RISK BASED LEAKAGE SURVEY

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AUSTRALIA
ABSTRACT

Gas companies worldwide have, for some time, supplemented the traditional “reactive” locate and repair of public reported gas escapes with a more proactive leakage survey approach.

SP AusNet’s objective was to find optimum balance between proactive leak management (leakage survey) and reactive leak management (public reported leaks).

By utilising a risk based leakage survey SP AusNet has been able to reduce the cost of conducting leakage survey and leak repair, lower environmental effects of gas leaking into the atmosphere and increased public and network safety.
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INTRODUCTION:

SP AusNet has 8,500 km of distribution and 180 km of transmission pressure pipeline supplying gas to over 500,000 customers in western Victoria, which is in the southeast corner of Australia. SP AusNet also distributes electricity to over 650,000 customers in the east of Victoria and own and operate the electricity transmission across Victoria. SP AusNet is a subsidiary of Singapore Power Industries who own and operate gas distribution, electricity distribution and electricity transmission in Singapore.


SP AusNet plays a vital role in the energy supply industry of Victoria, Australia. The Group’s electricity transmission and distribution networks, along with our gas distribution assets, enable the Group to deliver a full range of energy-related products and services to industrial and domestic customers.

SP AusNet have a history of innovation, of not just accepting traditional thinking. We challenge the common position and strive for technical and ingenious means to improve the efficiency of the gas network.

SP AusNet have successfully utilised Reliability Centred Maintenance (RCM) to reduce costs, but still maintain output performance in fields such as regulator station maintenance, exposed pipe and gas main replacement programs.
RISK BASED LEAKAGE MANAGEMENT:

Leakage survey is a risk mitigating activity that uses special gas detection equipment to survey transmission and distribution mains. The intent of leakage survey is to detect leaks at an early stage and, by timely repair, avoid gas concentration in air being raised (particularly in confined spaces) to the lower explosive limit (LEL) of 5% gas in air (i.e. 50,000 ppm). At LEL, gas will ignite in the presence of an ignition source (spark or flame) - the consequence being fire or explosion. Gas must be discernible at one-fifth of LEL (i.e. 10,000 ppm).

Leakage survey is also conducted to detect leaks less than 10,000 ppm (generally before the public can smell gas), thus both reducing repair cost and keeping the public perception of safety high. Leakage survey equipment is able to detect gas at concentrations as low as 1000 ppm.

Additionally, leakage survey is carried out as an environmental tool and used to reduce the volume of gas leaking into the atmosphere and reducing contributions to the ‘Greenhouse’ effect.

Previously three survey regimes were used, depending on the area category, to detect and repair leaks.

<table>
<thead>
<tr>
<th>Survey</th>
<th>Where applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Six-monthly</td>
<td>High-risk; internal services</td>
</tr>
<tr>
<td>Annual</td>
<td>Places of perceived higher risk due to their population density near gas assets or which have confined spaces (e.g. in office buildings, schools, hospitals etc);</td>
</tr>
<tr>
<td>Four-year ('Systematic')</td>
<td>All other locations</td>
</tr>
</tbody>
</table>

Table 1: Old Leakage Survey Regime

Catastrophic failures leading to fire/explosion are known to have already occurred (e.g. Larkhall, Scotland, December 2000, failure of 200mm DI pipe operating at 2bar, where failure and subsequent gas ingress to property resulted in an explosion which killed a family of four).

AIMS:

Gas companies worldwide have, for some time, supplemented the traditional “reactive” locate and repair of public reported gas escapes, with a more proactive leakage survey approach.

SP AusNet’s objective was to find optimum balance between proactive leak management (leakage survey) and reactive leak management (public reported leaks)

REVIEW OF INTERNATIONAL LEAKAGE SURVEY PRACTICES

A review of international leakage survey practices was conducted to determine world’s best practise.

Twelve gas companies from seven European countries and the USA were reviewed.

