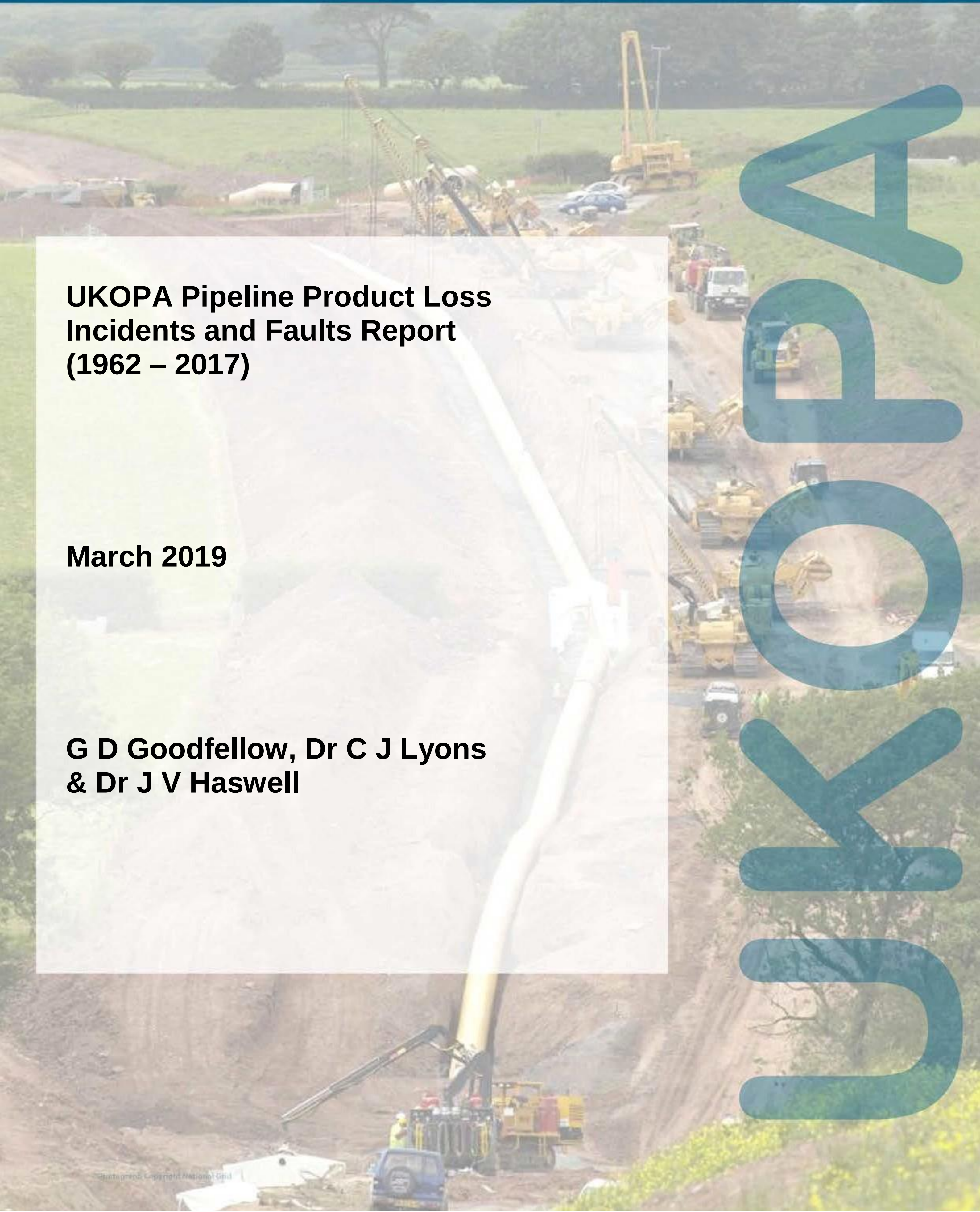
UKOPA

United Kingdom Onshore Pipeline Operators' Association



UKOPA Pipeline Product Loss Incidents and Faults Report (1962 – 2017)

March 2019

G D Goodfellow, Dr C J Lyons
& Dr J V Haswell

Photograph Copyright National Grid

UKOPA PIPELINE FAULT DATABASE

Pipeline Product Loss Incidents and Faults Report

(1962 – 2017)

Report of the UKOPA Fault And Risk Work Group

Comprising data from:
National Grid
Cadent
Northern Gas Networks
Scotia Gas Networks
Wales & West Utilities
Gas Networks Ireland
BPA
Essar Oil (UK) Limited
INEOS
Ineos FPS
Sabic
Shell
Uniper
Wood

and supported by the Health and Safety Executive

Report prepared by G D Goodfellow, Dr C J Lyons & Dr J V Haswell for FARWG

Report Reference: UKOPA/RP/18/002
March 2019

Comments, questions and enquiries about this publication should be directed to the Chair of the UKOPA Pipeline Fault and Risk Work Group:

United Kingdom Onshore Pipeline Operators' Association
Pipeline Maintenance Centre
Ripley Road
Ambergate
Derbyshire
DE56 2FZ

e-mail: enquiries@ukopa.co.uk

Disclaimer

This document is protected by copyright and may not be reproduced in whole or in part by any means without the prior approval in writing of UKOPA. The information contained in this document is provided as guidance only and while every reasonable care has been taken to ensure the accuracy of its contents, UKOPA cannot accept any responsibility for any action taken, or not taken, on the basis of this information. UKOPA shall not be liable to any person for any loss or damage which may arise from the use of any of the information contained in any of its publications. The document must be read in its entirety and is subject to any assumptions and qualifications expressed therein. UKOPA documents may contain detailed technical data which is intended for analysis only by persons possessing requisite expertise in its subject matter.

Summary

This report presents collaborative pipeline and product loss incident data from onshore Major Accident Hazard Pipelines (MAHPs) operated by National Grid, Cadent, Northern Gas Networks, Scotia Gas Networks, Wales & West Utilities, Gas Networks Ireland, BPA, Essar Oil (UK) Ltd., INEOS, Ineos FPS, Sabic, Shell, Uniper and Wood, covering operating experience up to the end of 2017.

MAHPs are defined by the UK statutory legislation, The Pipelines Safety Regulations 1996 as amended (PSR96), for natural gas, the classification is above 8 bar absolute.

The data presented here covers reported incidents where there was an unintentional loss of product from a pipeline within the public domain, and not within a compound or other operational area.

The overall failure frequency over the period 1962 to 2017 is 0.212 incidents per 1000 km.year, the same as in the previous report covering the period from 1962 to 2016. The trend continues to show an ongoing reduction in overall failure frequency.

The failure frequency over the last 20 years is 0.088 incidents per 1000 km.year whilst in the previous report this figure was 0.084 incidents per 1000 km.year (covering the 20 year period up to the end of 2016).

For the last 5 years the failure frequency is 0.110 incidents per 1000 km.year, whilst in the previous report this figure was 0.087 incidents per 1000 km.year (covering the 5 year period up to the end of 2016).

