results: Installations by Material

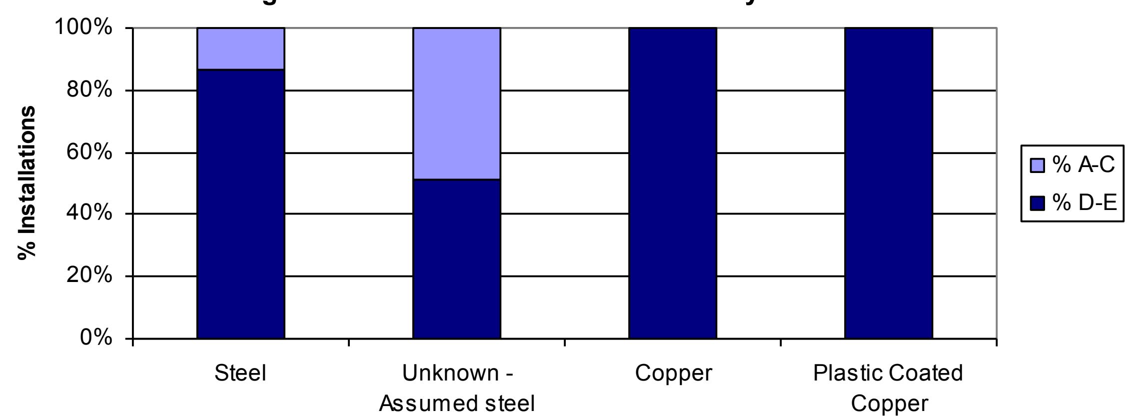
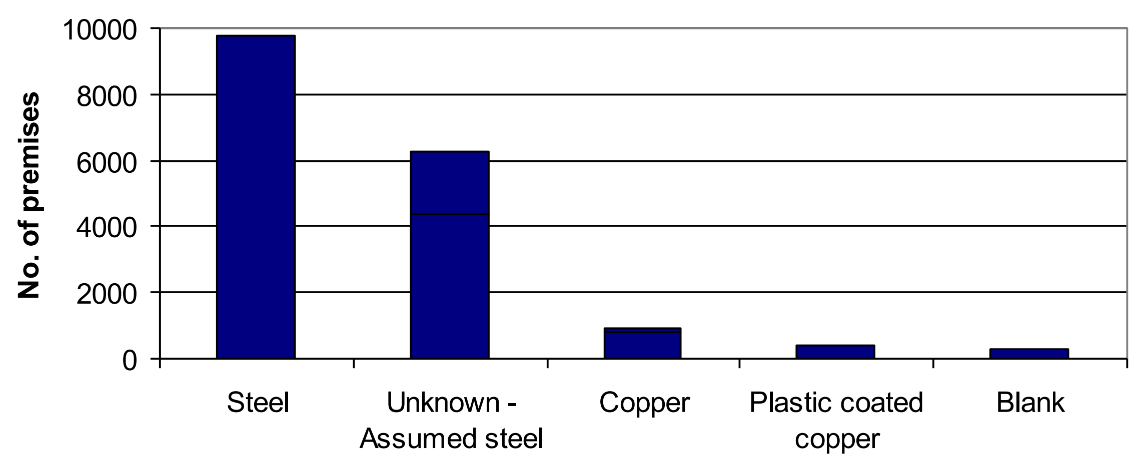


Figure A2.2: No. of D-E Installations - by Material



Key observations:

- All copper pipework is rated lower priority
- A much lower proportion of "unknown" than of steel pipework is of lower priority – this is because many "unknown material" will also be "unknown age" (both then assumed to have pessimistic values, i.e. carbon steel age 35 years).

