CALCULATION OF PE LEAKAGE

PE distribution main leakage estimation for Independent Gas Transporters

Independent Networks Association

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Objective: To determine an updated estimate of PE leakage based on historic National Leakage Tests but taking into account the newer age profile of INA mains.

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0	2020-10-14	First issue	Claire Ashton & Edward Faragher	Jay Naylor	Suzanne Bradbury
1	2020-10-26	Amendment to GTC pipe length and correction of cited leakage rate in Exec summary/Conclusions	Claire Ashton & Edward Faragher	Jay Naylor	Suzanne Bradbury
2	2020-12-23	Updated with IGT comments	Claire Ashton	Jay Naylor	Suzanne Bradbury

Table of contents

1 EXECUTIVE SUMMARY

The Independent Networks Association (INA) require an estimate of leakage from polyethylene (PE) mains for use in the gas industry Shrinkage and Leakage Model. Such estimates are available from the 1992 and 2002 National Leakage Tests (NLT) but the Independent Gas Transporters (IGTs) have newer PE mains than those represented in the 1992 and 2002 NLT.

The following conclusions have been drawn from a review of the 1992 and 2002 National Leakage Tests, analysis of IGT asset and failure data and consideration of PE pipe history:

- IGT pipe installation dates are, on average, more recent than GDN installation dates.
- PE pipes, whilst considerably less leaky than iron or steel mains, do exhibit occasional failures, including leaking joints and top tees, so a nominal leakage rate is appropriate.
- PE pipe installation and jointing techniques have changed little since the most recent National Leakage Tests (NLTs), and the leakage rate derived in 2002 is currently in use by the GDNs.
- A new leakage estimate for IGT PE mains has been calculated as **0.0061 m^3/hr/km** (which compares to the current GDN value of 0.0073 m^3/hr/km); this is based on a recalculation of the 1992 NLT PE leakage rate, followed by use of the recalculated 1992 value and the measured 2002 NLT value to estimate a leakage rate for networks with pipes laid since 1990.
- Neither the GDN or IGT leakage rate take into account potential differences in leakage rate between low and medium pressure mains. Differences in service pipe material are also discounted as both PE and steel services were found to have zero leakage in the 2002 NLTs. It may therefore be reasonable to conclude that the difference between the GDN and IGT leakage rates could be greater than the values cited here due to the possible impacts of steel services, medium pressure networks and mains replacement (additional joints etc.).
- Other factors, including venting, above ground installations, interference damage, own use gas and theft of gas, are taken into account elsewhere in the Shrinkage and Leakage Model (SLM) so are not considered within the PE leakage rate estimation.

2 INTRODUCTION

The Independent Networks Association (INA) require an estimate of leakage from polyethylene (PE) mains for use in the gas industry Shrinkage and Leakage Model (SLM). Such estimates are available from the 1992 and 2002 National Leakage Tests (NLT) but it is expected that the Independent Gas Transporters (IGTs) will have newer PE mains than those represented in the 1992 and 2002 NLT. As such, the following work has been undertaken in the sections below, to provide a specific PE leakage estimate for the IGT networks.

- comparison of IGT and NLT PE pipe assets (length and installation year)
- analysis of PE failure data from IGT companies
- review of PE pipe development
- comparison of other differences between IGT and GDN PE networks that may give rise to differences in the leakage estimate

These analyses have then been combined with the 2002 NLT data to provide an estimate of PE leakage for the current portfolio of IGT PE pipes.

2.1 1992 National Leakage Tests

A programme of work was undertaken in 1992 to perform leakage tests at 574 sites on a range of pipes of various diameters and materials (pit cast, spun cast, ductile iron, steel and PE). Of these, a leakage rate was successfully obtained at 32 PE sites [1].

2.2 2002 National Leakage Tests

A further programme of work was undertaken in 2002 to perform leakage tests at 862 sites, again on a range of pipes of various diameters and materials (pit cast, spun cast, ductile iron, steel and PE). Of these, a leakage rate was successfully obtained at 92 PE sites [2].

