New International Failure Frequency Database for High Pressure Gas Installations

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Quantitative risk assessment (QRA) methodologies for onshore natural gas transmission pipelines and associated installations are well established. Although such events are rare, the consequences of accidental releases from high pressure gas systems can be severe and it is important that operators understand the risks associated with their pipelines and installations in order to manage them effectively. An essential input to any QRA is the predicted failure frequency. For buried pipelines, there are several sources of historical data to derive failure frequencies. The development of a new database to collect detailed statistics on pipeline populations and gas release incidents was reported previously (at Hazards 27). However, no equivalent sources have been available for the high pressure gas installations that are an essential part of any gas transmission system. Historically, failure frequencies used in QRAs of onshore gas installations were derived from data collected for similar offshore installations, where there may be important differences due to space restrictions and environmental conditions.

The AGIFF (Above Ground Installation Failure Frequencies) project was initiated to establish a statistical database for incidents on high pressure gas installations to improve the knowledge available for estimating failure frequencies from historical data and to enhance understanding of the causes of incidents and the types of facilities most likely to be affected. There are nine participating companies, operating gas transmission networks in the UK and mainland Europe. The AGIFF database records incidents that have occurred since 2012 on installations operated by the AGIFF group members. The “installations” covered by the database are: “All installations associated with onshore steel gas transmission pipelines with a maximum operating pressure ≥ 16 bar which are under the direct responsibility of the company during its operating life”. Installations with multiple functions are divided into “functional units”.

Incidents are categorised as either “Significant” or “Notable”. In simple terms, a Significant incident is one that resulted in an actual hazard; whereas a Notable incident is one that had the potential to create a hazard but for which that hazard was not realised. Typically, a Significant incident resulted in a fire, an explosion or missile effects, whereas a Notable incident typically involves an unignited release of gas that had the potential to be a Significant incident had it ignited. In considering whether a leak is reportable as a Notable incident, the following thresholds are applied:

- A sudden, uncontrolled release of ≥500kg of natural gas in the open air, OR
- A sudden, uncontrolled release of ≥10kg of natural gas indoors.

For the period 2012 to 2018, the AGIFF database contains over 230,000 operating years of experience for all functional units. 72 incidents were recorded over the same period of which 3 were classified as Significant. Serious incidents on AGIs are rare, having an average frequency of 1.3 x 10^{-5} Significant incidents per year per unit (i.e. approximately one incident per 77,000 years of operation of a single functional unit). The database and further analysis are presented in this paper, including a comparison with the experience of gas release incidents on offshore installations to derive modification factors for leak frequencies, using the latest data published by IOGP (International Association of Oil & Gas Producers).

Introduction

Quantitative risk assessment (QRA) methodologies for onshore natural gas transmission pipelines and associated installations are well established. Although such events are rare, the consequences of accidental releases from high pressure gas systems can be severe and it is important that operators understand the risks associated with their pipelines and installations in order to manage them effectively. An essential input to any QRA is the predicted failure frequency. For buried pipelines, there are several sources of historical data to derive failure frequencies. The development of a new database to collect detailed statistics on pipeline populations and gas release incidents was reported previously at Hazards 27 [1]. However, no equivalent sources have been available for the high pressure gas installations that are an essential part of any gas transmission system. Historically, failure frequencies used in QRAs of onshore gas installations were derived from data collected for similar offshore installations, where there may be important differences due to space restrictions and environmental conditions.

The AGIFF (Above Ground Installation Failure Frequencies) project was initiated to establish a statistical database for incidents on high pressure gas installations to improve the knowledge available for estimating failure frequencies from historical data and to enhance understanding of the causes of incidents and the types of facilities most likely to be affected. There are nine participating companies, operating gas transmission networks in the UK and mainland Europe: Cadent (UK), Enagas (Spain), Energinet (Denmark), Fluxys (Belgium), Gasunie (Netherlands), GRTgaz (France), National Grid (UK), Open Grid Europe (Germany) and Swissgas (Switzerland).

The AGIFF database records incidents that have occurred since 2012 on installations operated by the AGIFF group members.

Structure of the AGIFF Database

In order to establish a database for the purposes described above, it is necessary:

- to adopt an appropriate incident definition;
- to define the types of installation to which the incident definition is applied;
- to define how to count the installation population for statistical analysis;
- to design a clear system for collecting data in a uniform way.

To address these requirements, the following detail levels are defined for the description of the installation associated with the event (Figure 1):

LEVEL 0: Corresponding to the site where one or more different installation functions can be present (for instance a compressor station with pig traps); this level is used only for localising the incident identifying possible domino effects.

LEVEL 1: Corresponding to the single installation function, defined according to its main operational function (for instance Compressor Station or Reduction Station); this level corresponds to the "Functional Unit" used in the database.

LEVEL 2: Corresponding to the main parts or subsystems in which an installation can be divided (for instance in a Compressor Station can be identified four main parts as station pipework, gas compressor units, station control system, auxiliary equipment). This is used for localising the incident.

LEVEL 3: Corresponding to the basic equipment items (pipes, valves, filters, flanges and so on). This level is used when an incident is reported and the actual equipment involved can be identified.