A3.2 Pipework Age

Figure A2.3: GL Results: Installations by Age of Pipework

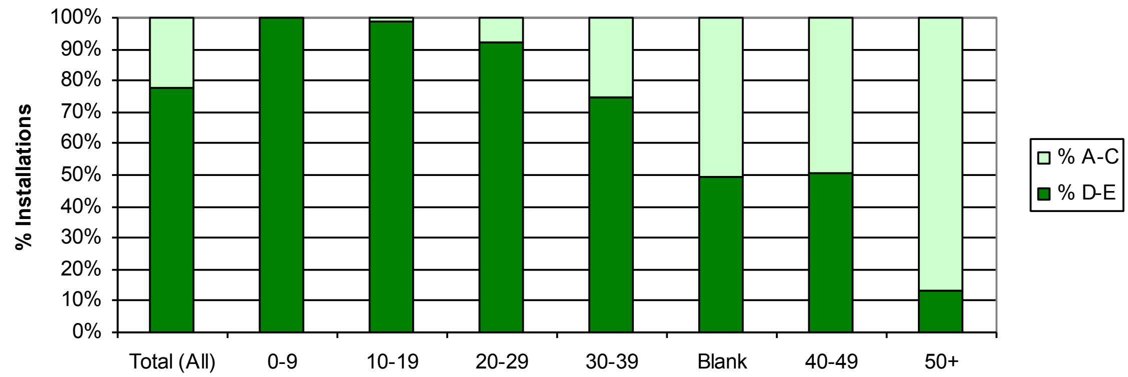
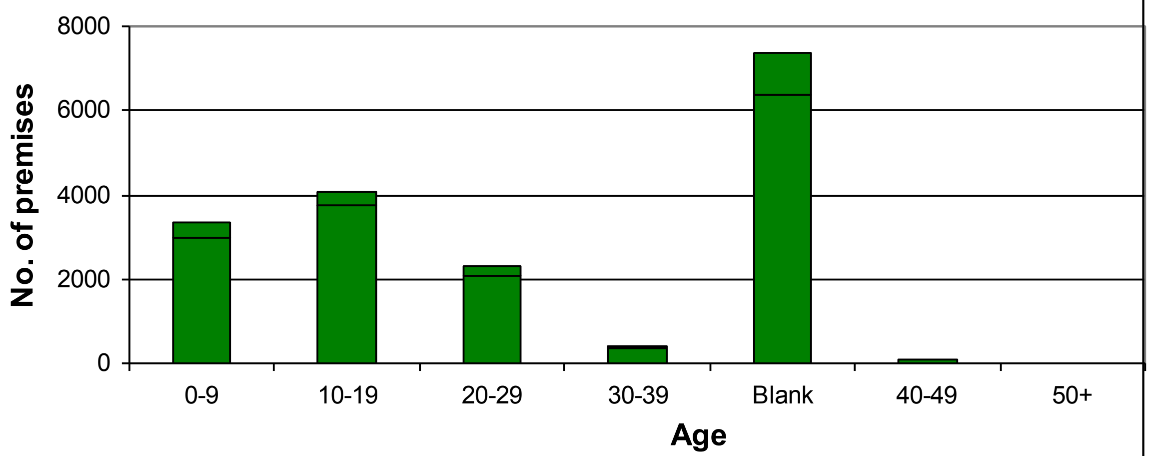


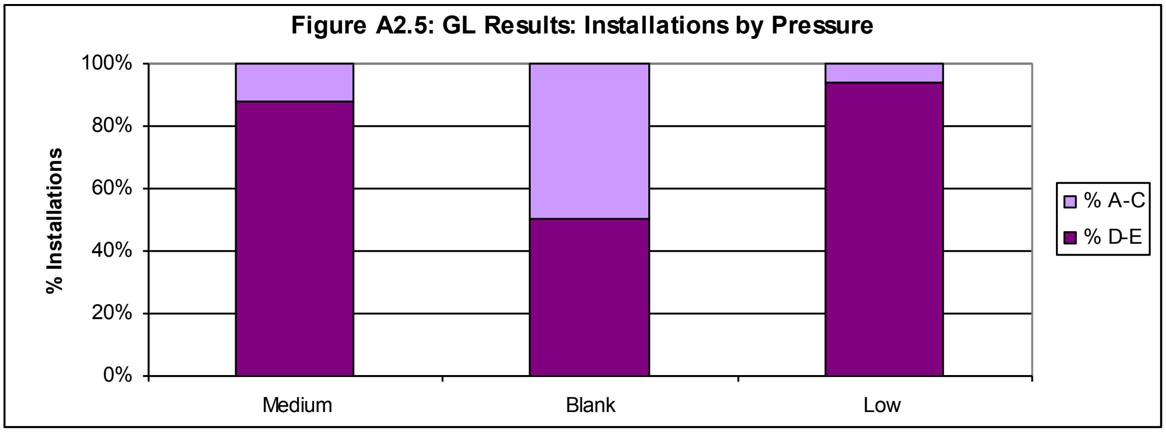
Figure A2.4: No. of D-E Installations - by Age of Pipework