3 ASSET DATA

PE asset data has been collated from six of the IGT companies and distributed by installation date and length (Table 1). Where the installation year was unknown this has been estimated based on advice from the company i.e. spread evenly over period x-y. Assets with estimated installation dates account for 4,072 km (17.9%) of IGT PE mains. The IGT pipe data has then been compared to the installation dates for the PE pipes tested in the 1992 NLT [1] and 2002 NLT [2] and also the estimated length laid per year for the GDNs (Table 2 and Figure 1). The GDN data has been compiled from values cited in the NLT reports and, since 2002, by using the replacement length cited by the HSE for the Iron Mains Risk Reduction Programme as an estimate.

It can be seen that the 2002 NLT covered a broader range of PE installation years than the 1992 NLT, (1972-2001 for the 2002 NLT, compared to 1974-1990 for the 1992 NLT). The IGTs have pipes dating from 1996 to 2019, with a slightly increasing installation rate in the past few years; the GDN PE pipes have been laid since 1970, with a fairly consistent installation rate from the 1980s onwards. This highlights that the leakage estimate used by the GDNs, derived from the 2002 NLT, may be inappropriate to use by the IGTs.

Table 1: INA PE pipe length by installation year

Installation year	Total length (km)
1996	19
1997	282
1998	397
1999	564
2000	590
2001	1812
2002	913
2003	1007
2004	870
2005	777
2006	1357
2007	907
2008	1068
2009	583
2010	1029
2011	951
2012	1329
2013	874
2014	866
2015	1009
2016	1280
2017	1663
2018	1246
2019	1412
TOTAL	**22,804**

Table 2: 1992 and 2002 NLT PE pipe length by installation year [1] [2]

Installation year	Pipe length (m)	
	1992 NLT	2002 NLT
1972		100
1973		0
1974	101	0
1975	192	300
1976	171	0
1977	276	220
1978	0	0
1979	282	100
1980	173	879
1981	157	301
1982	245	200
1983	324	398
1984	0	699
1985	183	365
1986	0	310
1987	303	495
1988	69	387
1989	159	653
1990	254	305
1991		694
1992		401
1993		220
1994		211
1995		403
1996		100
1997		200
1998		80
1999		365
2000		0
2001		98
TOTAL	**2,889**	**8,484**