The countries reviewed were:

- Belgium
- France
- Germany
- Italy
- The Netherlands
- Spain
- United Kingdom
- USA
Leak detection surveys usually take the form of road-going vehicles fitted with suitable leakage detection equipment, coupled with walking surveys for those pipes not accessible by vehicles.

The types and frequencies of such surveys vary considerably dependant on the type of distribution system that is being operated (i.e. pressure, material, age, any previous leakage history etc.), or through legislative requirements imposed by the country's safety regulator.

The principle focus of leakage surveying in the UK is to locate and repair “serious” escapes (i.e. those likely to lead to fire/explosion), which in turn will give the safety regulator, and the general public, the confidence that the gas supply system is being managed in a safe and responsible manner.

Within the context of increasing liberalisation of the gas markets, and growing competition, gas distribution companies are increasingly finding it necessary to reduce operating costs.

**Summary Of Findings:**
- Legislation (either direct or implied) requires leakage surveys in five countries.
- Frequencies of surveys range from one to five years for iron and steel pipes without corrosion protection, and from one year to seven years for polyethylene pipe and corrosion protected steel pipes.
- Material, pressure and previous leakage history (of the particular section of pipe) were the major factors considered when considering the frequency of leakage surveys.
- Safety was the unanimous consideration when asked the main reason for undertaking leakage surveys.
- Flame ionisation detection is the most commonly used detector.
- The number of leaks found per km during survey ranged from zero to 1.56, reflecting the differing materials and principles of leakage detection in Europe.
- As expected, leakage from ductile and grey cast irons was 10 times the rates of polyethylene pipe and corrosion protected steel.
- Costs ranged from £20 to £121 per km surveyed, averaging at £50.
- Timescales ranged from 0.75 hrs to 4 hrs per km of pipe surveyed depending on whether the pipe was surveyed by vehicle or on foot.
- Leak deferment for non-urgent leaks varied from immediate repair to ongoing monitoring (USA).

It is clear there is a wide range of approaches to leakage surveying techniques throughout the European gas companies. The lack of synergies in the areas of legislation, the choice of what pipes are surveyed and at what frequencies, leakage rates and costs, despite the industries having being established since the mid 1800’s and their relatively close proximity to each other, is somewhat surprising.

The one common thread was that all companies overwhelmingly agreed that safety was the reason for undertaking leakage surveys. However, there was no consistency in approach to focus leakage survey on assets that are most ‘at risk’. No company ranked either environmental issues or minimising gas lost to atmosphere higher than safety.
QUANTITATIVE RISK ANALYSIS

Whilst leakage survey is principally undertaken on safety (not economic) grounds, the optimum level of leakage survey is clearly the balance between reasonable expenditure and acceptable risk reduction. There's little point in locating “pin-hole” leakage on steel or polyethylene pipes where the likelihood of subsequent catastrophic failure is very low (as the integrity of the remaining pipe surrounding the hole is sufficient to contain the failure, unlike its iron counterparts), and importantly where the cost of gas lost to atmosphere is negligible compared to the cost of locating and undertaking repairs.

Using quantitative risk analysis, SP AusNet initially reviewed and analysed risks inherent in the current survey and repair processes to establish both acceptable risk and cost datum’s. The risk-based alternative survey regime was then able to be benchmarked to those datum’s and deliver substantial on-going annual savings at an acceptable risk.

Methodology
SP AusNet undertook the following steps to consider and move from current to proposed survey regime:

- Analysis of current survey process and determination of current risk (to establish datum’s)
- Analysis consisted of identification of the following key parameters:
  - Pipe types
  - Area categories
  - Leak definition
  - Fault tree analysis – probabilities of preconditions
  - Outcome analysis – probabilities of consequences

Pipe Types
The following pipe types are used in the SP AusNet network:
- Cast iron
- ‘Unprotected’ steel (i.e. not cathodically protected)
- ‘Protected’ steel (i.e. cathodically protected)
- Polyethylene
- Polyvinylchloride (PVC)

Historical Leakage Data
Historical leakage data is shown in the table below. The data has been accumulated from the SP AusNet network over a 10-year period from 1993 to 2002 for the entire length of all mains (in metres) by pipe type. For each pipe type, leakage has been calculated in leaks/km/yr (the system average is also shown in bold).