This report also presents data for part-wall damage and defects, known as fault data; and the statistical distributions derived for estimating pipeline failure probabilities due to external interference events.

Contents

1 Introduction

1.1 Background

One of the key objectives of UKOPA is to develop a comprehensive view on risk assessment and risk criteria as they affect Land Use Planning aspects adjacent to, and operational ALARP assessments on, major hazard pipelines. The main multiplier in pipeline risk assessments is the per unit length failure rate, which directly influences the extent of the risk zones adjacent to the pipelines.

Historically, regulators and consultants who carry out risk assessments for UK pipelines relied on US and European data to provide the basis for deriving failure rates, due to the shortage of verified published data relating to UK pipelines. To counteract this lack of UK specific data, UKOPA published the first report in November 2000, presenting the first set of data for pipeline incidents resulting in the unintentional release of product up to the end of 1998.

1.2 Purpose of the Database

The purpose of the database is to:

- Record leak and fault data for UK MAHPs;
- Estimate leak and pipeline rupture frequencies for UK pipelines, based directly on historical failure rate data for UK pipelines;
- Provide the means to estimate failure rates for UK pipelines for risk assessment purposes based on analysis of damage data for UK pipelines; and,
- Provide the means to test design intentions and determine the effect on failure of engineering changes (e.g. wall thickness of pipe, depth of burial, diameter, protection measures, inspection methods and frequencies, design factor etc.)

1.3 Key Advantages

The database is designed to reflect the ways in which the UKOPA operators design, build, operate, inspect and maintain their pipeline systems. Although the pipeline population is extensive and the data covers over 50 years of operation, there are pipeline groups (e.g. large diameter, recently constructed pipelines) on which no faults or failures have occurred, or for which failure data is not statistically significant; however it is unreasonable to assume that the failure frequency for these pipelines is zero.

This UKOPA database contains extensive data on pipeline failures and on part-wall damage known as fault data, allowing prediction of failure frequencies for pipelines for which insufficient failure data exist.

Using Structural Reliability Analysis and fracture mechanics techniques it is possible to determine the range of defect dimensions that will cause a specific pipeline to fail; analysis of the statistical distributions of actual defect dimensions from the part-wall defect data allows the probability of a critical defect to be determined and failure frequencies for external interference failures to be calculated.

This approach has been used extensively and successfully by contributing companies in pipeline uprating projects and quantified risk assessments.

2 Pipeline System Data

2.1 Exposure

The total length of MAHPs* in operation at the end of 2017 for all participating companies (National Grid, Cadent, Northern Gas Networks, Scotia Gas Networks, Wales & West Utilities, Gas Networks Ireland, BPA, Essar Oil (UK) Ltd., INEOS, Ineos FPS, Sabic, Shell, Uniper and Wood) was 23,897 km. The total exposure in the period 1952 to the end of 2017 was 951,250 km.yr; the development of this exposure is illustrated in Figure 1.

Pipeline exposure before first recorded incident in 1962 = 3,740 km.yr (included in exposure and incident frequency calculations).
Above ground sections of cross-country pipelines are included in totals.

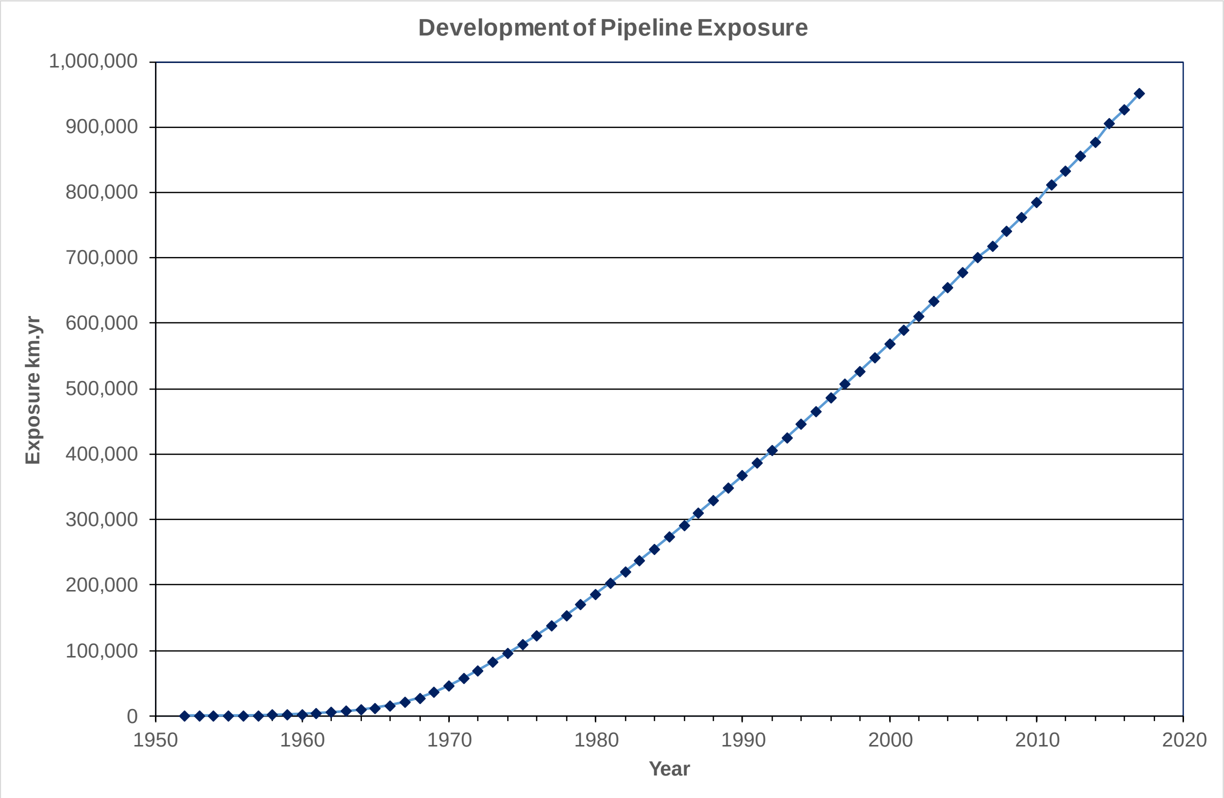


Figure 1: Pipeline Operating Exposure from 1952 to 2017

* MAHPs are defined by UK statutory legislation – The Pipelines Safety Regulations 1996 (PSR96) [1] – for natural gas the classification is above 8 bar absolute.

2.2 Transported Products

The lengths (in km) of pipeline in operation at the end of 2017, by transported product, are shown in Table 1 below.