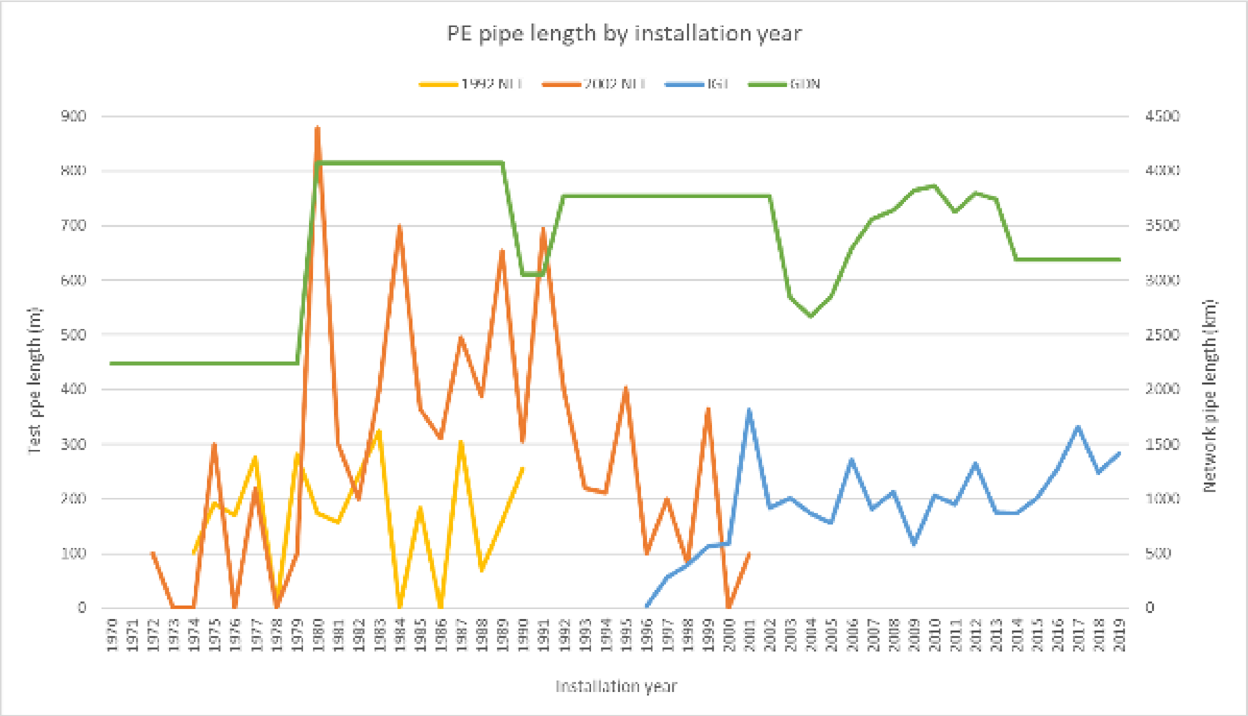

Figure 1: Comparison of IGT, GDN and NLT PE pipe length by installation year

4 FAILURE DATA

4.1 IGT failures

Five of the IGT companies provided DNV GL with failure data. This was reviewed to understand the causes of failure most frequently associated with PE pipes on their networks. A summary of the failure data is provided in Table 3; interference damage has not been included, and text descriptions have been interrogated to categorise the leaks as comprehensively as possible. It can be seen that leaks on joints, couplers and fittings are very unusual (although joint failures during the installation process will not be included in this data). However, leaks from top tees do occur occasionally, as do other leaks on mains (no further information was available in the text descriptions for these failures other than 'leak on main' or similar).

This analysis shows that small numbers of failures do occur so PE pipes should have a leakage rate (above zero) assigned to them.

Table 3: IGT failure data by type

Type of failure	Total failures/year	Failures/km/year
Leak on main	7.7	0.00061
Joint	1.6	0.00013
Coupler	0.7	0.00005
Top tee	15.4	0.00122
Fitting	1.5	0.00012
Other leak	7.1	0.00056

5 HISTORY OF PE PIPE

5.1 Development of PE pipe

The following grades of PE polymer have been developed since its first use on the UK gas distribution network in 1969:

- 1969: Original formulation (PE63): Dupont Aldyl
- 1976: PE-A (PE63)
- 1983: PE-X (PE80)
- 1989: PE-S (PE100): first used for Intermediate Pressure (2-7barg) pipe (orange)

Additionally, developments in pipe structure were made more recently:

- 1998: Corrugated low pressure PE80 service pipe (Uponor/Radius Serviflex)
- 2002: Peelable Low and Medium Pressure pipe (PE100): thin walled pipe (SDR21) (eg Radius Profuse)

The IGT networks only comprise PE80 and PE100 pipe, and Serviflex service replacements have not been used. The developments in the PE polymer were aimed at improving its long-term strength (the increasing PE classifications (63-80-100) represent the long-term (50 year) strength of the material). The developments in polymer processing also aimed to reduce the material's susceptibility to failure by Slow Crack Growth (SCG). This failure mode has been observed in 1st-generation (e.g. Dupont Aldyl / Stewart & Lloyd) PE pipes laid on uneven support (e.g. over a hard inclusion in the bedding) as shown in Figure 2, but was largely eliminated through improvements to the polymer for the PE-X and later formulations, testing for which was incorporated into later versions of GIS/PL2 Part 2 [3]. Resistance to Rapid Crack Propagation (RCP) failure was also improved, however this failure mode relates more to pipes operating at considerably higher pressures than those found in a distribution network (see Figure 3).

The introduction of a higher strength and stiffer PE100 allowed for a thinning of pipe walls (from SDR 17.6 to SDR 21) whilst maintaining an acceptable operating pressure. Slow and rapid crack growth resistance has also been validated in these materials through accreditation testing (GIS/PL2 Part 2 [3]).

Figure 2: Example of SCG over 35 years in 1st generation PE63 (Aldyl) pipe laid in rocky ground

Figure 3: Improvement in RCP resistance from early PE (on left) to PE100 (on right)

5.2 PE pipe joints

There have been several developments in PE jointing methods since the introduction of PE to UK gas distribution. The approximate dates of key advances are as follows:

- 1969: Mechanical joints
- 1969: Hot iron/socket fusion
- 1985: Electrofusion introduced
- 1989: Electrofusion replaces hot iron fusion
- 1991: Semi-automated and fully automated butt fusion introduced
- 2000s: Automation of electrofusion controllers

As the IGT networks only comprise pipe laid since 1996, only semi-automated or fully automated butt fusion or electrofusion joints are found.