<table>
<thead>
<tr>
<th>Material</th>
<th>10 year total</th>
<th>Length (m)</th>
<th>leaks/km/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron</td>
<td>17,218</td>
<td>1,031,000</td>
<td>1.67</td>
</tr>
<tr>
<td>Unprotected steel</td>
<td>4,632</td>
<td>597,567</td>
<td>0.78</td>
</tr>
<tr>
<td>System average</td>
<td><strong>28,770</strong></td>
<td><strong>8,093,567</strong></td>
<td><strong>0.36</strong></td>
</tr>
<tr>
<td>PVC</td>
<td>1,839</td>
<td>655,000</td>
<td>0.28</td>
</tr>
<tr>
<td>Protected steel</td>
<td>2,943</td>
<td>2,525,000</td>
<td>0.12</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>2,127</td>
<td>3,102,000</td>
<td>0.07</td>
</tr>
<tr>
<td>Transmission</td>
<td>11</td>
<td>183,000</td>
<td>0.01</td>
</tr>
</tbody>
</table>

1993 to 2002 data

Area Categories
The following area categories, were based on Australian Standard AS1697 1985 (SAA Gas Pipeline Code), are applicable for the purpose of leakage survey:
• **Category 1:** any location that has 10 or fewer buildings per kilometre (100 m frontage) intended for human occupancy and within 20 m of the pipe. Eg. Open rural areas

• **Category 2:** any location that has more than 10 but fewer than 100 buildings per kilometre (up to 10m frontage) for human occupancy and within 20 m of the pipe. Eg. Suburban domestic housing, strip/commercial shops up to 10

• **Category 3:** any location that has more than 100 buildings per kilometre (<10 m frontages) for human occupancy or a building occupancy of 20 persons or more during normal use. Eg. Flats/units up to 4 floors, restaurants, enclosed sporting complexes, schools, strip commercial shops greater than 10, community hospitals etc

• **Category 4:** any location where buildings with four or more storeys above ground are prevalent. Eg. High-rise buildings, high-rise shopping centres, internal services greater than 20 m in length.

**Leak Classifications**
SP AusNet used two classes of leak. These were–

**Class 1** - for immediate attention *(unplanned repair)*
- Public reported
- Presence of gas in or around buildings
- Gas in confined spaces (pits, drains, tunnels, etc).

**Class 2** - repair within 6 or 12 months *(planned repair)*
- Leaks detected on systematic cycle - 48 months
- Leaks detected on annual cycle - 12 months

A greater cost is incurred for Class 1 compared with Class 2 leaks by virtue of the need for immediate response. Costs include Call Centre processing, stand-by emergency response personnel as well as stand-by repair crew (as needed). Hence a reduction in reliance on unplanned repair contributes to both risk reduction and significant cost savings.

**Fault Tree Analysis – Probabilities Of Preconditions**
A gas leak constitutes a *loss of containment* of gas from a pipe. A numbers of factors ‘lead up to’ or are the ‘preconditions’ for such loss of containment. Preconditions include ground movement, manufacturing defect, faulty installation, tree roots, third-party damage, joint deterioration etc.
In the fault tree analysis shown in figure 1 for cast iron pipe, probabilities are assigned to the preconditions and computed to give a final overall probability of a gas leak.
Outcome Analysis – Probabilities Of Consequences
Outcome analysis considers the probabilities of possible consequences once loss of containment occurs. As shown below, consequences have been categorised into ‘not detected by the public’, ‘not detected by inspection’, ‘response not successful’, ‘gas confined’, ‘LEL achieved’, ‘ignition’ which was then subdivided into ‘fire’ and ‘explosion’.