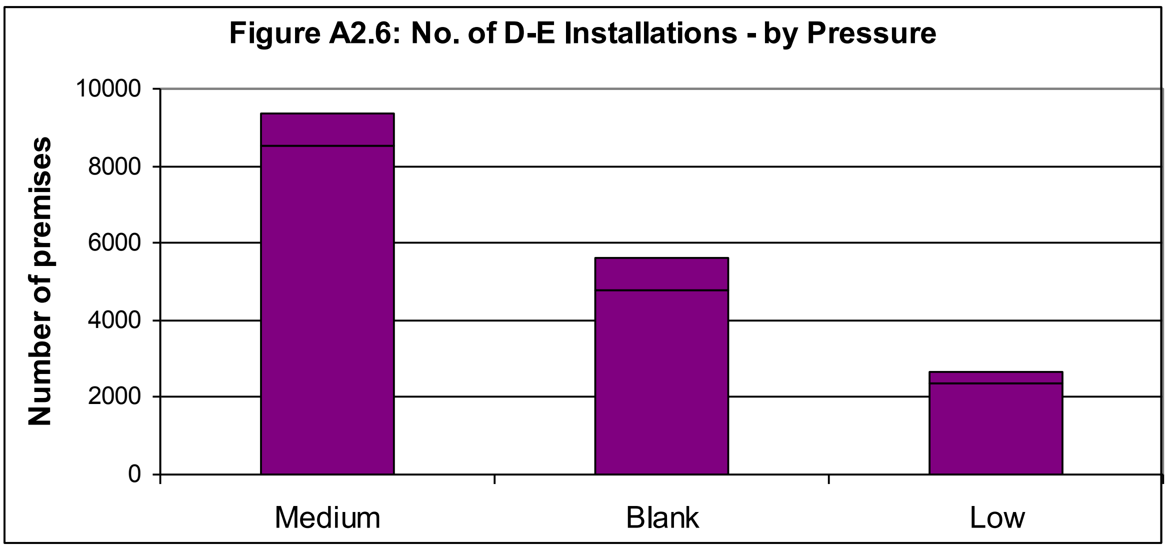


Key observations:

- All premises with pipework under 10 years old fell into the lower D-E categories
- From 10-19 years old about 99% of premises were lower priority D-E
- There are large numbers of premises for which the pipework age is not known; these were assumed to be 35 years old and are accordingly shown in-between the 30-39 and 40-49 categories.

