New International Failure Frequency Database for High Pressure Gas Installations

IChemE Hazards 31 Conference

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18 November 2021

Overview

- Introduction
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- Installation population and incident data
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- Conclusions

Introduction

- QRA methodologies for onshore gas transmission pipelines and installations well established
- Accidental releases are rare, but consequences can be severe
- Operators need to understand the risks to manage them effectively
- Predicted failure frequencies are essential to any QRA
- Historical data and methods available to derive failure frequencies for buried pipelines
  - New database to collect detailed statistics was presented at Hazards 27
- No equivalent for the high pressure gas installations that are essential to gas transmission
- Failure frequencies used in QRAs of onshore gas installations usually derived from data from offshore installations
  - Important differences due to space restrictions and environmental conditions

Introduction

- AGIFF (Above Ground Installation Failure Frequencies) project initiated to establish statistical database for incidents on high pressure gas installations
- Aims to improve knowledge for estimating failure frequencies from historical data and enhance understanding of the causes of incidents and the types of facilities most likely to be affected
- Nine participating companies, operating gas transmission networks in Europe
  - Cadent (UK), Enagas (Spain), Energinet (Denmark), Fluxys (Belgium), Gasunie (Netherlands), GRTgaz (France), National Grid (UK), Open Grid Europe (Germany) and Swissgas (Switzerland)
- AGIFF database records incidents since 2012 on installations operated by the AGIFF companies

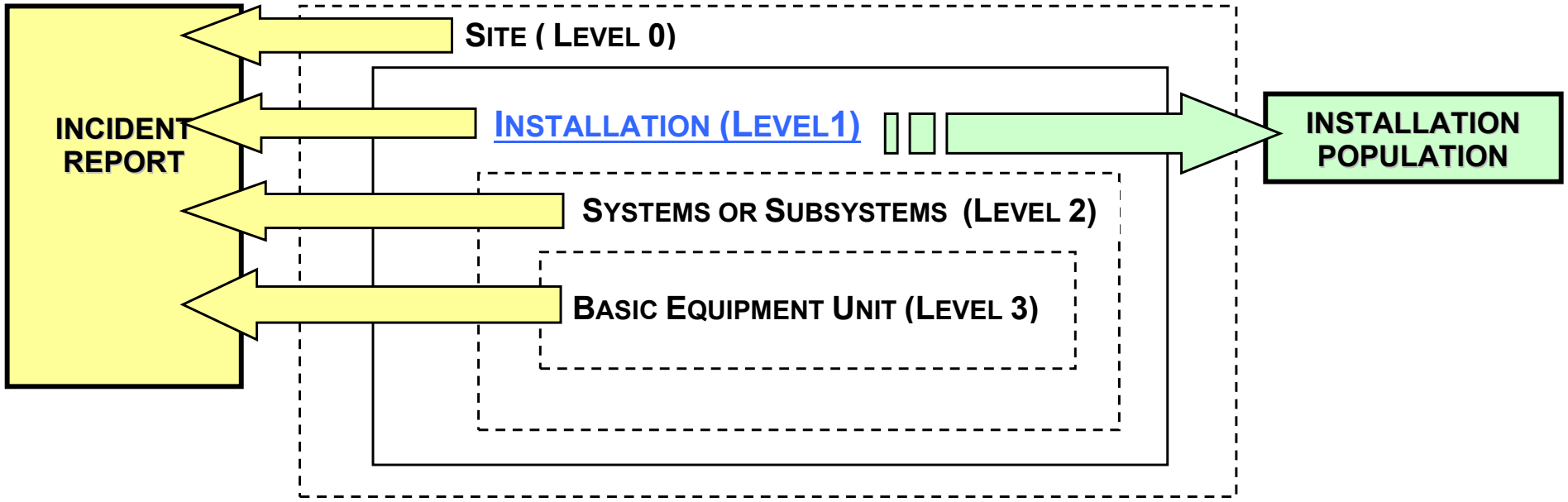
Structure of the database

- In order to establish the database, it was 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
- Not straightforward for high pressure gas installations, ranging from complex sites with multiple functions to simple sites with a single line valve