Product	Length (km)	%age of Total
Natural Gas (Dry)	22,126	92.6
Ethylene	1,141	4.8
Natural Gas Liquids	251	1.1
Crude Oil (Spiked)	224	0.9
Ethane	38	0.2
Hydrogen	14	0.1
Propylene	37	0.2
Condensate	24	0.1
Propane	21	0.1
Butane	20	0.1
TOTAL	**23,897**	**100.0**

Table 1: 2017 Pipeline Operating Lengths

Note: The database includes 543 km of decommissioned pipelines (440 km previously used to transport natural gas, 56 km ethylene, 37 km carbon monoxide, 5 km propane and 5 km butane).

3 Product Loss Incident Data

A product loss incident is defined in the context of this report as:

- An unintentional loss of product from the pipeline;
- Within the public domain and outside the fences of installations;
- Excluding associated equipment (e.g. valves, compressors) or parts other than the pipeline itself; and,
- Excluding deliberate or malicious external interference by third parties including any attempts at theft.

A total of 202 product loss incidents were recorded over the period between 1962 and 2017 compared with 197 product loss incidents documented in the report covering the period to 2016. No product loss incidents were recorded prior to 1962. An annual breakdown of incidents is illustrated in Figure 2.

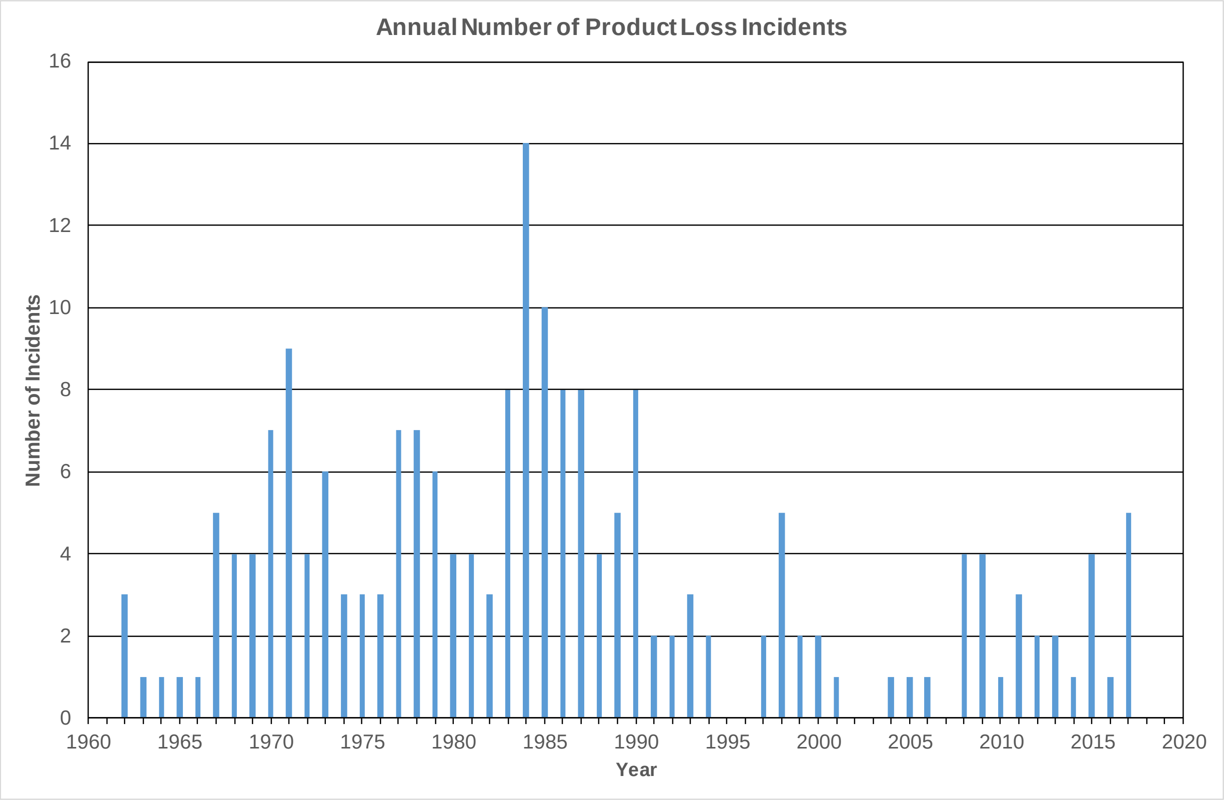


Figure 2: Product Loss Incidents per year since 1962

3.1 Differences between 2016 and 2017 product loss statistics

Five product loss incidents were recorded in 2017, one leak due to external corrosion, three small leaks at socket and spigot welds and a very small seep from a crack in a dented seam weld, which was originally damaged during pipeline construction. In comparison, in 2016 there was one product loss incident recorded; a leak at a socket and spigot weld. The cumulative number of incidents over the period 1962 to 2017 is shown in Figure 3.