The butt-fusion process is now almost entirely automated (for temperature, heat soak and cooling times, and fusion pressure), however this is typically used on larger diameter mains only (e.g. =>180mm). It may be used on some smaller diameters (down to 90mm is possible) but at smaller sizes the pipe wall is too thin to retain its shape under heating.

At smaller sizes (<180mm), electrofusion coupler jointing is more common as the method is quicker, and the fittings (couplers) relatively economical, and whilst some process improvements have taken place (notably automation of the control box, auto-recognition of fusion parameters and operator ID/data capture for audit trail), there are recognised ongoing problems with surface preparation/cleanliness and alignment which continue to cause failures in new networks.

5.3 PE pipe fittings

Non-fused components remain in the network, two examples being service connections (saddle tee/top tee) and connections to metallic meter installations.

5.3.1 Service connections (saddle tee/top tee)

These are fitted with an elastomer seal around the top of the cutter (located under the "completion cap"). These fittings have led to failures of tightness tests where they have been incorrectly assembled (i.e. the cutter not returned to its fully home position, and/or the completion cap not fully tightened). Examples are shown in Figure 4.

Figure 4: Electrofusion saddle tee with black completion cap (left); cap removed to operate the integral cutter, exposing elastomer seal (right)

5.3.2 Connections to metallic meter apparatus

Incomplete crimping of the PE pipe to the adaptor may result in slight leakage, again this should be observable via tightness testing. See Figure 5 for adapter examples.

Figure 5: Meter Box Adapter (left) and Service Head Adaptor (Right)

5.4 Loss of Containment

The various modes through which PE pipe may exhibit loss of containment are dealt with in turn below.

5.4.1 Material/Manufacturing Defects

Manufacturing defects in PE pipe may occur if there are contaminants in the PE feedstock or errors in processing temperatures (e.g. causing blow holes / porosity). These are not at all common in either new or old PE grades, but should they occur, they should be detected during manufacturing quality control. The control of manufacturing and quality control is assumed to have improved over time since 1969. Any through-wall defects that were undetected at the factory would be expected to be identified during the commissioning pressure testing on site.

5.4.2 Degradation of PE Material

PE material is largely chemically inert and unreactive in most ground conditions. Therefore, age-related degradation and loss of containment is not expected to occur over the design life (50 years) of pipe or fittings made from the modern PE resins. Degradation occurs in particular cases of contaminated ground (e.g. hydrocarbons which can soak into the PE, or detergents which can oxidise it).

5.4.3 Permeation through PE

Unlike metals (steel, cast iron) PE has an inherent permeability from its structure as a mass of intertwined (and crosslinked) polymer chains, and in theory gas may pass through the material.

The key factor affecting permeability at a constant temperature is the internal pipe gas pressure. Permeation has not been recognised as a significant loss factor for PE mains in general, therefore making an allowance for it in the IGT population (which is likely to be of small diameter and low pressure) does not seem necessary.

5.4.4 Failure of historical hot iron / socket fusion joints

Hot iron and socket fusion joints were prone to failure due to the reliance on operators to ensure the correct pressure, temperature and alignment. Examples of hot iron joint failures are shown below in Figure 6. Such failures are most likely to have occurred at the time of installation and will therefore not be relevant to the IGTs.

Figure 6: Examples of hot iron joint failures: saddle (upper), pipe joint (lower)

5.4.5 Failure of butt fusion / electrofusion joints

Failures of butt fusion joints arise from deficient jointing practices which typically weaken the joint by creating brittleness (e.g. due to contamination), poor alignment/restraint, or insufficient heat input. Examples are shown in Figure 7. These are workmanship deficiencies and the size of any breach would depend on their extent around the joint circumference and would not therefore be directly related to the diameter of the main. The diameter would be a contributing factor if a full-bore separation occurred, as it would govern the amount of gas from what would effectively be an open-ended release. Butt fusion joints are more common on larger diameter mains (e.g. =>180mm diameter), therefore these are likely to be less prevalent in IGT distribution networks.