Structure of the database

- LEVEL 0: Corresponding to a site with one or more different installation functions
  - Used only for identifying the incident location
- LEVEL 1: Corresponding to a single installation function
  - 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
  - Used for localising the incident
- LEVEL 3: Corresponding to the basic equipment items (pipes, valves, filters, flanges and so on)
  - Used when an incident is reported and the actual equipment involved can be identified

Structure of the database



- AGIFF database has forms for installation population and incident data
- The use of “functional unit” for population is a simplification to limit effort needed to collect data
  - If detailed equipment counts were required, many companies would have been unable to participate

Reporting criteria – installation population

- “Above Ground Installations (AGIs)” include: “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 divided into several “functional units”
  - e.g. a single fenced area including a pig trap AND a pressure reduction unit is recorded as one pig trap and one pressure reduction functional unit
- Functional unit groups used in the database

line valve stations	metering stations
pig-trap stations	compressor stations
multi-junctions	blending stations
pressure reduction stations	gas storage devices

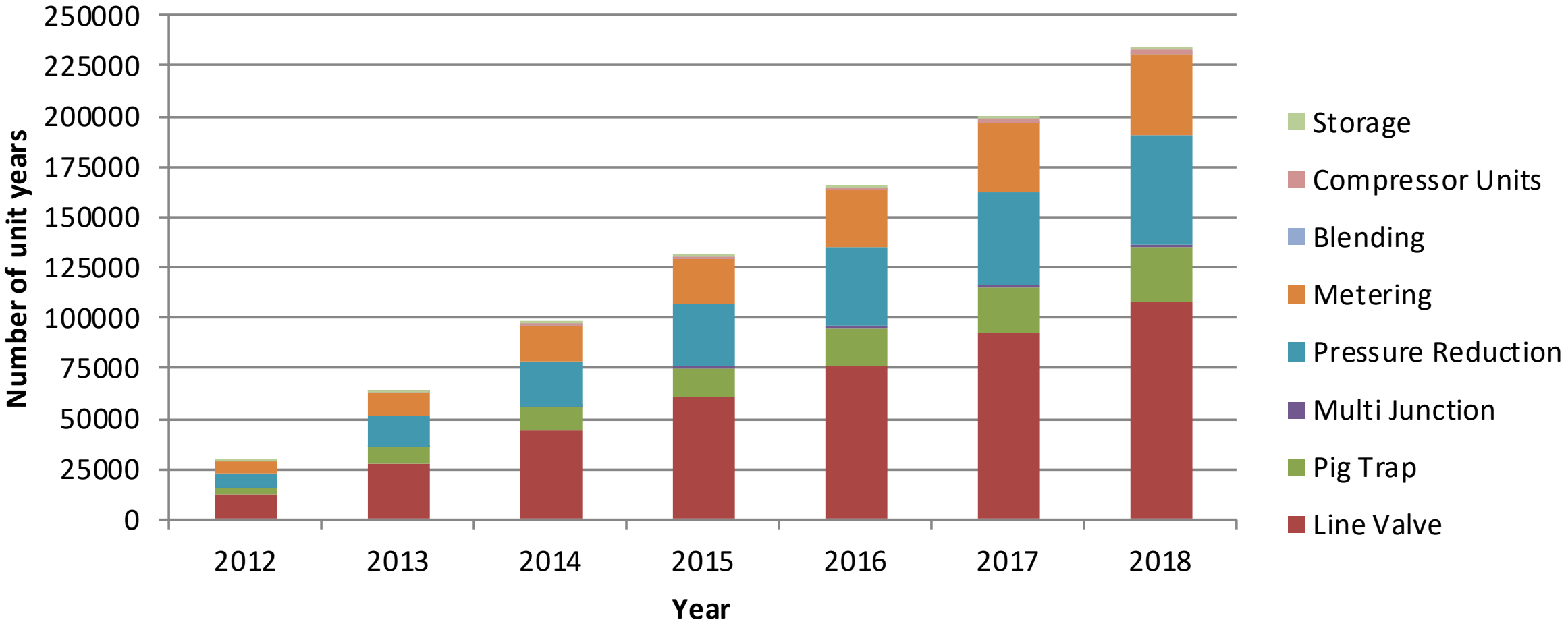
Reporting criteria - incidents

- Incidents categorised as either “Significant” or “Notable”
  - Significant incident resulted in an actual hazard
  - Notable incident had the potential to create a hazard that was not realised
- Significant incidents involve fire, explosion or missile effects
  - Notable incidents typically involve unignited releases of gas
- To decide whether a leak is Notable, criteria used in the UK for RIDDOR 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
- Uncertainty in cases where events are reported which are non-hazardous, but of long duration
  - Tends to overestimate the frequency of dangerous occurrences at AGIs