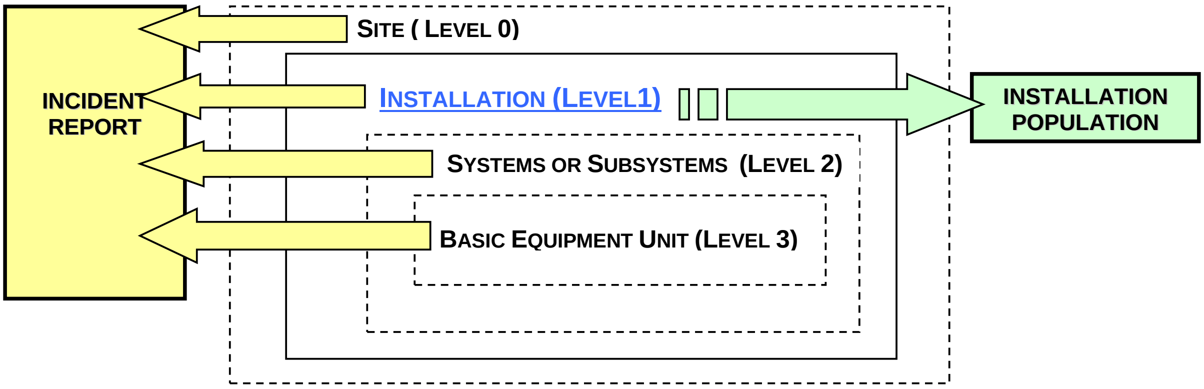

Figure 1: Installation data detail level and use destination representation

The AGIFF database project has forms for companies to supply both installation population and incident data. The use of the functional unit as the population reporting category is a simplification but it means that the participating companies were able to include all their assets with less effort. If detailed equipment counts for each of the sites had been required, it is unlikely that many of the companies would have been able to participate, as the effort required to gather the equipment population data would have been too onerous.

Reporting Criteria

The "Above Ground Installations (AGIs)" covered by the database are: "All installations associated with onshore steel gas transmission pipelines with a maximum operating pressure ≥ 16 bar which are under the direct responsibility of the company during its operating life".

Installations with multiple functions are divided into several functional units because it is acknowledged that for any given site type there is a variety of designs, with some sites having only a single function and others consisting of several functions on a single site. Hence, the population is reported by functional unit. For example, a single fenced area including a pig trap AND a pressure reduction unit is recorded as one pig trap station and one pressure reduction station.

LNG sites are explicitly excluded. Functional unit groups used in the database are:

- line valve stations;
- pig-trap stations;
- multi-junctions (points of interconnection);

- pressure reduction stations;
- metering stations;
- compressor stations;
- blending stations;
- gas storage devices.

Incidents are categorised as either "Significant" or "Notable". In simple terms, a Significant incident is one that resulted in an actual hazard; whereas a Notable incident is one that had the potential to create a hazard but for which that hazard was not realised. Typically, a Significant incident resulted in a fire, an explosion or missile effects, whereas a Notable incident typically involves an unignited release of gas that had the potential to be a Significant incident had it ignited. In considering whether a leak is reportable as a Notable incident, the following thresholds (aligned with the criteria used in the UK for RIDDOR [2] reporting to the HSE) are applied:

- A sudden, uncontrolled release of ≥500kg of natural gas in the open air, OR
- A sudden, uncontrolled release of ≥10kg of natural gas indoors.

It is recognised that there will be uncertainty in some cases as to whether the threshold criteria are met and that some events may be reported which are non-hazardous, but of long duration. This will tend to overestimate the frequency of dangerous occurrences at AGIs. At the outset of data collection, it was recommended that the incident definitions would be reviewed and refined in the light of experience as more incidents were recorded. Group members participated in a workshop using real examples to clarify when incidents should be included or excluded. The main clarifications were:

- Injuries only make the incident "Significant" if they are caused by fire, blast or missiles associated with the release. Hence, incidents causing hearing damage are not automatically reportable and are not included in the incident frequency analysis.
- Incidents such as one causing hearing damage can still be included in the information shared with the group if there are lessons to be learned.
- Incidents where there is not enough information to assess if the reportable gas release mass criterion has been exceeded are examined to see if they should be excluded from the statistics. This assumes that more major incidents will include more detailed information.
- A question was added to the incident form to record the leak location as inside or outside.

Installation Population Data

In each case, the population is reported as the number of major site functional units, defined as LEVEL 1 in the database guidelines. That is, a typical site will have one or more units. The only exception to this is that compression is defined by the number of compressors. The number of units of population data per year in the dataset (cumulative) used to derive the incident frequencies is shown in Figure 2. For the period 2012 to 2018, the AGIFF database contains over 230,000 operating years of experience for all functional units. Analysis of the numbers of functional units versus the pipeline length data for each of the AGIFF group members showed that the companies have a broadly similar ratio of pipeline lengths to functional units and, hence, aggregating the operating experience to give a larger dataset appears reasonable.