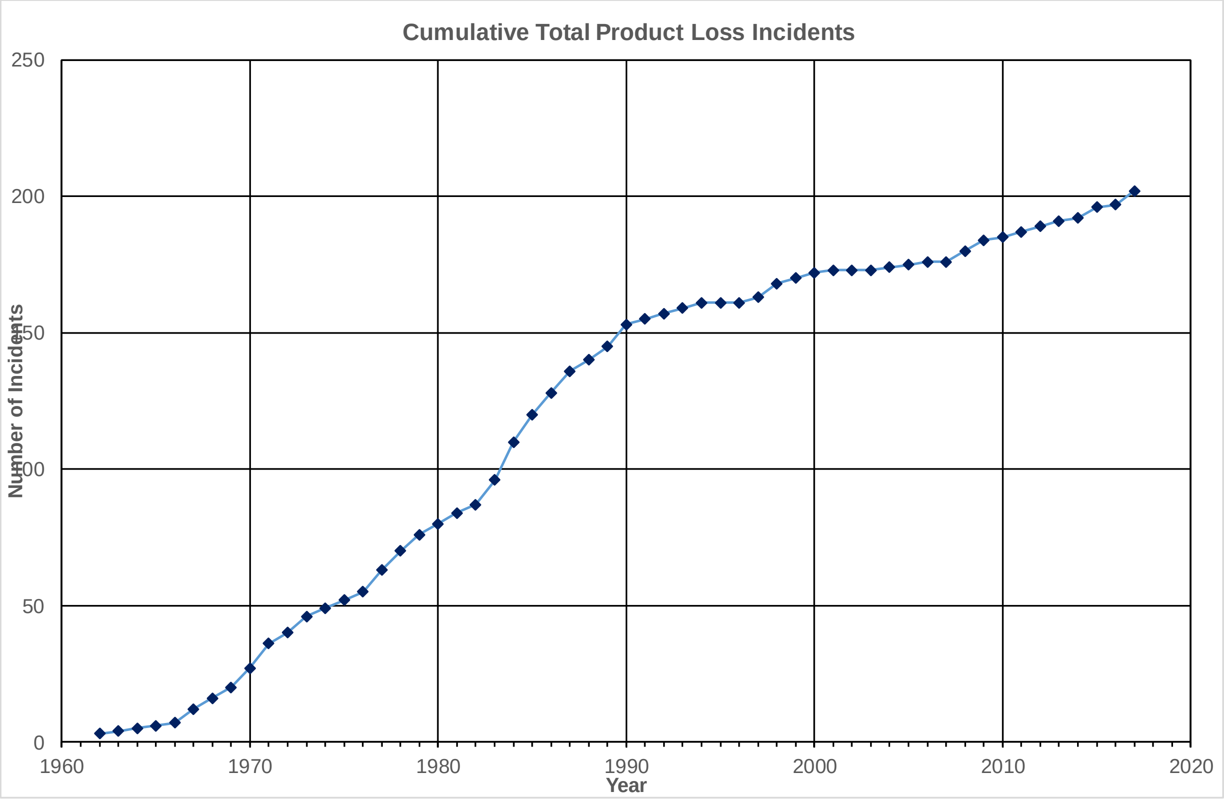


Figure 3: Cumulative Product Loss Incidents since 1962

3.2 Incident Ignition

Only nine out of 202 (4.5%) product loss incidents have resulted in ignition. Table 2 below provides more detail.

Affected Component	Cause of Fault	Hole Diameter Class	Date
Pipe	Pipe Defect	0 - 6 mm	1963
Bend	Internal Corrosion	0 - 6 mm	1969
Pipe	Girth Weld Defect	6 - 20 mm	1970
Bend	Pipe Defect	6 - 20 mm	1971
Pipe	Unknown	6 - 20 mm	1972
Pipe	Ground Movement	Full Bore	1984
Pipe	Other	40 - 110 mm	1991
Pipe	Seam Weld Defect	0 - 6 mm	1994
Pipe	Lightning Strike	0 - 6 mm	1998

Table 2: Ignited Product Loss Incidents

3.3 Incident Frequency

3.3.1 Trends over the Past 5, 20 and 55 Years

The overall incident frequency by hole size over the period 1962 – 2017 is shown in Table 3.

Equivalent Hole# Size Class	Number of Incidents	Frequency [Incidents per 1000 km.yr]
Full Bore* and Above	6	0.006
110 mm – Full Bore*	2	0.002
40 – 110 mm	9	0.009
20 – 40 mm	24	0.025
6 – 20 mm	30	0.032
0 – 6 mm	131	0.138
TOTAL	**202**	**0.212**

Table 3: Overall Incident Frequency by Hole Size

* *Full Bore ≡ diameter of pipeline*

\# *Equivalent hole size quoted in this report is the circular hole diameter in mm with an area equivalent to the observed (usually non-circular) hole size.*

The incident frequency over thirteen consecutive 5-year periods up to the end of 2017 is shown in Table 4.

Period	Number of Incidents	Total Exposure [km.yr]	Frequency [Incidents per 1000 km.yr]
1953 - 1957	0	408	0.000
1958 - 1962	3	4,565	0.657
1963 - 1967	9	15,931	0.565
1968 - 1972	28	48,378	0.579
1973 - 1977	22	68,463	0.321
1978 - 1982	24	82,362	0.291
1983 - 1987	48	89,991	0.533
1988 - 1992	21	95,103	0.221
1993 - 1997	7	101,422	0.069
1998 - 2002	10	104,814	0.095
2003 - 2007	3	107,006	0.028
2008 - 2012	14	114,331	0.122
2013 - 2017	13	118,475	0.110
TOTAL	**202**	**951,249**	**0.212**

Table 4: 5-Year Incident Frequency

The total exposure for the last 20 years (1998 – 2017) is 444,625 km.yr and the resulting incident frequency by hole size is shown in Table 5.

Equivalent Hole Size Class	Number of Incidents	Frequency [Incidents per 1000 km.yr]
Full Bore* and Above	0	0.000
110 – Full Bore*	0	0.000
40 – 110 mm	1	0.002
20 – 40 mm	6	0.013
6 – 20 mm	3	0.007
0 – 6 mm	29	0.065
TOTAL	**39**	**0.088**

Table 5: 20-Year Incident Frequency by Hole Size

The failure frequency over the last 20 years is 0.088 incidents per 1000 km.yr and for the last 5 years (2013 – 2017) is 0.110 incidents per 1000 km.yr. In the previous report [2] the 20 year failure frequency (for the period 1997 – 2016) was 0.084 per 1000 km.yr and the 5 year failure frequency was 0.087 incidents per 1000 km.year (covering the period 2012 - 2016).

The current 5- and 20-year failure frequencies can be compared with the overall failure frequency during the period 1962 – 2017 of 0.212 incidents per 1000 km.yr. An overview of the development of this failure frequency is shown in Figure 4 below.