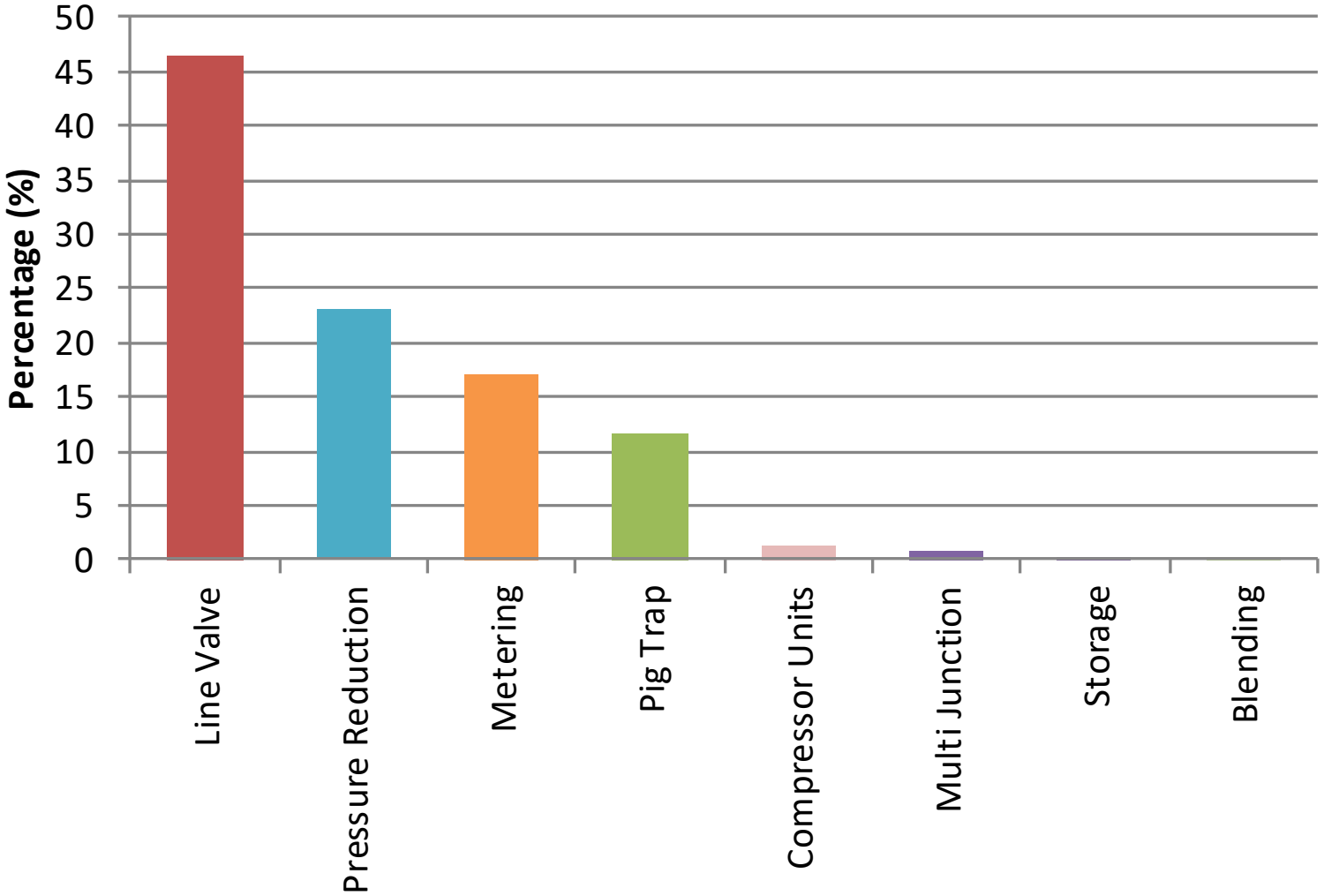
Installation population data

- Population reported as the number of major site functional units, defined as LEVEL 1 in the database guidelines
  - Typical site will have one or more units
  - Exception is that compression is defined by the number of compressors
- For 2012 to 2018, AGIFF database contains over 230,000 operating years of experience for all functional units
- Analysis of functional units versus pipeline length for AGIFF group members showed companies have broadly similar ratio of pipeline lengths to functional units
  - Aggregating operating experience to give a larger dataset seems reasonable