The following outcome analysis Figure 2 was developed for cast iron pipe.
Figure 2: Consequence Analysis For Cast Iron Pipe In Area Category 2

Known or ‘best-estimate’ costs were assigned to each of the consequences. The risk was determined as the product of the probability and the estimated or actual cost of the consequence and is therefore expressed in dollar cost. Note that the cost of leak repair was also taken into consideration as a known (and very significant) cost associated with detected leaks.

Key findings from fault tree and outcome analyses

- The number of leaks per length of pipe is material-dependent.
- With the exception of cast iron, leakage rate is not significantly influenced by age.
- Leak risk for a given pipe type varies with area category.
- Leak risk cost is extremely small compared to repair cost
- Cost of leakage survey is small compared with repair cost.
Optimising Survey Intervals And Repair
The graph below figure 3 depicts total pipe leakage costs against survey interval for cast iron pipe in area category 2. Depicted costs are leakage survey; repair from leakage survey, public reported leakage repair and total.

![Graph of leakage costs plotted against survey interval for cast iron pipe in risk category 2](image)

Figure 3: Graph of leakage costs plotted against survey interval for cast iron pipe in risk category 2

As the leakage survey interval is extended then, per annum the:

- Number of public reported leaks increases, thus cost of public reported leak repairs increases
- Number of leakage survey leaks detected reduces, thus cost of leakage survey detected leak repairs decreases
- Number of leaks not detected increases, thus cost of unaccounted for gas (UAFG) increases
- The probability of a leak creating a fire increases. Thus the risk cost of a fire increases
- The probability of a leak creating an explosion increases, thus the risk cost of an explosion increases
- Cost of surveying is decreased

The graph in Figure 4 depicts the sum of costs (shown above) for cast iron pipe and highlights an optimum (least cost) condition at 2 years.
Risk-Based Leakage Survey Outcomes

As a result of the in-depth analysis within the constraint of maintaining an acceptable risk, the outcomes derived from the first stage constitute a quantum change for the leakage survey process. The changes have resulted into a significant reduction in operating costs, without increasing network performance.

Although the quantitative risk assessment showed that leakage survey intervals could be vastly increased (leakage survey on polyethylene pipe < 20 years), a more conservative or optimised approach was adopted. The following tables show comparative survey intervals for current and old practices, calculated (theoretical) and proposed (optimised) regimes. The very significant benefits projected come notwithstanding the conservative nature of the changes that were confined to area categories 1 and 2.

<table>
<thead>
<tr>
<th>PIPE TYPE</th>
<th>SURVEY INTERVALS (Years)</th>
<th>AREA CATEGORY</th>
<th>1 &amp; 2</th>
<th>3 &amp; 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current</td>
<td>Calc’d</td>
<td>Optimised</td>
<td>Current</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Unprotected Steel</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Polyethylene pipe and Protected Steel</td>
<td>4</td>
<td>20</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>PVC</td>
<td>4</td>
<td>20</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Transmission Pipe</td>
<td>4</td>
<td>20</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Internal Services</td>
<td>0.5</td>
<td>-</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 1 Survey intervals
<table>
<thead>
<tr>
<th><strong>Leak Class</strong></th>
<th><strong>Action</strong></th>
<th><strong>Detail</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Immediate repair</td>
<td>Public reported leaks. Confined space leaks.</td>
</tr>
<tr>
<td>2</td>
<td>Repair in 6 months</td>
<td>All leaks detected by survey in category 3 and 4 locations.</td>
</tr>
<tr>
<td>3</td>
<td>Repair in 12 months</td>
<td>All leaks &gt;1000 ppm detected by survey in category 1 and 2 locations.</td>
</tr>
<tr>
<td>4</td>
<td>Monitor annually</td>
<td>All leaks &lt;5000 ppm detected by survey in category 1 and 2 locations with open ground between main and building line.</td>
</tr>
</tbody>
</table>

Table 2 Adopted leak and repair classifications

Benefits of the new Leakage Survey regime were:

- Reduced risk of liability to senior management
- Cost of leakage survey is reduced
- Higher proportion of leaks are undertaken in a planned manner
- Reduced water ingress and subsequent consumer outages,
- Improved reliability Key Performance Indicators (KPI)
- Reduced cost to sub contractors
- Reduced maintenance cost
- Improved rapport with technical regulator
- Consumer confidence in gas safety will be increased as fewer leaks will be detected by the public

SP AusNet introduced the first stage changes to leakage management in 2002.