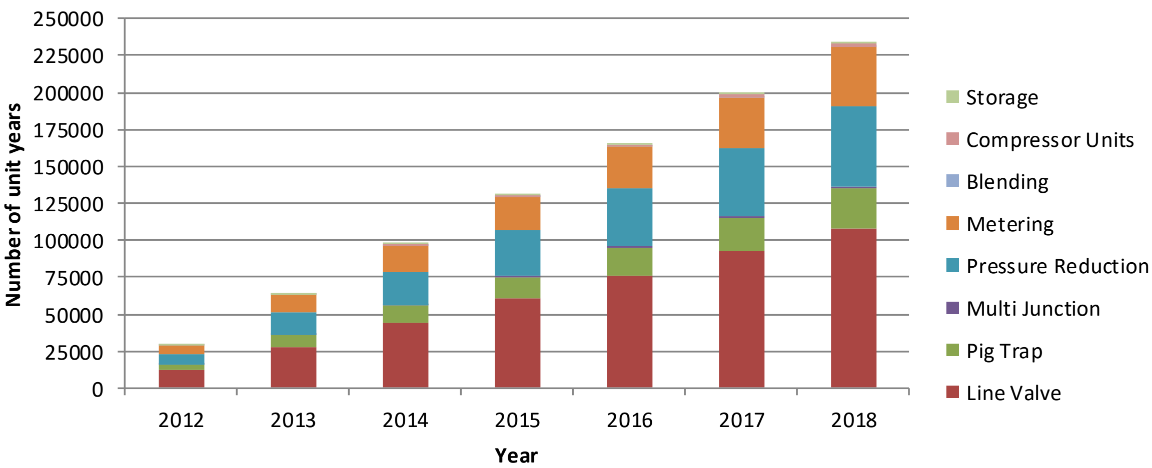

Figure 2: AGIFF Database cumulative population data

Figure 3 shows the relative proportion of each unit type. (In this figure, the number of compressors is used rather than the number of compressor stations; on average, there are four compressors per site but this can vary significantly between sites.)

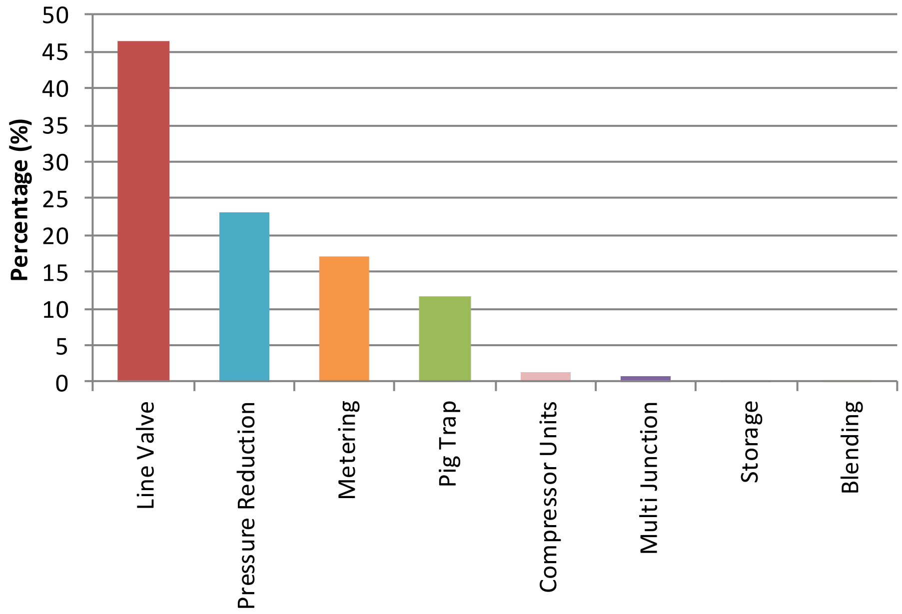

Figure 3: Relative proportions of different functional unit types

Installation Incident Data

72 incidents were recorded over the same period as the installation population data (2012 to 2018). Of these 72 incidents, only three met the classification for "Significant"; 69 fell under the less severe classification "Notable".

Five incidents involved an ignited release of gas. Two of the ignited cases resulted in trivial hazards and as such were not included as "Significant". The remaining 67 incidents did not ignite and were all classified as "Notable".

No fatalities or injuries have been reported to date associated directly with gas release incidents at installations covered by the database. The one fatality included was as a result of a motorcycle crashing into an AGI (believed to be an intentional act of suicide).

Figure 4 shows incidents split by functional unit type. This figure can be compared directly with the split of units in the overall population (Figure 3). It is notable that nearly 60% of the incidents are associated with Pressure Reduction units, even though Pressure Reduction units only make up less than 25% of the population data.

Figure 5 shows incidents split by cause. The category "Other" includes all incidents for which the cause was unknown or not included in the incident report. Material Defect is the most common cause (44% of the incidents) followed by Human Error (21% of the incidents).