Population data used to derive incident frequencies



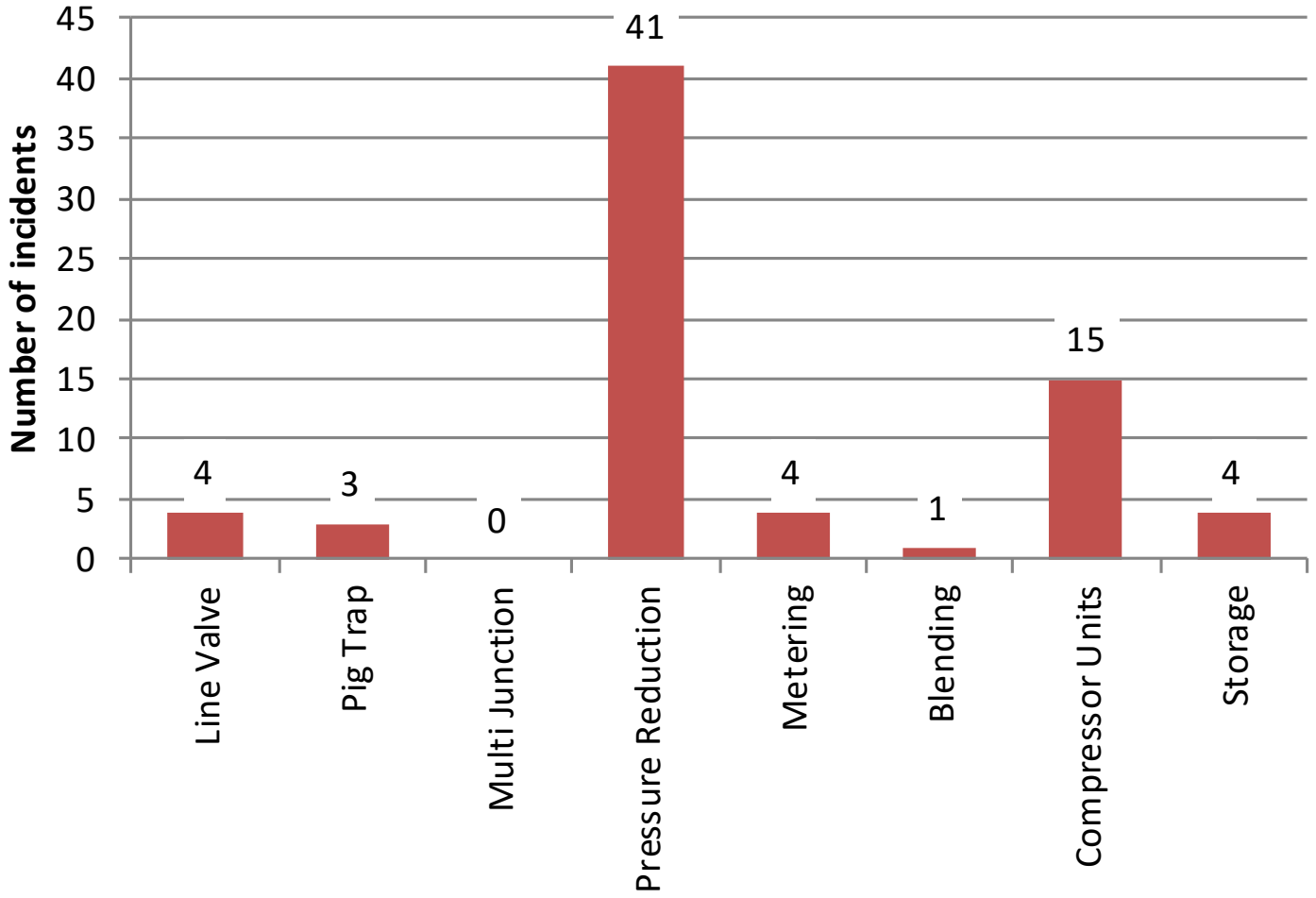
Relative proportions of each unit type



Installation incident data

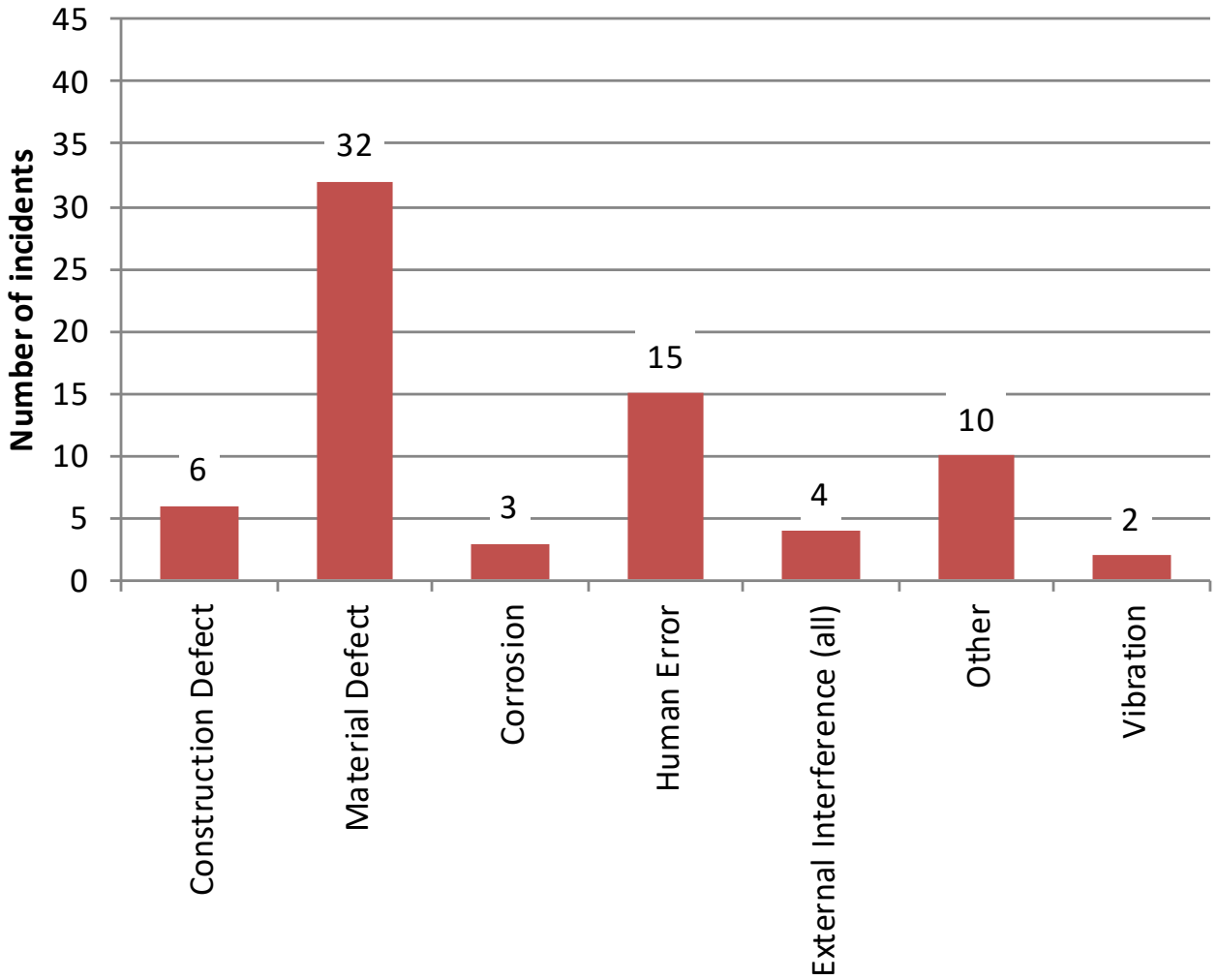
- 72 incidents recorded in 2012 to 2018
  - 3 “Significant”
  - 69 “Notable”
- 5 involved an ignited release of gas
  - 3 “Significant” and 2 “Notable” (resulting in trivial hazards)
- 67 incidents did not ignite and were all classified as “Notable”
- No fatalities or injuries from gas release incidents at installations in the database to date
  - 1 fatality from a motorcycle crashing into an AGI (suspected suicide)