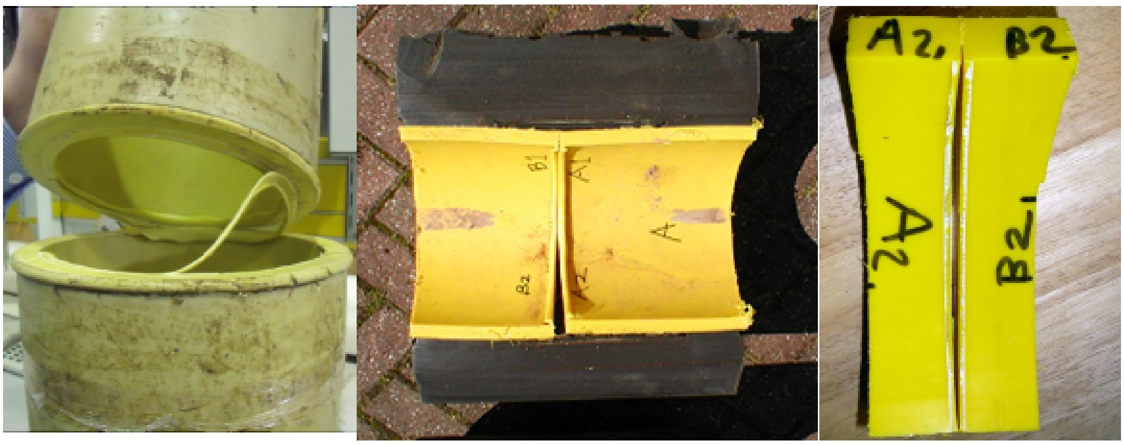

Figure 7: Examples of butt fusion joint failure: Fully circumferential in early PE (Left), partially circumferential due to misalignment (centre), internal view of partly circumferential joint separation (right)

Failure of electrofusion coupler joints occurs for the same reasons as butt fusion joints (contamination, cold lap joints, misalignment). Examples are shown in Figure 8. The extent of a breach would again depend on the area of contamination, or the poorly heated zone, and the degree of misalignment would also have an effect. It may be the case that smaller diameter pipes can be bent more easily into the required alignment, which suggests a diameter influence on likelihood. The magnitude of release would again depend on the extent of the defect (i.e. it would not be diameter dependent), but would be smaller than a full-bore release as the leak path is the relatively narrow gap along the failed interface between the pipe and coupler, which may be of the order of 1-2mm wide. Again, such failures are likely to have been apparent at the time of installation and to be remediated during commissioning. The use of "remote" supervision ("ControlPoint" being the most well-known example) further improves the quality of modern PE joints and is used by many of the companies undertaking PE main laying.

Figure 8: Examples of electrofusion coupler joint failure: gross contamination (left), gross misalignment (centre), and section through misaligned joint showing constrained leakage path (right)

5.4.6 Leakage from pipe fittings (service connections)

Where the failure is in a fitting (i.e. a saddle/top tee), then leakage would occur where the fitting has separated from the pipe (either partially or fully), shown in Figure 9. The amount of leakage would depend how much of the joint surface had parted, and maximum leakage would occur if the fitting is totally detached from the pipe, and the rate would be governed by the drilled hole (which is typically 20-30mm). The leakage from this breach would be independent of the PE main diameter.

Figure 9: Electrofusion saddle joint failure causing complete separation of top tee from pipe

For mechanical service and meter connections, leakages would be rectifiable e.g. by correctly tightening the completion cap or re-making the crimp. Whilst they would contribute to a small element of leakage (of the order of fractions of a litre per hour), it is debatable whether or not avoidable installation defects of this type would be accepted as a valid component of network leakage.

The nature of IGT networks (domestic/estate networks connecting directly to properties) may result a greater concentration of service connections (per km of network length) compared to a larger GDN's network which may include a larger proportion of larger diameter carrier mains. The sum of any leakages (if they occur) from these fittings may therefore be proportionately larger per kilometre of main for an IGT than for a GDN.

5.5 Summary of PE history

Whilst there have been developments in PE pipe material and manufacture since it was first used in the 1970s, failure or degradation of the pipe barrel is virtually a non-issue (except for the very early grades of PE, where it can in theory result from a long period of sustained stress).