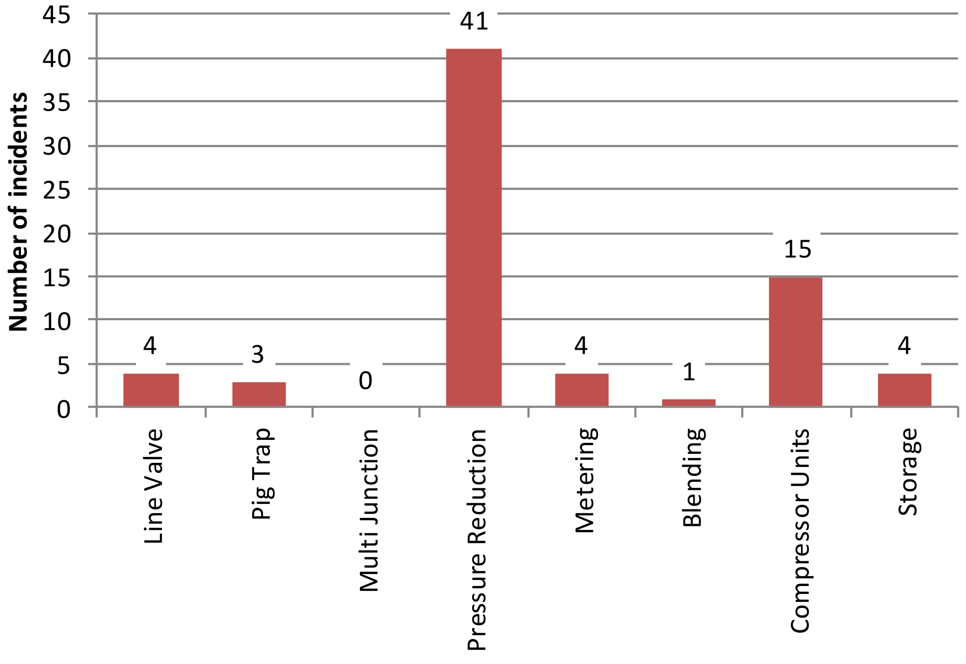

Figure 4: Incident data, split by functional unit

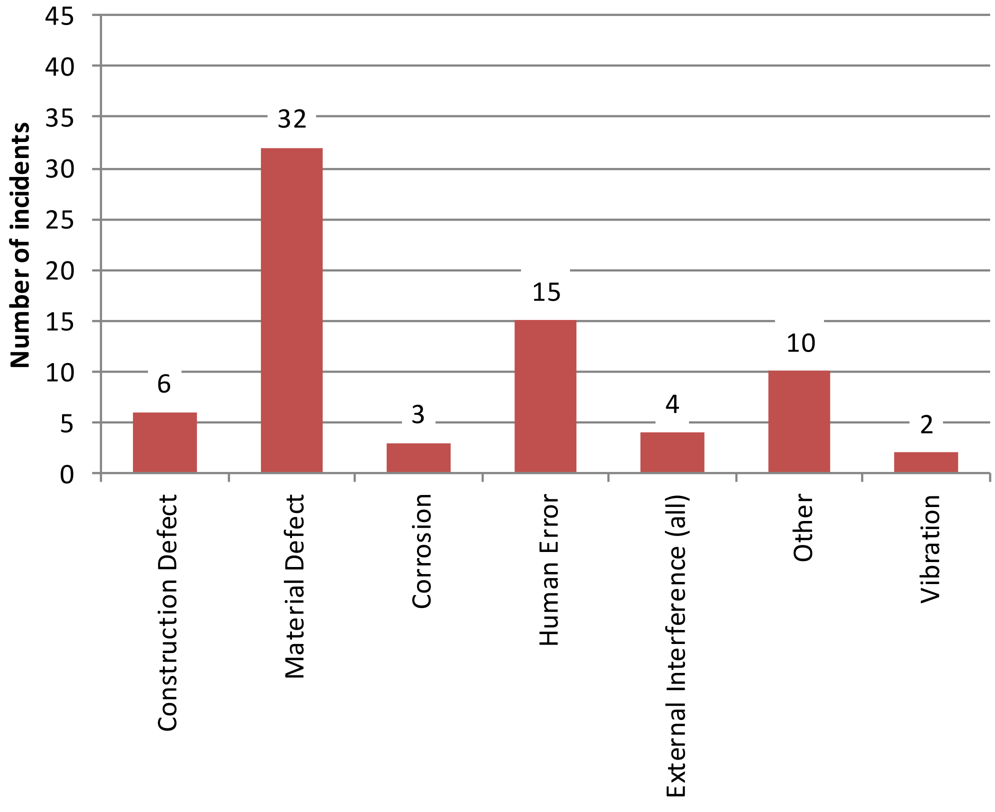

Figure 5: Incident data, split by cause

Event Frequency Estimation

Overall, incidents on AGIs are rare, having an average frequency of 3.1 x 10^{-4} incidents (Significant and Notable) per year per functional unit. 4.2% of the incidents are reported as Significant, giving an average frequency for Significant incidents of 1.3 x 10^{-5} per year per functional unit.

In deriving more detailed event frequencies, recognising the limitations of the small number of incidents for statistical analysis, the approach taken is based on that used by [3]. The approach is:

- To reflect the uncertainty associated with the limited basic data, each incident per year frequency is given with the upper and lower 95% confidence internal based on the Poisson distribution.
- For cases where no event has been recorded (for example "multi junction" functional units), a frequency has been derived for this event using the 50% confidence interval relating to the Poisson distribution.

A Poisson distribution is appropriate for a distribution of independent rare events in a larger population. If, in a given interval or population, *n* distinct events occur, then the 95% confidence interval is given by: $n \pm 1.96\sqrt{n}$. For categories where there is a larger number of unit years, the range defined by the confidence interval is smaller.

The event frequencies derived using this approach are given in Table 1 and shown in Figure 6.

The number of incidents associated with different causes can be combined with the overall event frequency to give an event frequency by cause. This is summarised in Table 2.