Incidents by functional unit type



- Nearly 60% of the incidents from Pressure Reduction units, even though Pressure Reduction units make up less than 25% of the population

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 incidents) followed by Human Error (21%)

Event frequency estimation

- Overall average frequency 3.1 x 10^{-4} incidents per year per functional unit
- 4.2% of incidents classed as Significant
  - Average frequency for Significant incidents of 1.3 x 10^{-5} per year per functional unit.
- Small number of incidents in the database to date limits the possibilities for statistical analysis
- Uncertainty handled following approach adopted by UK HSE
- Approach taken follows that used by HSE
  - Incident frequencies given together with upper and lower 95% confidence interval based on Poisson distribution
  - Where no event has been recorded (i.e. “multi junction” functional units), frequency derived using 50% confidence interval

Event frequencies (per functional unit per year)

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

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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	$3.1x10^{-4}$

Onshore vs offshore AGIFF factor

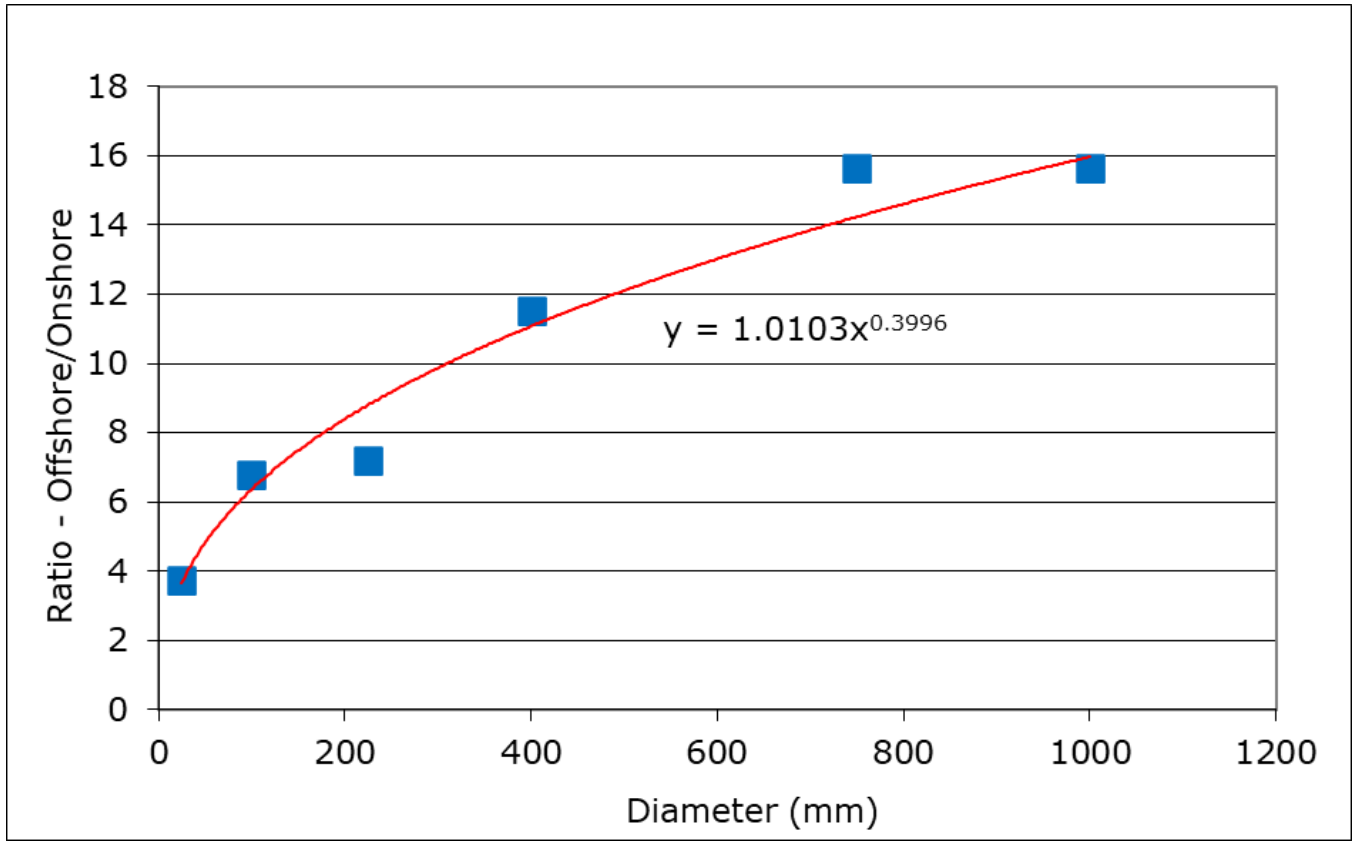
- Onshore failure frequencies often derived from data for similar offshore installations
  - Important differences due to space restrictions and environmental conditions
- Offshore incident data, collected by HSE from operators, is used to derive leak frequencies for process equipment
  - Updated analysis recently published by IOGP (International Association of Oil & Gas Producers)
- Incident rates steadily decreasing, so 10-year average leak frequency used in this analysis
- Leak frequencies from offshore experience likely to overestimate those for onshore AGIs
- Onshore reduction factor (“AGIFF reduction factor”) developed by comparing leak frequencies for process pipework on onshore sites used by HSE for the purposes of Land Use Planning (LUP) advice with data for offshore process pipework
  - LUP values for fully welded gas pipe could not be directly compared with offshore data
  - Leak frequencies for process pipework should be conservative for gas AGIs