However, we believed further improvements could be made and that a united approach with the other two gas distribution companies in Victoria was required. SP AusNet had proved theoretically that further changes could be made. The quantitative risk assessment showed that leakage survey on polyethylene pipe could be extended beyond 20 years. A wider statistical analysis with, superior and broader data, was needed.

AUSTRALIAN STANDARDS

In 2003 Standards Australia launched an initiative with the Australian gas industry to shape the future development of national gas Standards. Following changes in the Australian gas industry, Standards Australia became responsible for the development and maintenance of gas technical Standards. The Australian Gas Association [AGA] previously carried out this role that principally covered technical Standards relating to gas installations and gas appliances and components.

To ensure transparency and sound standardisation outcomes for the gas industry and the Australian public, Standards Australia reviewed all the gas distribution Standards.

In 2005 the Australian Standards introduced a new standard for the gas distribution businesses, AS 4645 – 2005 “Gas distribution network management”. The Standard was prepared to provide an adequate risk based framework for management of a gas distribution system, by specifying performance requirements and avoiding detailed prescription as much as is possible. AS 4645 – 2005 specifies requirements for safe management of a fuel gas distribution network throughout the life cycle of all elements of that network.
Section 6.2.5 Leakage surveys states:
“The network shall be surveyed for leaks to a schedule designed on risk management principles”

LEAK MANAGEMENT SECOND STAGE

The changes to the Australian Standard have allowed gas distribution businesses in Australia to introduce further innovation in the management of gas networks.

With the assistance of the other two distribution companies in Victoria an analysis of Victorian leakage data was conducted.

Gas assets with high probability of failure that are in high hazard locations have the greatest potential for future failure from breaks. Worldwide experience indicates that it is the release of large volumes of gas from breaks that has the potential to create an explosive mixture in a property.

Joint leakage or pinhole corrosion failures do not release significant volumes of gas and have proved elsewhere internationally not to be a failure type that leads to serious incidents such as explosions in properties.

Data Analysis
Victorian mains leakage data from 2001 to 2004 was analysed for each company and as, combined data, by: -

- Mains Leakage type – broken mains, corrosion, joint leak
- Mains Material type
- Leak identification – leakage survey or public reported leak
- Leaks per 1,000km of material
- Diameter – small (< 150mm), medium (150mm), large (> 150mm)
- Month and Year
- Breakage Zone – low (<0.2), medium (0.2 to 0.4) and high (>0.4) (breaks/km/year)
- Breakage Zone vs. future failures

The higher risk leaks (breaks) tend to be found by public reported leak rather than leakage survey by about a factor of 10. This can be expected, as these failures tend to be a significant release of gas that is easily identified by the public and reported.

Figure 5 shows the average number of broken mains by material type over 12 months. There are seasonal peaks in broken mains between February and April – at the end of a long dry summer, when maximum tensile ground movement affects cast iron mains. There is also a peak in July – which occurs after seasonal rain.
The public reported leak response process is critical in identifying higher risk cast iron breaks that generally release larger gas volumes when compared to joint and corrosion leaks.

The chance of identifying breaks at the time of the leakage survey is much less. The small number breaks identified by leakage survey are frequently hairline breaks that are not releasing significant amounts of gas and hence not found by public reported leak response.

Leakage survey identified 5 times the number of joint leaks than by public reported leak response, suggesting that the majority of leaks found by leakage survey are small, low risk leaks that are not easily identified by smell. These tend to be joint leakage in low breakage zones.

Leakage survey is not focused at times of maximum ground movement.

Leakage survey on low risk polyethylene pipe and protected steel assets is providing little if any benefit.