Table 1 : Derived event frequencies

AGI unit	AGIFF Database			Based on Poisson distribution		
	Unit years	Incidents	Incident/unit years	95% confidence		50% confidence
				Lower	Upper	
All data	233809	72	3.1x10^{-4}	2.4 x10^{-4}	3.8x10^{-4}	
Line Valve	108395	4	3.7x10^{-5}	7.4 x10^{-7}	7.3x10^{-5}	
Pig Trap	26923	3	1.1x10^{-4}	< 10^{-9}	2.4x10^{-4}	
Multi Junction	1544	0				4.5x10^{-4}
Pressure Reduction	53712	41	7.6x10^{-4}	5.3 x10^{-4}	1.0x10^{-3}	
Metering	39788	4	1.0x10^{-4}	2.0x10^{-6}	2.0x10^{-4}	
Blending	186	1	5.4x10^{-3}	< 10^{-9}	1.6x10^{-2}	
Compressor Units	2785	15	5.4x10^{-3}	2.7 x10^{-3}	8.1x10^{-3}	
Storage	476	4	8.4x10^{-3}	1.7 x10^{-4}	1.7x10^{-2}	

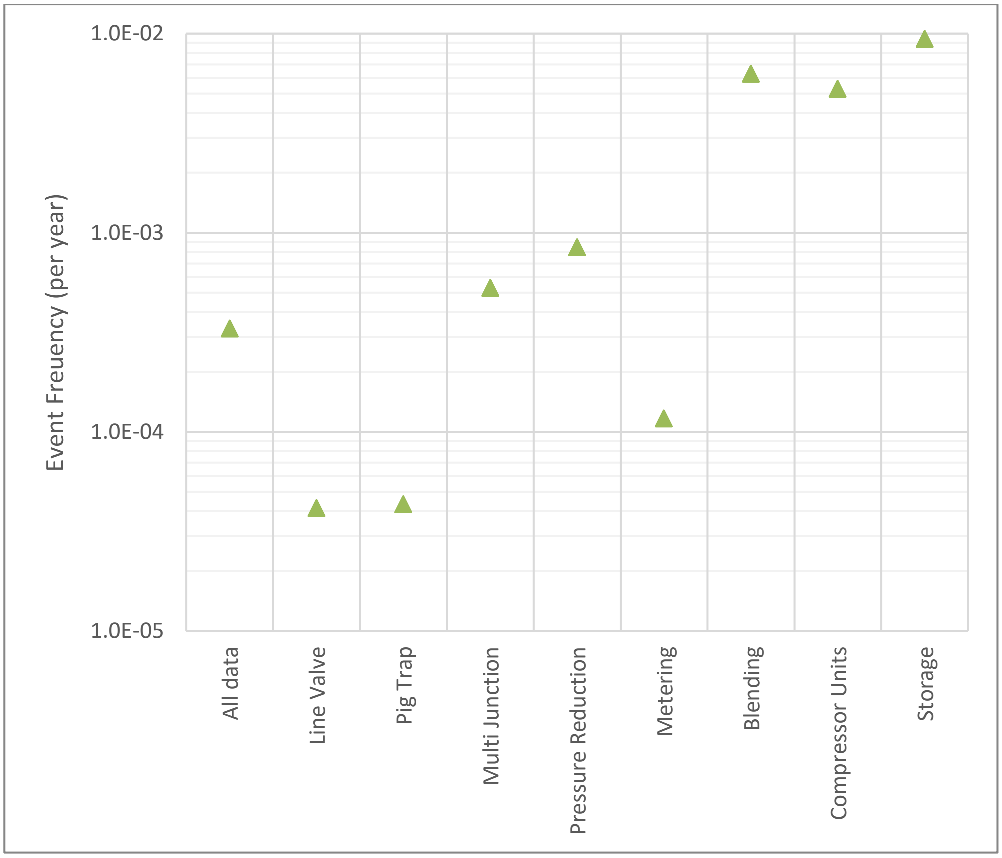

Figure 6: Derived event frequencies for each functional unit

Table 2 : Derived event frequencies by cause

Cause	Incident Type		Total	Proportion (%)	Incident per Unit year by cause
	Notable	Significant			
Construction Defect	4	2	6	8.3	$2.6x10^{-5}$
Material Defect	32		32	44.4	$1.4x10^{-4}$
Corrosion	3		3	4.2	$1.3x10^{-5}$
Human Error	15		15	20.8	$6.4x10^{-5}$
External Inference	3	1	4	5.6	$1.7x10^{-5}$
Other / Cause not reported	10		10	13.9	$4.3x10^{-5}$
Vibration	2		2	2.8	$8.5x10^{-6}$
Total	69	3	72	100	$3.1x10^{-4}$

Calculating the Onshore vs Offshore AGIFF Reduction Factor

Historically, failure frequencies used in QRAs of onshore gas installations were derived from data collected for similar offshore installations, where there may be important differences due to space restrictions and environmental conditions. Offshore incident data, collected by the UK Health and Safety Executive (HSE) from operators, is used to derive generic leak frequencies for process equipment. The latest update has recently been published by IOGP (International Association of Oil & Gas Producers), [4], [5]. The number of incidents recorded per year has been steadily decreasing and so the 10-year average leak frequency is used in this analysis. Using the correlation parameters given for offshore process equipment, a full set of leak frequencies can be developed for onshore AGI sites.

Leak frequencies calculated from experience of incidents reported in the UK offshore sector of the North Sea are likely to overestimate those for onshore AGIs that typically operate with dry sweet natural gas in a more benign environment. To accommodate this, an onshore reduction factor, referred to as the AGIFF reduction factor, has been developed by comparing the leak frequencies for process pipework on onshore sites used by HSE for the purposes of Land Use Planning (LUP) advice [6] with the data for offshore process pipework. Table 3 provides a comparison of this data. The final column in the table presents the ratio of offshore to onshore leak frequency and ranges from about 4 for the smallest pipe diameter through to 16 for the largest pipe diameter. This means that in all cases, the unmodified offshore data always predicts larger leak frequency values than given in the LUP guidance.