Onshore and offshore leak frequencies for process pipework

PROCESS PIPEWORK DIAMETER RANGE	ONSHORE LEAK FREQUENCY (PER M-YEAR) FOR HOLE SIZE DIAMETER OF					RATIO
	1/3 x pipe Diameter	25 mm	4 mm	3 mm	Total	
0 to 49 mm		5.0×10^{-6}		1.0×10^{-5}	1.5×10^{-5}	5.6×10^{-5}	3.8
50 to 149 mm		1.0×10^{-6}		2.0×10^{-6}	3.0×10^{-6}	2.0×10^{-5}	6.8
150 to 299 mm	4.0×10^{-7}	7.0×10^{-7}	1.0×10^{-6}		2.1×10^{-6}	1.5×10^{-5}	7.2
300 to 499 mm	2.0×10^{-7}	5.0×10^{-7}	8.0×10^{-7}		1.5×10^{-6}	1.7×10^{-5}	11.5
500 to 1000 mm	1.0×10^{-7}	4.0×10^{-7}	7.0×10^{-7}		1.2×10^{-6}	1.9×10^{-5}	15.6
> 1000 mm	1.0×10^{-7}	4.0×10^{-7}	7.0×10^{-7}		1.2×10^{-6}	1.9×10^{-5}	15.6

- Unmodified offshore data predicts larger leak frequencies than onshore LUP in all cases
- Ratio of offshore to onshore leak frequency increases with pipe diameter from 4 to 16

Correlation of offshore to onshore leak frequencies



- Correlation applied to pipework, valves and flanges
- Similar exercise carried out for leaks from vessels
  - Reduction factor of 10.8
  - Applied to all other equipment types except pipework, valves and flanges

Historical Leak Frequency Comparison

- To illustrate the influence of the AGIFF factor, parts counts were supplied by two of the AGIFF members for different functional unit types
- Total leak frequencies calculated with and without AGIFF reduction factor applied and compared to incident frequencies from the AGIFF database
- Data used to calculate total leak frequencies includes all leaks from holes above 1mm diameter
- LUP guidance suggests that 50% to 70% of leaks are in 1mm to 5mm hole diameter range
  - UK offshore database records a similar proportion
- Total leak frequencies also calculated for holes above 5mm in diameter, with and without the AGIFF factor, for comparison