Jointing techniques have been a major source of loss of containment from a PE network. Since the first National Leakage Test exercise in 1992, PE jointing techniques have become significantly better controlled in general, and the potential for human-induced error has reduced. It is reasonable to assume that the newer the PE in the network, the lower the joint failure frequency should be. Site supervision innovations such as ControlPoint have not been fully rolled out into all parts of the industry (GDNs, alliance contractors, or IGTs), therefore the benefits will not have been realised in those parts of the network. Failure of pipe fittings, specifically top tees and connections to meters, has also been identified as a source of leakage.

Most of the major improvements in materials, jointing (fittings, processes, equipment and quality control) took place before the creation of the IGTs in the late 1990s. Since that time, there have been minor improvements to jointing control processes that may have obtained slight additional reductions in failure potential.

6 REVIEW OF IGT AND GDN NETWORK DIFFERENCES

There are a number of differences between the INA networks and those managed by the GDNs, which may affect the leakage rate determined for their respective PE mains. These differences are dealt with in turn below. It should be noted that this discussion is only pertinent to PE mains, so the higher proportion of ferrous mains (and other materials such as PVC and asbestos cement) in the GDN networks is already accounted for as separate leakage rates are assigned to each material.

6.1 Service pipe material

In most cases, the service pipe material for IGT PE mains will also be PE and will have been connected by electrofusion. In the case of the GDNs, more recent installations will have PE services but at the start of the Iron Mains Risk Reduction Programme new PE mains were connected to the existing steel services. However, the 2002 NLT report included a comparison of leakage from PE pipes with steel services and those with PE services [2]. It was concluded that leakage from either type of service was zero and this is the assumption that has been made in calculating the PE leakage rate used in the SLM i.e. it is assumed to come from the mains only.

6.2 PE mains length and jointing

Historically, PE mains were typically installed in relatively short lengths with frequent joints. More recently, PE mains have been supplied in large coils (for sizes up to 180mm), with infrequent joints, although coiled PE has been available since the 1970s. As joints are a source of leakage, the more modern networks with fewer joints would be expected to have lower leakage levels. It is assumed that the IGTs primarily have modern PE (from long coils) whilst the GDNs will have a mixture of PE, including shorter lengths with more frequent jointing.

From the timeline information, there has been relatively little change in jointing methods since the 2002 NLT. Hence there is no clear reason why PE leakage rates for new networks will have improved appreciably since that time and the IGT PE networks are largely new builds dating from 1997 onwards. The IGT networks show service connections as primary source of leakage (Section 4.1), and IGT networks will have a greater proportion of service connections per km than GDN networks (as they include longer lengths of larger diameter pipes without service connections). However, IGT networks are newer than GDN ones, so will, on average, have better quality connections and joints (not on pipes now being laid, but because the GDNs have more older pipe which will have more jointing issues). GDN networks will also have more valves and mechanical joints between material types (due to the mains replacement programme) which are also a source of leakage.

Overall, therefore, it is considered that the leakage rate from IGT networks has the potential to be slightly lower than both the 1992 and 2002 NLT rates, as these both covered all PE mains of any age (and jointing method) in the entire UK gas distribution network.

6.3 Effect of pipeline pressure

IGT networks are predominantly comprised of low pressure pipelines whilst GDN assets may comprise a higher proportion of medium and intermediate pressure pipelines. Higher pressure mains will typically have a higher rate of leakage, however this is not currently taken into account in the Shrinkage and Leakage Model (SLM) [4]. Work is currently in progress to review whether a pressure factor should be added into the MP model [4], and if this is implemented there will potentially be a greater distinction between the IGT and GDN average leakage rates for PE.

6.4 Own use gas and theft of gas

Own use gas refers to gas that is lost due to network operations such as purging and mains abandonment. The GDNs are likely to have a higher rate of own use gas then the IGTs, particularly due to the Iron Mains Risk Reduction Programme. Theft of gas refers to the illegal connection to a gas network. It is considered less likely that theft of gas will be an issue for the IGTs than for the GDNs as their networks are usually new developments with little scope for illegal connections.