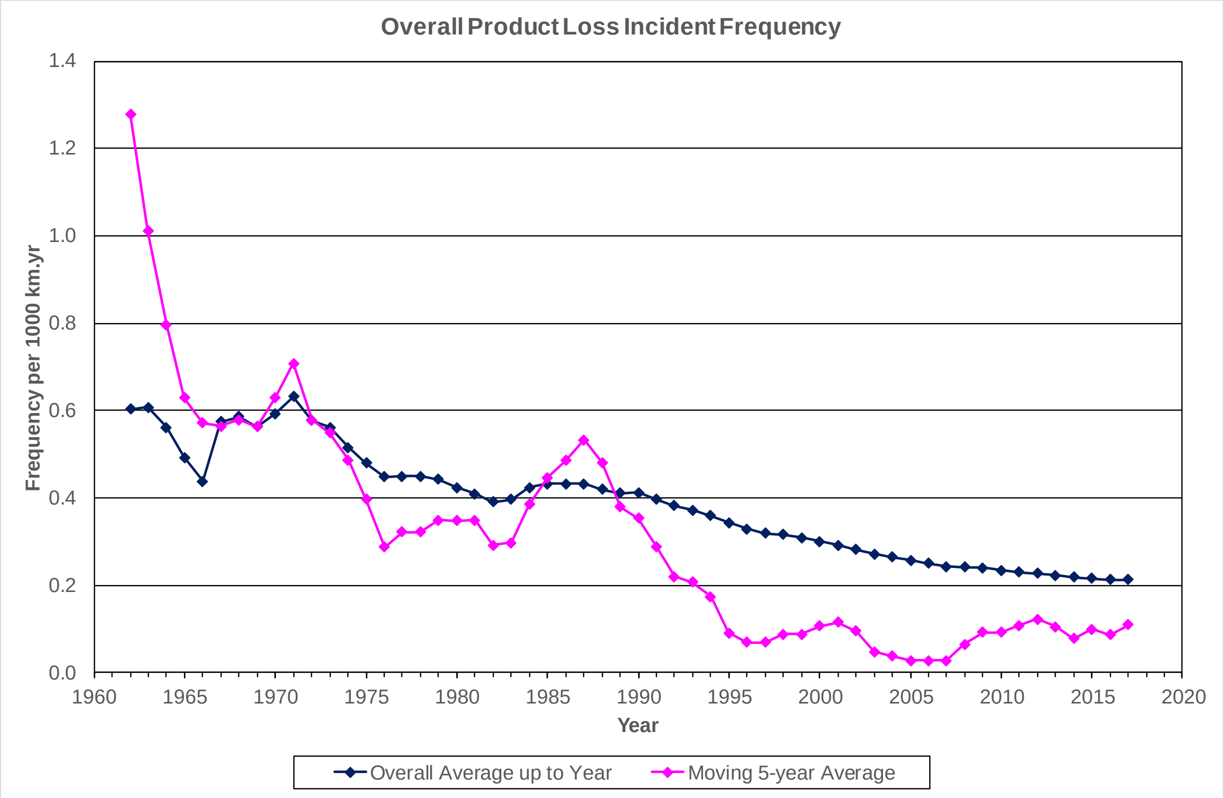


Figure 4: Overall and 5-Year Frequency Development

In order to see the results over recent periods, the moving average for each year has been calculated with reference to the incidents from the previous 5 years (2013 – 2017, 2012 – 2016, 2011 – 2015 etc.).

3.3.2 Confidence Intervals

Confidence intervals take uncertainty into account. For a specified confidence level (e.g. 95%), the greater the exposure, the narrower the confidence interval. In other words, the uncertainty decreases as more operating experience is gained.

Pipeline failures are discrete events, that tend to occur randomly, and are independent of each other. To calculate the confidence intervals, it is therefore assumed that the failure data will follow a Poisson distribution. The 95% confidence intervals for the overall average failure frequency are shown in Figure 5, and for the 5-year average in Figure 6.

Figure 5 shows that the overall frequency for the whole period is 0.212 per 1000 km.yr +/- 0.030 and Figure 6 shows that the 5-year average failure frequency for 2013 – 2017 is 0.110 per 1000 km.yr +/- 0.061.