Figure 7 provides a graph of this ratio against pipeline diameter along with a curve of best fit to produce the AGIFF reduction factor for pipework. This reduction factor is also considered appropriate for use with valves and flanges and can be given by:

$$F_{off}(d) = (1.0103\, D^{0.3996}\,)\, F_{on}(d)$$

Where the offshore frequency (F_{off}) of a leak exceeding a hole size of diameter d (mm) is dependent on the equipment diameter D (mm) and the onshore frequency (F_{on}) of a leak exceeding a hole size of diameter d (mm).

LUP also gives failure frequencies for a limited number of hole sizes for a fully welded above ground pipelines in a gas installation. This cannot be directly compared with the offshore data; however, the total leak frequency (2.6 x 10^{-7} per m-year) can be used as an indicative measure to show that the leak frequencies calculated for onshore pipework with the AGIFF reduction factor are conservative and considered appropriate for use in onshore risk assessments.

A similar exercise can be carried out for leaks from vessels. The total frequency of leaks using the LUP guidance for onshore process vessels was 6.0 x 10^{-5} per year; compared with 6.5 x 10^{-4} per year for offshore process vessels. This gives an AGIFF reduction factor of 10.8 which is considered appropriate for use with all equipment type except for pipework, valves and flanges.

Table 3: Comparison of onshore and offshore leak frequencies for process pipework

Process Pipework Diameter range	**Onshore Leak Frequency (per m-year) for hole size diameter of [6]**					**Offshore Leak Frequency (per m-year) [4]**	**Ratio**
	1/3 x pipe Diameter	**25 mm**	**4 mm**	**3 mm**	**Total**		
0 to 49 mm		$5.0x10^{-6}$		$1.0x10^{-5}$	$1.5x10^{-5}$	$5.6x10^{-5}$	3.8
50 to 149 mm		$1.0x10^{-6}$		$2.0x10^{-6}$	$3.0x10^{-6}$	$2.0x10^{-5}$	6.8
150 to 299 mm	$4.0x10^{-7}$	$7.0x10^{-7}$	$1.0x10^{-6}$		$2.1x10^{-6}$	$1.5x10^{-5}$	7.2
300 to 499 mm	$2.0x10^{-7}$	$5.0x10^{-7}$	$8.0x10^{-7}$		$1.5x10^{-6}$	$1.7x10^{-5}$	11.5
500 to 1000 mm	$1.0x10^{-7}$	$4.0x10^{-7}$	$7.0x10^{-7}$		$1.2x10^{-6}$	$1.9x10^{-5}$	15.6
> 1000 mm	$1.0x10^{-7}$	$4.0x10^{-7}$	$7.0x10^{-7}$		$1.2x10^{-6}$	$1.9x10^{-5}$	15.6

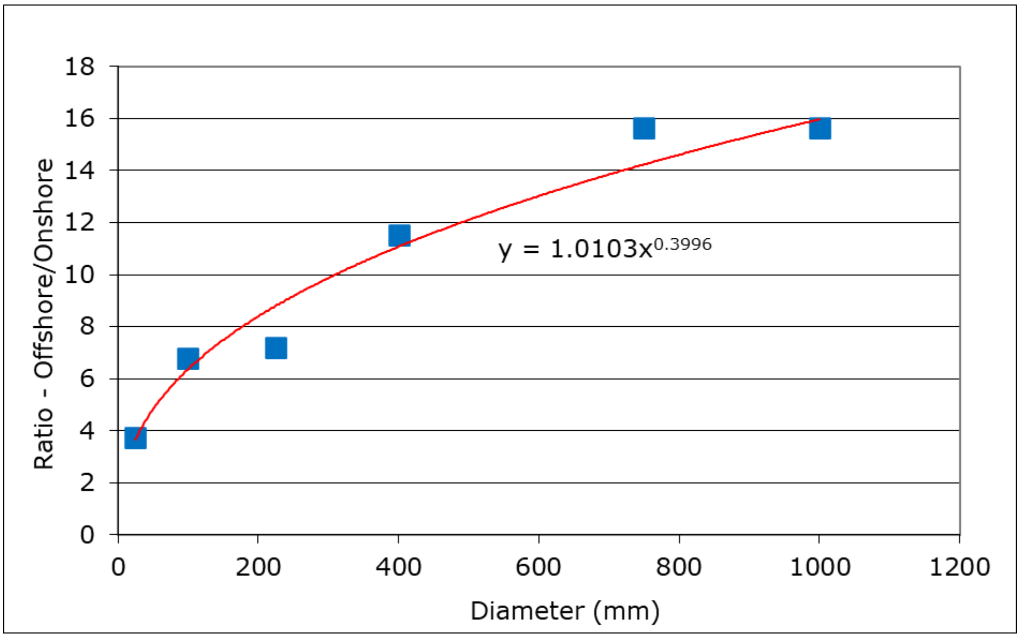

Figure 7: Correlation of offshore to onshore leak frequency for process pipework

Historical Leak Frequency Comparison

To illustrate the influence of the AGIFF leak frequency and associated reduction factor, example parts counts for a range of sites have been supplied by two of the AGIFF member companies for a selection of different unit types. The total leak frequency calculated for each of these systems are given in Table 4, which gives the values both with and without the AGIFF reduction factor applied. These are also compared to the incident frequency for each site type as recorded within the AGIFF database.