A3.3 Service Pressure

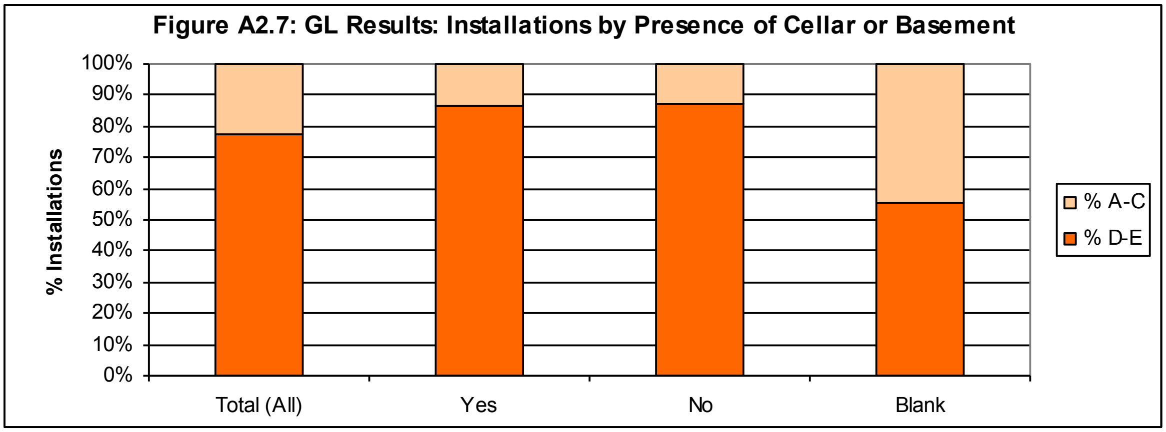


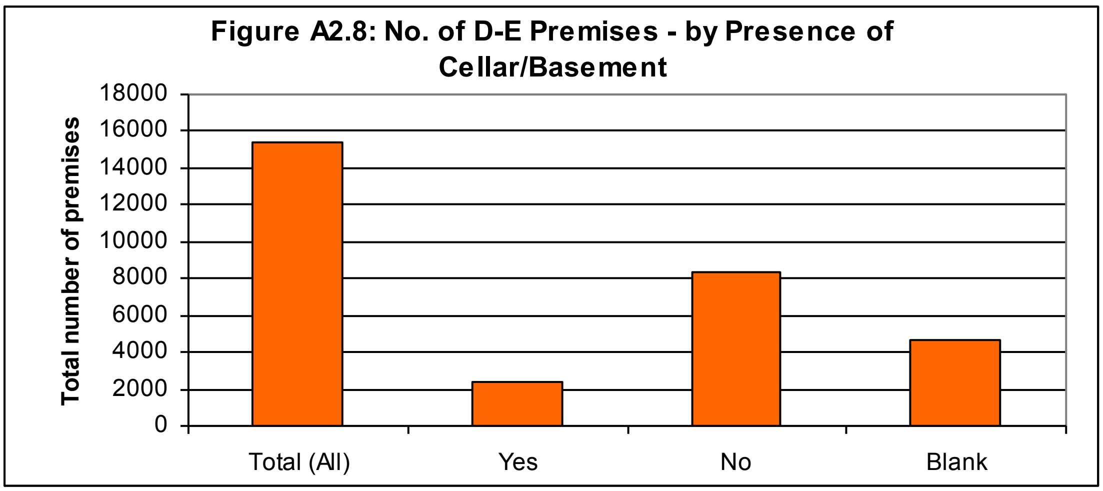


Key observations:

- A higher proportion of Low Pressure installations rated D-E than of Medium Pressure.
- A large proportion (about half) of unknown pressure installations were rated A-C. As for Pipework Age this is because premises with unknown pressure (for which a pessimistic assumption of "MP" was made) are more likely than other premises to have other unknown attributes such as age and material (for which pessimistic assumptions are also made).
- A high proportion of commercial premises have MP service pipework.