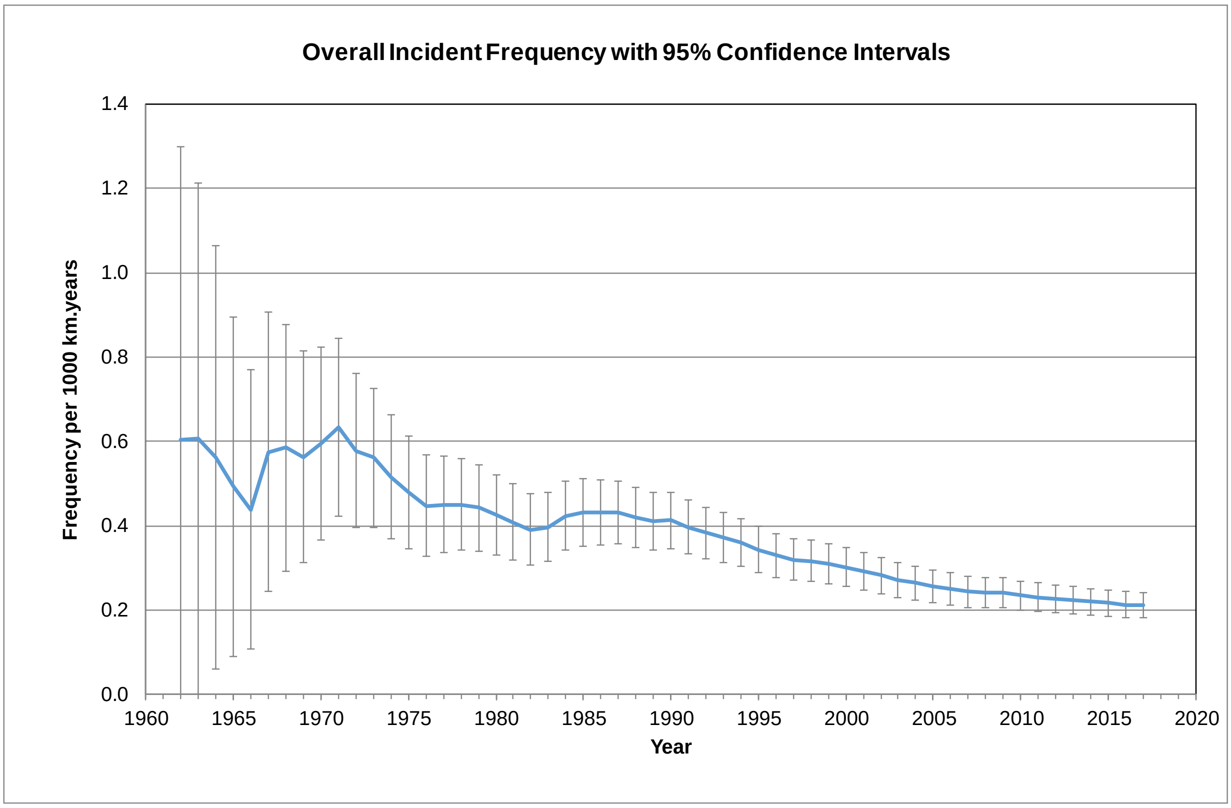


Figure 5: Overall Incident Frequency with 95% Confidence

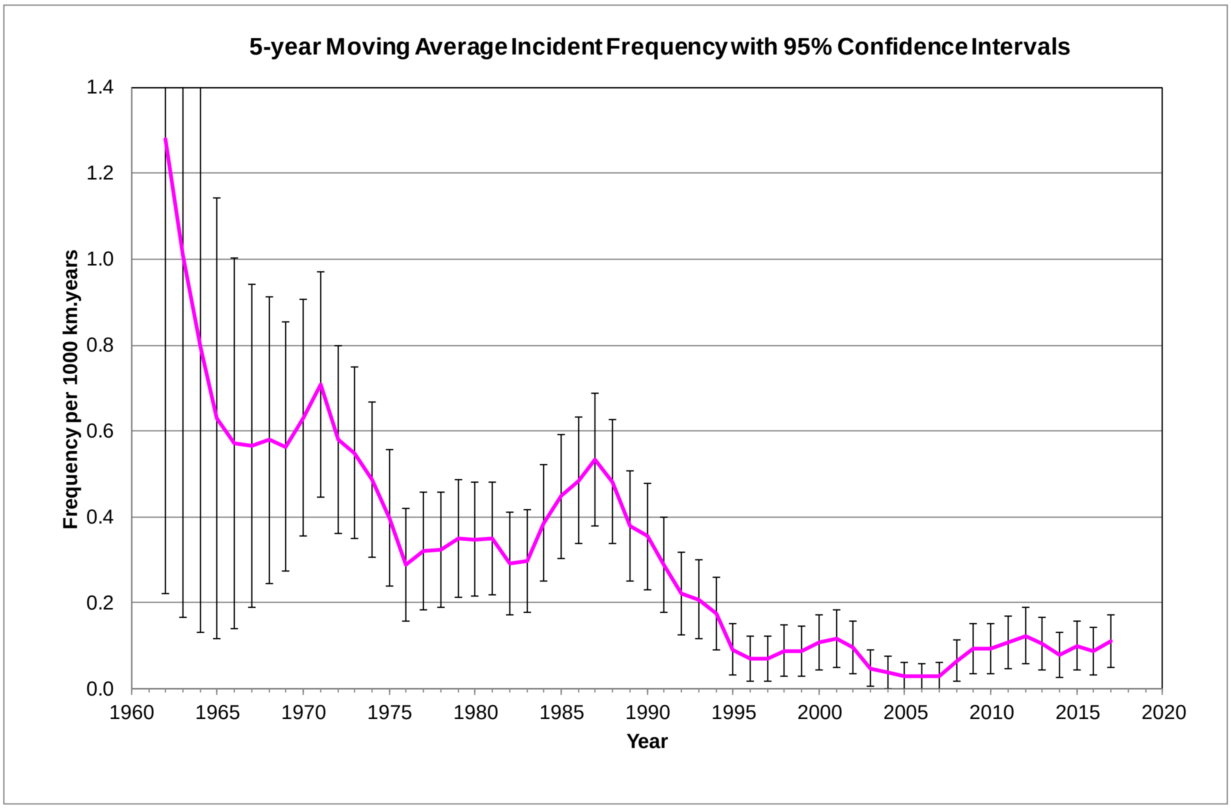


Figure 6: 5-year Incident Frequency with 95% Confidence

3.4 Incident Frequency by Cause

The development of product loss incident frequency by cause is shown in Figure 7, and the number of incidents due to each cause is listed in Table 6.

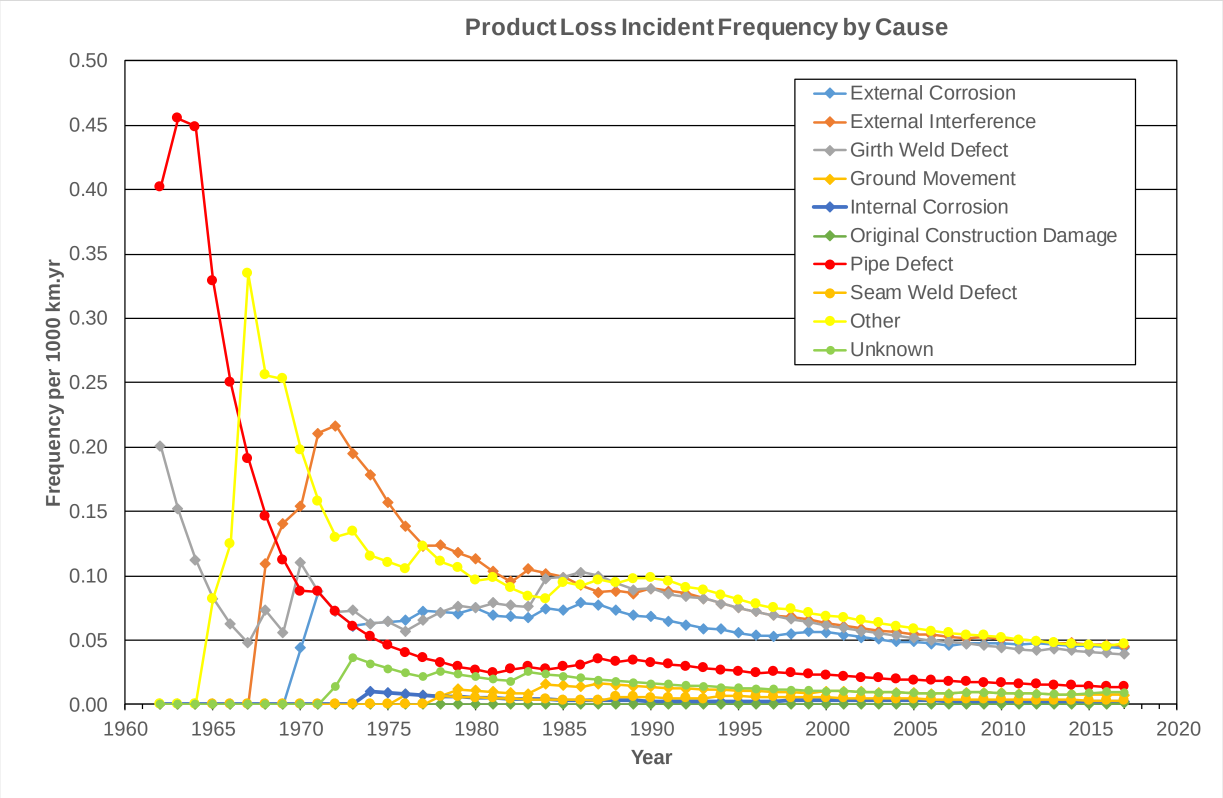


Figure 7: Product Loss Incident Frequency by Cause

Product Loss Cause	No. of Incidents	%age of Total
External Corrosion	42	20.8
External Interference	43	21.3
Girth Weld Defect	37	18.3
Ground Movement	7	3.5
Internal Corrosion	2	1.0
Original Construction Damage	1	0.5
Pipe Defect	13	6.4
Seam Weld Defect	3	1.5
Other	45	22.3
Unknown	9	4.5
TOTAL	**202**	**100**

Table 6: Product Loss Incidents by Cause

Further details on the product loss incidents where the cause is described as Other can be found in Section 3.8.

Figure 8 shows the product loss incident frequency by cause for the 202 product loss incidents over the period 1962 – 2017 compared with the incident frequency by cause for the 13 incidents over the last 5 years (2013 – 2017).