Whilst own use gas and theft of gas are both components of shrinkage, they sit outside the leakage rate in the SLM and as such have values that are derived separately to the leakage rate calculation [4]. They are therefore discounted from this study.

6.5 Venting, above ground installations and interference damage

Venting and lost gas from above ground installations are likely to be lower for the IGTs than the GDNs due to the nature of their networks. Interference damage may also be less prevalent, at least in the initial years after a main is laid, as most new housing estates have little construction or utility activity immediately after completion.

Whilst venting, above ground installations and interference damage are all components of the leakage element of the SLM, they all have values derived separately from the leakage rates for mains and services [4]. As such, they are excluded from further analysis in this study.

7 LEAKAGE RATE DERIVATION

In Section 4 it was shown that IGT PE pipelines do occasionally sustain identifiable failures, indicating that lower levels of leakage may also be occurring and that a background leakage rate of zero is not appropriate. However, in Section 3 and Section 5 the IGT PE network was compared to the GDN network and differences in PE installation dates, pipe material and jointing were identified. As such, the 1992 and 2002 NLT results have been used as a basis to develop a bespoke PE leakage rate for the IGTs, but with some adjustment for the more modern IGT networks.

Initially, it was intended that the 2002 NLT results alone would be used to derive a new leakage rate for the IGTs. However, when the results were obtained and reviewed it was found that only summary data was available and that individual test results could not be obtained. This meant that a comparison of newer and older PE mains was not possible, so a change in leakage rate with time could not be derived.

The 1992 NLT results were then reviewed and compared to the 2002 NLT results to enable a change in PE leakage rate to be derived. However, it was found that the PE leakage rate had decreased significantly (by 65%) from the 1992 NLT to the 2002 NLT, and no explanation at the time was given. The leakage rates for other materials also showed unexplained differences, such as substantial decreases for pit cast and ductile iron (see Table 4). A comparison of installation years for the pipes used in the test was carried out (see Figure 1) and it was found that the 2002 NLTs spanned a greater period of installation than the 1992 NLT, including a number of older pipes, so the difference in leakage rate measured was not due to pipe vintage. As similar decreases in leakage value are also seen for other pipe materials, this indicates that the issue may be due to something inherent in the testing process. As such, and given that the 2002 NLT values are used in the Shrinkage and Leakage Model (SLM) today, it was decided to use the 2002 NLT value as a baseline for a new IGT PE leakage rate.

Table 4: 1992 and 2002 NLT leakage rates for all materials [1] [2]

Material	1992 NLT		2002 NLT	
	Number of tests	Leakage rate m^3/hour/km	Number of tests	Leakage rate m^3/hour/km
Steel <=3″	33	0.0657	28	0.3900
Steel >=4″	33	0.4694	32	0.4400
Pit cast <=3″	21	0.5455	33	0.2748
Pit cast 4-5″	57	0.3901	197	0.1872
Pit cast 6-7″	22	0.2195	64	0.2883
Pit cast 8-11″	30	0.8118	53	0.2516
Pit cast >=12″	21	1.7017	82	0.8520
All spun cast	231	0.1493	131	0.1228
Ductile iron <=5″	40	0.1987	72	0.0821
Ductile iron >=6″	32	0.1215	36	0.0658
All PE	35	0.0208	89	0.0073

Table 4 shows that the value for PE leakage is substantially lower (in both sets of results) than for ferrous materials. The leakage rate for PE currently used in the SLM is 0.0073 m^3/hr/km, which was derived in the 2002 NLT. This assumes a zero leakage for service pipes, based on tests of both metallic and PE services [2].

Given the difference between the results from the two NLTs, and the assumption that the 2002 rates are likely to be more accurate and are used in the current model, an attempt has been made to recalculate the 1992 results, to enable a value for older PE pipes to be derived. Based on engineering judgement, it is estimated that the leakage from pit cast iron mains may have increased by 10% over the period between the two tests (assuming a largely stable population of very old pipes, with mostly joint deterioration occurring). Applying the same correction to other pipe materials gives a small decrease (7.8%) in PE mains leakage, a small increase (4.0%) in ductile iron mains leakage and a large increase (34.6%) in spun iron leakage; this is considered reasonable as the spun iron is likely to be deteriorating fastest due to its age and properties. Other correction factors were considered but gave one or more results that seemed implausible.