The source data used to calculate the total leak frequencies includes all leaks from all holes above 1mm in diameter (both for the LUP guidance and the IOGP data). As described earlier, the AGIFF database records incidents involving:

- A sudden, uncontrolled release of ≥500kg of natural gas in the open air, OR
- A sudden, uncontrolled release of ≥10kg of natural gas indoors.

Examination of the LUP guidance suggests that approximately 50% to 70% of leaks are in the 1mm to 5mm diameter hole size category. The UK offshore database records a similar proportion in this category. Therefore, two further columns are included in Table 4 which provide the leak frequencies from holes above 5mm in diameter, both with and without the AGIFF reduction factor applied.

Table 4: Total leak frequencies for example AGIs

Company	Unit Type	AGIFF (Actual Incidents)	Calculated from the UK offshore database			
			All holes >1mm (unmodified)	All holes >1mm (with factor)	Holes > 5mm (unmodified)	Holes > 5mm (with factor)
A	Compressor Station (with 2 units)	0.01080	0.05603	0.00896	0.01472	0.00225
A	Pressure Reduction Station	0.00076	0.01252	0.00272	0.00338	0.00069
B	Blending Station	0.00540	0.53897	0.05762	0.11150	0.01298
B	Block Valve Site	0.00004	0.00076	0.00011	0.00024	0.00003
B	Metering Station	0.00010	0.00384	0.00079	0.00092	0.00018
B	Multi Junction	0.00045	0.01510	0.00317	0.00406	0.00083
B	Pig Trap	0.00011	0.00167	0.00026	0.00054	0.00008

The table above indicates that even with an onshore modification factor the leak frequencies for all hole sizes calculated for a particular unit type are higher than those recorded in the AGIFF database in all cases. This may, in part, be due to differences in the underlying data capture requirements as discussed above. Therefore, the leak frequencies calculated for holes > 5mm in diameter are also provided. These indicate that if the AGIFF reduction factor is used, closer agreement is obtained. However, it is highly unlikely that all leaks < 5mm in diameter on high pressure gas systems are unreported in the AGIFF database, suggesting that the use of the HSE LUP process leak values as a benchmark is cautious for high pressure gas installations.

For example, Company A provided a parts count for a pressure reduction station, which is the functional unit type with the largest number of incidents in the AGIFF database. This gives the predicted incident frequencies:

- Using the unmodified offshore data:
  - 0.01252 per unit-year for all hole sizes and
  - 0.00338 per unit-year for holes > 5mm in diameter.
- Using the modified offshore data with the AGIFF reduction factor:
  - 0.00272 per unit-year for all hole sizes and
  - 0.00069 per unit-year for holes > 5mm in diameter.

The AGIFF database includes data from 53712 unit-years for pressure reduction functional units. Hence, based on the frequencies above, the expected range of incidents would be:

- Using the unmodified offshore data:
  - 672 for all hole sizes and
  - 182 for holes > 5mm in diameter.
- Using the modified offshore data with the AGIFF reduction factor:
  - 146 for all hole sizes and
  - 37 for holes > 5mm in diameter.

This compares with 41 incidents involving accidental releases recorded in the AGIFF database, for releases of all hole sizes that meet the reporting criteria.

This type of comparison exercise can only be an approximation, but the results tend to support the use of the IOGP offshore leak frequencies in conjunction with the AGIFF reduction factor for onshore AGIs. The unmodified offshore frequencies could otherwise significantly overpredict the observed incident frequencies for onshore AGIs and hence the modified frequencies obtained using the AGIFF reduction factor are considered to be more appropriate for this application.

Rupture Frequencies

The assessment above provides a set of leak frequencies for all equipment items; however, it does not take into consideration the risk from catastrophic failure events such as ruptures of large diameter above-ground pipework, buried onshore gas pipelines or process vessels. This section develops a set of rupture frequencies for process vessels and above-ground pipework servicing Above Ground Installations.

The UK HSE LUP guidance provides data for above ground pipelines both in process areas and within the AGI site and process vessels; see Table 5.

Table 5: UK HSE Land Use Planning (LUP) Guidance Rupture Failure Frequencies [6]

Equipment Type	Equipment Diameter	Rupture Failure Frequency
Fully Welded Pipeline – AGI Site	All	6.5×10^{-9} per m-year
Process Pipeline	D < 2”	1.0×10^{-6} per m-year
Process Pipeline	2” ≤ D < 6”	5.0×10^{-7} per m-year
Process Pipeline	6” ≤ D < 12”	2.0×10^{-7} per m-year
Process Pipeline	12” ≤ D < 20”	7.0×10^{-8} per m-year
Process Pipeline	20” ≤ D < 40”	4.0×10^{-8} per m-year
Process Pipeline	D ≥ 40”	4.0×10^{-8} per m-year
Process Vessel	All	4.0×10^{-6} per year

There are no pipe ruptures recorded within the AGIFF database.

The offshore database does not distinguish between large holes and ruptures in topsides equipment as the consequences from these types of releases are similar due to the level of congestion and confinement offshore.

A review of a range of sites indicates that there is a significant level of flanges, valves and connections on all above-ground pipe. Therefore, it is considered that the following rupture frequencies should be used on AGI sites:

- Above-ground pipework: UK HSE Land Use Planning guidance for process pipework (see green shaded values in Table 5).
- Process vessels: UK HSE Land Use Planning guidance for process vessels (4.0×10^{-6} per year).