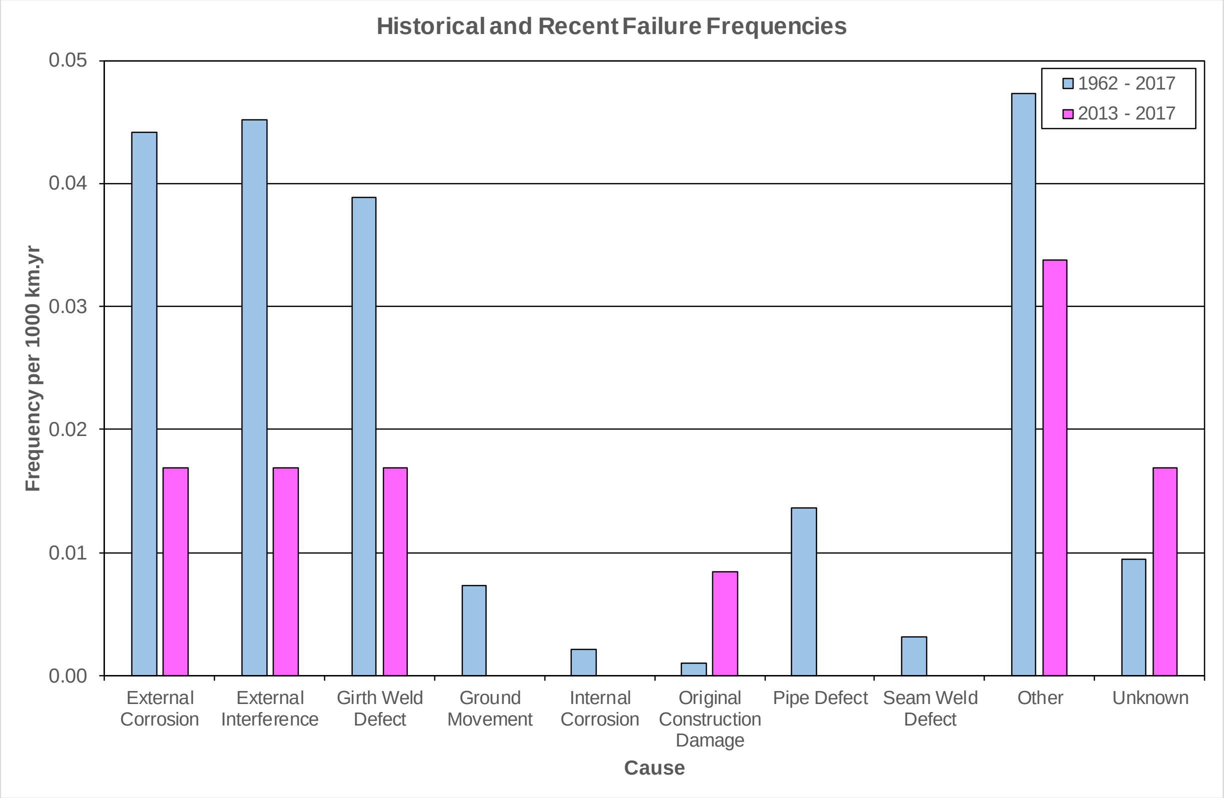


Figure 8: Overall and 5-year Product Loss Incident Frequency by Cause

An overview of the product loss incident frequency by cause and size of leak in the period 1962 to 2017 is shown in Figure 9.

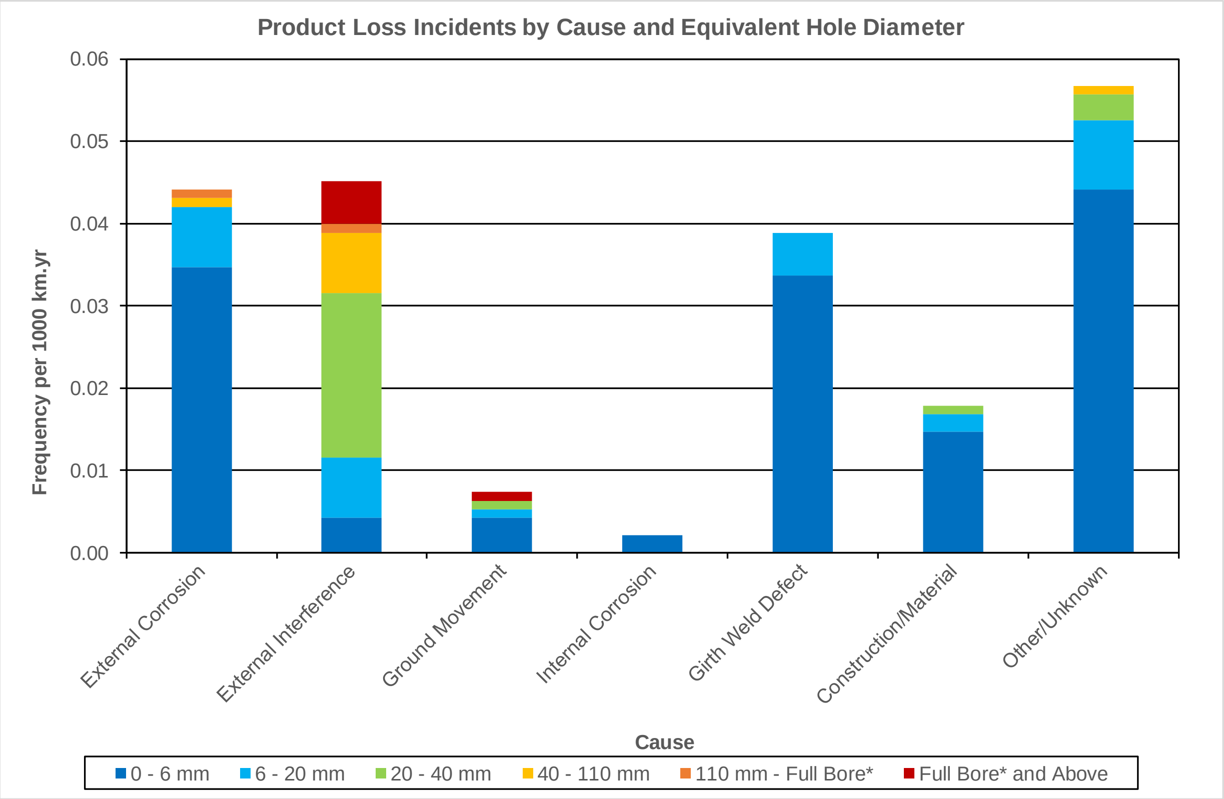


Figure 9: Product Loss Incident Frequency by Cause and Size of Leak

Construction/Material = Seam Weld Defect + Pipe Defect + Pipe Mill Defect + Damage during Original Construction
** Full Bore ≡ diameter of pipeline*

3.5 Girth Weld Defects

Figure 10 shows that 37 leaks due to girth weld defects were recorded in pipelines constructed before 1985, 35 of which were in pipelines constructed before 1972. All of the leaks had an equivalent hole diameter less than 20 mm with the majority less than 6 mm.

The reduction in the number of girth weld defects in pipelines constructed after 1972 is associated with the improvements in field weld inspection and quality control procedures, and the increasing capability of in-line inspection tools to detect girth weld anomalies.