Total leak frequencies (per year) for sample AGIs

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

Comparison of total leak frequencies for sample AGIs

- Even with AGIFF factor applied the leak frequencies for all hole sizes (> 1mm diameter) are higher than the event frequencies recorded in the AGIFF database in almost all cases
  - Use of HSE LUP values as benchmark appears cautious for high pressure gas installations
  - Possibly partly due to differences in the underlying data capture requirements
- Comparison with leak frequencies for holes > 5mm in diameter gives closer agreement
  - Highly unlikely that all leaks < 5mm unreported by AGIFF
  - Supports the use of AGIFF reduction factor for onshore gas installations
- Example analysis carried out for pressure reduction station to illustrate
  - Functional unit type with most incidents in the AGIFF database and significant population exposure
  - Narrow confidence limits from statistical analysis

Comparison of expected incidents for PRS units

- Example analysis carried out for pressure reduction station for illustration
  - Functional unit type with highest confidence in AGIFF results
- Using the unmodified offshore data:
  - 0.01252 per unit-year for all hole sizes > 1mm
  - 0.00338 per unit-year for holes > 5mm in diameter
- With AGIFF factor applied:
  - 0.00272 per unit-year for all hole sizes > 1mm
  - 0.00069 per unit-year for holes > 5mm in diameter

- AGIFF database includes data from 53712 unit-years for pressure reduction, hence expected range of incidents is:
- Using the unmodified offshore data:
  - 672 for all hole sizes > 1mm
  - 182 for holes > 5mm in diameter
- **With AGIFF factor applied:**
  - **146 for all hole sizes > 1mm**
  - 37 for holes > 5mm in diameter
- **Actual number of AGIFF incidents = 41**

Rupture frequencies

- Assessment provides leak frequencies but not catastrophic failure events
  - e.g. ruptures of large diameter pipework, pipelines or process vessels
- No pipe ruptures recorded within the AGIFF database
- Offshore database does not distinguish between large holes and ruptures
- UK HSE LUP guidance provides values for above-ground pipelines both in process areas and within the AGI site and process vessels
  - Propose to follow UK HSE LUP guidance for ruptures of process pipework and vessels onshore
- Different possible sources of rupture frequencies for buried pipelines
  - Pipeline databases (EGIG, UKOPA, FFA)
  - Structural reliability analysis (SRA) predictive techniques
  - Use established methods for cross-country pipelines with fenced site limiting external interference damage

Conclusions 1

- AGIFF database established for gas transmission companies to share data and learning from incidents at above-ground installations (AGIs)
  - Several sources of historical data to derive failure frequencies for onshore pipelines but not for AGIs
- 9 contributing companies, operating gas transmission networks in the UK and mainland Europe
  - Installation population and incident data stored in the AGIFF database since 2012
  - Data collected by “Functional Unit” to limit effort required for data collection
  - Relatively new, but participating companies operate large numbers of high pressure gas installations
  - Total exposure of over 230,000 unit years by 2018 and growing
- Serious incidents on AGIs are rare
  - Estimated average frequency for Significant incidents of 1.3×10^{-5} per year per functional unit
  - No reported injuries or fatalities associated with gas releases recorded to date

Conclusions 2

- Historically, leak frequencies for QRAs of onshore gas installations derived from offshore data
- Comparison of AGIFF data with analysis of offshore data published recently by IOGP suggests that frequency of gas leaks is significantly lower for onshore installations
  - Use of functional units in the AGIFF database means that direct comparisons cannot readily be performed
- Reduction factors from comparison of offshore leak frequencies with values used by UK HSE for Land Use Planning around onshore sites gives better agreement with AGIFF data
- Analysis of the expected number of incidents for Pressure Reduction Stations (where the AGIFF data is most robust) indicates that use of leak frequencies with AGIFF reduction factor is cautious
  - Suggests HSE LUP values for process pipework and equipment cautious for onshore gas installations
  - Plan to derive more appropriate values for onshore gas AGIs as experience in AGIFF database grows

Acknowledgements

- The member companies of the AGIFF Group for sponsoring the work, providing their data and granting permission to present the paper

- Co-authors Carol Humphreys (maintaining the AGIFF database) and Zoë Wattis (benchmarking analysis vs offshore data)

- Hanne Olafsen and Energinet for Chairing the AGIFF Group and support and encouragement for preparing the paper

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