Many of the gas pipeline failures worldwide are on buried transmission pipelines outside the fenced area of an AGI and there are a variety of databases that capture information on these incidents. The information stored within these databases varies with the reporting criteria. In all cases it is possible to calculate rupture failure frequencies for buried pipelines:

- European Gas Incident Data Group (EGIG), [7]. Incident and system exposure data is available for the period from 1970 to 2019. Within this database, a rupture is defined as a hole with a diameter greater than the diameter of the pipe.
- United Kingdom Onshore Pipeline Operators' Association (UKOPA), [8]. Incident and system exposure data is available for the period from 1962 to 2018. Within this database, a rupture is defined as a circular hole diameter with an area equal to, or greater than, the cross-sectional area of the pipe. It is noted that the UKOPA database also includes information on part-wall damage as well as pipeline failures.
- Failure Frequency Analysis (FFA), [1]. Incident and system exposure data is captured over the period from 2008 to 2019. Within this database, a rupture is defined as a large release from a pipe where the cross-sectional area of the release is equal to, or greater than, twice the cross-sectional area of the pipe, or a complete break in a pipe. It is noted that this database allows failure frequencies to be calculated taking into consideration multiple pipeline-specific parameters.

One possible approach to assessing the failure frequencies of buried pipelines within the fenced boundary of an AGI could be to use the frequencies applied to the same buried pipeline outside the fence but modified to take account of expected differences in the likelihood of interference damage within a controlled environment, by either removing or reducing the contribution from external interference damage.

As an alternative to historical failure data, probabilistic Structural Reliability Analysis (SRA) techniques have been developed to estimate failure frequencies (including ruptures) for buried pipelines based on detailed pipeline-specific parameters. The SRA models calculate a limit state corresponding to the maximum damage that a pipeline could sustain before propagating and follow a probabilistic approach to estimating the likelihood that the pipeline could suffer damage exceeding the calculated limit state for different threats.

Discussion

There are nine contributing companies in the AGIFF project, operating gas transmission networks in the UK and mainland Europe. Installation population and incident data is currently stored in the AGIFF database for years from 2012 up to and including 2018. Although the database is relatively new, because some of the participating companies operate large numbers of high pressure gas installations, the quantity of data in the database has already reached a total exposure of over 230,000 unit years. Serious incidents on AGIs are rare, with an estimated average frequency for Significant incidents of 1.3×10^{-5} per year per functional unit.

As part of the comparisons of data, the derived AGIFF event frequencies were benchmarked against the data for offshore installations, recently published by the IOGP [4]. As well as additional operating years, this update included an extensive review to improve the quality of both the incident data and the equipment population data. Leak frequencies calculated from experience of incidents reported in the UK offshore sector of the North Sea are likely to overestimate those for onshore AGIs that typically operate with dry sweet natural gas in a more benign environment. The IOGP data is presented in terms of leak frequencies for individual equipment types and, as a result, the use of functional units in the AGIFF database means that a direct equipment category comparison could not be performed. A comparison was therefore undertaken to benchmark the leak frequencies derived from offshore experience and published by IOGP with selected values used by the UK HSE for the purposes of Land Use Planning advice around onshore sites. This allowed a series of multiplying factors to be derived for process pipework and vessels, to be applied to offshore leak frequencies to account for the differences in the operational environment.

The next step was to derive a parts count for functional units supplied by two of the participating companies that could then be used to predict the expected leak frequencies for that unit based on offshore experience according to the IOGP analysis and check for consistency with the actual experience of incidents at onshore AGIs recorded in the AGIFF database. By applying the IOGP leak frequencies to the component parts, the expected numbers of accidental releases large enough to be considered either "Notable" or "Significant" in the AGIFF database can be estimated and then compared with the actual number of recorded incidents. The comparison showed that using an unmodified version of the 2019 IOGP offshore data significantly over-estimated the number of actual incidents observed in the AGIFF database. However, by applying the

AGIFF reduction factors derived, closer agreement was obtained, giving confidence that the use of the modified leak frequencies, although cautious, is appropriate for onshore AGIs.

Conclusions

The AGIFF database has been established to allow gas transmission companies to share data and learning from incidents at their above-ground installations (AGIs). For buried pipelines, there are several sources of historical data to derive failure frequencies. However, no equivalent sources were previously available for AGIs. Although the database is relatively new (commencing in 2012), because some of the participating companies operate large numbers of AGIs, the installation exposure captured in the database is growing rapidly has already reached a total exposure of over 230,000 unit years. The experience to date demonstrates that serious incidents on AGIs are rare events, with no reported injuries or fatalities associated with gas releases recorded to date.

Historically, leak frequencies used in QRAs of onshore gas installations were derived from data collected for similar offshore installations, where there may be important differences due to space restrictions and environmental conditions. Comparison of the experience collected in the AGIFF database for onshore high pressure gas installations with recently published analysis of similar data for offshore installations suggests that the frequency of gas leakage is significantly lower for onshore installations. A series of reduction factors, derived from comparison of offshore leak frequencies with values for leak frequencies for process pipework and equipment used by the UK HSE for Land Use Planning purposes around onshore sites, is proposed and was found to give better agreement with the observed incident history as recorded in the AGIFF database. However, the comparisons with operational experience in the AGIFF database suggest that the modified values are still overly cautious for high pressure gas installations and it is planned to derive more appropriate values in future as the experience captured in the AGIFF database grows.

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