The revised 1992 NLT values are compared to the original values and the 2002 values in Table 5. A weighted average has been used for pit cast iron and ductile iron as the original results were split by diameter; steel has been excluded from the analysis as the difference between the 1992 and 2002 tests were so extreme (+494% for <=3% steel pipes and -6% for >=4" steel pipes).

Table 5: Comparison of 1992 and 2002 NLT leakage rates, and estimated 1992 leakage rates

Material	Leakage rate m^3/hr/km			
	1992 NLT (weighted average)	Estimated 1992	2002 NLT (weighted average)	% change (2002 NLT – 1992 estimated)
Pit cast iron	0.6530	0.3096	0.3440	+10.0%
Spun iron	0.1493	0.0742	0.1228	+39.6%
Ductile iron	0.1644	0.0736	0.0767	+4.0%
PE	0.0208	0.0078	0.0073	-7.8%

Using this approach, an estimated average value for PE leakage in 1992 has been derived of 0.0078 m^3/hr/km. This revised 1992 value can then be used, with the 2002 value, to estimate a leakage rate for newer PE pipes only, that would be applicable to the IGTs. To do this, the estimated 1992 value has been applied to all pipes in the 2002 NLTs with an installation date pre-1991. A new estimated leakage rate has then been derived from the 2002 NLT tests pipes with installation years post-1990, which align approximately with the early IGT mains population. The process undertaken was as follows:

1. Calculate total leakage rate for 2002 NLT pipes laid pre-1991 (in m^3/hr), using the estimated 1992 value
2. Subtract the pre-1991 leakage from the total PE leakage measured in the 2002 NLT
3. Normalise the post-1990 total leakage by the test pipe length to give the average estimated leakage post-1990 leakage rate

Using this methodology the post-1990 PE leakage rate has been estimated to be **0.0061 m^3/hr/km**. A comparison with the other measured and estimated PE leakage rates is given in Table 6. It should be noted that, whilst the estimated IGT leakage rate does not take into account pipes laid since 2002, neither does the value used by the GDNs. It is not possible to estimate the levels of leakage in newer PE pipes (IGT or GDN) as no recent leakage tests have been performed. However, given the factors discussed above, it may be reasonable to conclude that the difference between the GDN and IGT leakage rates could be greater than the values cited here due to the possible impacts of steel services, medium pressure networks and mains replacement (additional joints etc.).

Table 6: Summary of measured and estimated PE mains leakage rates

Data source	Leakage rate m^3/hr/km
Original 1992 NLT	0.0215
Estimated 1992 NLT	0.0078
2002 NLT	0.0073
Estimated IGT (post-1990 pipes only)	**0.0061**

8 CONCLUSIONS

The following conclusions have been drawn from a review of the 1992 and 2002 National Leakage Tests, analysis of IGT asset and failure data and consideration of PE pipe history:

- IGT pipe installation dates are, on average, more recent than GDN installation dates.
- PE pipes, whilst considerably less leaky than iron or steel mains, do exhibit occasional failures, including leaking joints and top tees, so a nominal leakage rate is appropriate.
- PE pipe installation and jointing techniques have changed little since the most recent National Leakage Tests (NLTs), and the leakage rate derived in 2002 is currently in use by the GDNs.
- A new leakage estimate for IGT PE mains has been calculated as **0.0061 m^3/hr/km** (which compares to the current GDN value of 0.0073 m^3/hr/km); this is based on a recalculation of the 1992 NLT PE leakage rate, followed by use of the recalculated 1992 value and the measured 2002 NLT value to estimate a leakage rate for networks with pipes laid since 1990.
- Neither the GDN or IGT leakage rate take into account potential differences in leakage rate between low and medium pressure mains. Differences in service pipe material are also discounted as both PE and steel services were found to have zero leakage in the 2002 NLTs. It may therefore be reasonable to conclude that the difference between the GDN and IGT leakage rates could be greater than the values cited here due to the possible impacts of steel services, medium pressure networks and mains replacement (additional joints etc.).
- Other factors, including venting, above ground installations, interference damage, own use gas and theft of gas, are taken into account elsewhere in the Shrinkage and Leakage Model (SLM) so are not considered within the PE leakage rate estimation.

9 REFERENCES

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