A3.4 Presence of Cellar/Basement

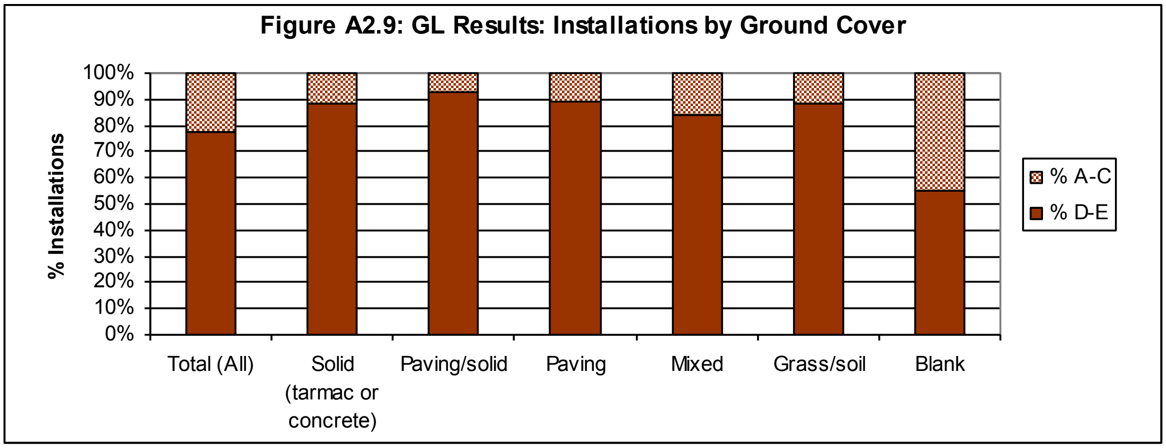


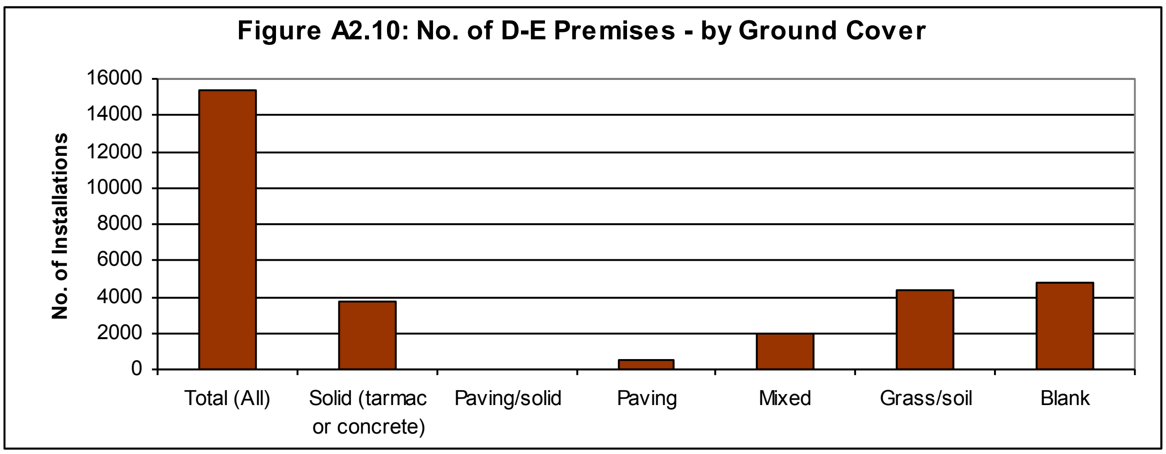


Key observations:

- Presence or otherwise of a cellar or basement does not appear to have made much difference to the proportion of premises classified as D-E
- As with other parameters, a higher proportion of blanks have resulted as higher priority (i.e. lower proportion of D-E) because of the pessimistic assumptions made where attributes were not known.
- A relatively small proportion of premises (just over 10%) have cellars or basements.

A3.5 Ground Cover outside Building





Key observations:

- In comparison with other factors, ground cover does not appear to have a consistent substantial impact on the A-E prioritisation – the two most substantial numbers of responses (Solid tarmac or concrete on the one hand; grass/soil on the other) emerged with similar proportions of premises in the lower (D-E) category.
- As for other attributes, the "outlier" in terms of prioritisation was the blank entry, because of the combined pessimistic assumptions used for premises with multiple blank entries.

[end of Appendix 2]

Appendix 3: Glossary

CO	Carbon monoxide
COIN	HSE database of accident and incident investigations
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations (SI 2002 No. 2776)
GIB	Gas in buildings
GL	GL Noble Denton Ltd
GSUIR	The Gas Safety (Installations and Use) Regulations (SI 1998 No. 2451)
HSE	the Health and Safety Executive
ICL	ICL Plastics, scene of the Glasgow explosion in 2004
JCB	Familiar brand name for mechanical diggers/excavators
LA	Local Authority
LFL	Lower flammable limit (For LPG approximately 2 to 10% gas in air)
LPG	Liquefied Petroleum Gas – for this report assumed to be commercial propane.
MDPE	Medium Density Polyethylene
PSSR	Pressure Systems Safety Regulations (SI 2000 No. 128)
RIDDOR	Reporting of Injuries, Diseases and Dangerous Occurrences (regulations 1995, and associated HSE incident database in this report)
TTAC	TTAC Ltd, author of 2009 report into risk at domestic LPG installations
UKLPG	Trade body of the UK LPG industry. UKLPG was made up of the amalgamation of the two previous organisations LPGA (which was originally known as LPGITA) and ALGED.