Leakage survey frequencies can be extended on medium risk assets (medium and low breakage zone cast iron, PVC, non protected steel), taking account of each categories failure/breakage rate and their location (e.g. hazard locations).

For each main, a breakage zone has been calculated that depends on the breakage rate per km of all other cast iron main within 500m of the main.

There is a general pattern of medium breakage zones between high and low breakage zones, which are a good sense, check of the concept. High breakage zones align with clay type soils, whilst low breakage zones align with sandy soils. The linear patterns confirm there is a relationship between the high breakage zones and geophysical features across Melbourne.
Cast Iron High Breakage Zones are readily identified and have a high likelihood of future breaks. These are potential targets to increase the effectiveness of leakage survey. Figure 6 shows the spread of high breakage zones.

Figure 6: Melbourne Metropolitan Breakage Zones

In scheduling the repair of leakage survey indications, priority should be given to small diameter cast iron mains in high breakage zones in high hazard locations. These are most likely to fail as a break.

Leakage survey indications that are not classified for investigation and repair should be deferred and monitored on subsequent leakage surveys and/or replaced on the block renewal programme.

Focus leakage survey on higher risk cast iron assets at times of higher ground movement.

CONCLUSION:

SP AusNet will alter its leakage survey regime to include:

- Annual survey all high breakage zone cast iron assets in high hazard locations at times of high breakage (around March/April). Breakage zones are to be reviewed annually.

- “Trigger” surveys to be introduced on high breakage zone assets in high hazard locations at any other time of high ground movement/breakage rates. Leakage survey sensitivity to be adjusted to only find higher risk gas releases from breaks.

- Leakage survey frequencies on the remaining cast iron, other iron, PVC and non protected steel assets shall be extended, taking account of the potential likelihood of higher risk failure/breaks and the location of the asset (e.g. hazard locations). These frequencies shall be subject to continuous monitoring and modulation.

- Leakage survey priority is to be given to small diameter cast iron mains in high breakage zones in high hazard locations. These are more likely to result in a break failure than any other category.

- Only polyethylene pipe or protected steel assets considered high risk of catastrophic failure due to age, quality control and previous failure are to be considered for leakage survey.
• Leakage survey shall be discontinued on all other polyethylene pipe and protected steel assets.

• Any leakage survey indications that are not classified for investigation and repair (i.e. those that are not Class 1 or Class 2 leak) shall be deferred and monitored on the subsequent leakage surveys and/or replaced by block mains renewal programme.

The progression from the old leakage survey regime, to quantitative risk assessment as of 2002, and then to the new leakage management system is shown in table 3.

<table>
<thead>
<tr>
<th>PIPE TYPE</th>
<th>SURVEY INTERVALS (Years)</th>
<th>AREA CATEGORY</th>
<th>1 &amp; 2</th>
<th>3 &amp; 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Old</td>
<td>2002</td>
<td>New</td>
<td>Old</td>
</tr>
<tr>
<td>Cast Iron</td>
<td>4</td>
<td>2</td>
<td>Trigger</td>
<td>1</td>
</tr>
<tr>
<td>Unprotected Steel</td>
<td>4</td>
<td>4</td>
<td>Trigger</td>
<td>1</td>
</tr>
<tr>
<td>Polyethylene pipe and Protected Steel</td>
<td>4</td>
<td>8</td>
<td>Nil</td>
<td>1</td>
</tr>
<tr>
<td>PVC</td>
<td>4</td>
<td>6</td>
<td>Trigger</td>
<td>1</td>
</tr>
<tr>
<td>Transmission Pipe</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Internal Services</td>
<td>0.5</td>
<td>0.5-</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 3: New leakage management system

By utilising a risk based leakage survey SP AusNet has been able to reduce the cost of conducting leakage survey and leak repair, lower environmental effects of gas leaking into the atmosphere and increased public and network safety.
ACKNOWLEDGEMENTS:

Alinta Gas Services
Origin Energy
GTL Business International
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