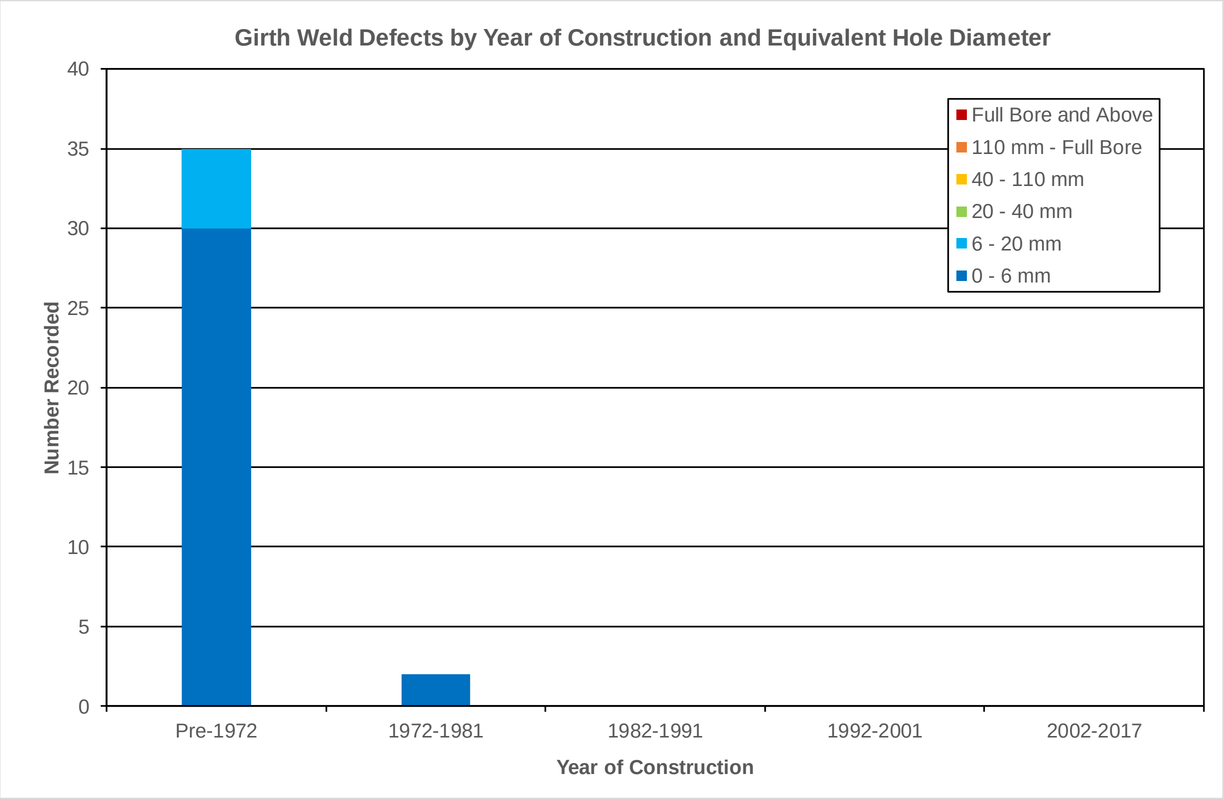


Figure 10: Girth Weld Defects

3.6 External Interference

Accidental external interference is one of the main causes of product loss incidents with 43 recorded failures attributable to this cause.

3.6.1 External Interference by Diameter Class

Figure 11 shows the product loss incident frequencies associated with external interference by hole size for each diameter class and the total frequencies by diameter class are shown in Table 7.

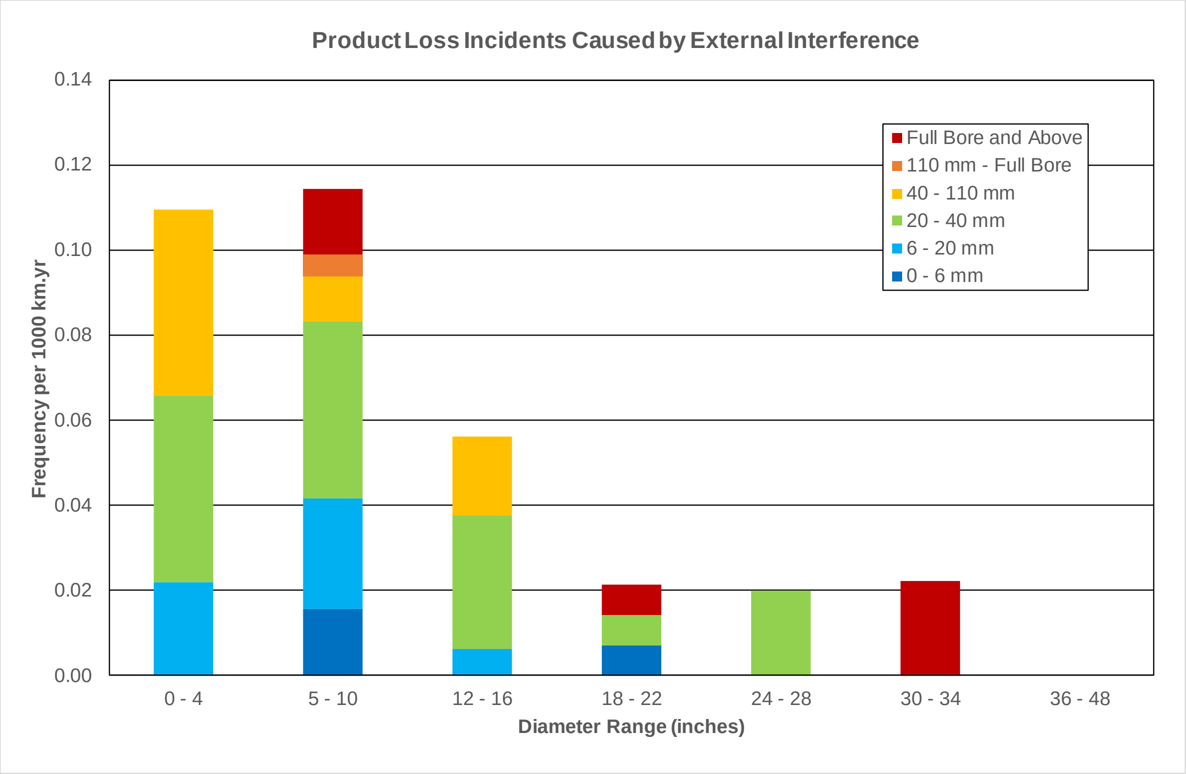


Figure 11: External Interference Product Loss Frequency by Diameter and Equivalent Hole Size

Diameter [inches]	Exposure [km.yr]	External Interference Incidents	Frequency [per 1000 km.yr]
0 - 4	45,649	5	0.110
5 - 10	192,214	22	0.114
12 - 16	160,161	9	0.056
18 - 22	140,897	3	0.021
24 - 28	151,832	3	0.020
30 - 34	45,219	1	0.022
36 - 48	215,278	0	0.000
OVERALL	**951,250**	**43**	**0.047**

Table 7: External Interference Incidents by Diameter Class

3.6.2 External Interference by Measured Wall Thickness Class

The relationship between product loss incidents caused by external interference and wall thickness is shown in Figure 12 and Table 8 below.

Figure 12: External Interference Product Loss Frequency by Wall Thickness and Equivalent Hole Size

Note: The largest wall thickness for a product loss incident caused by external interference to date is 12.7 mm.

Wall Thickness [mm]	Exposure [km.yr]	External Interference Incidents	Frequency [per 1000 km.yr]
<5 mm	60,815	13	0.214
6 - 10 mm	447,171	26	0.058
11 - 15 mm	364,176	4	0.011
>15 mm	78,737	0	0.000
Unknown	350	0	0.000
OVERALL	**951,250**	**43**	**0.045**

Table 8: External Interference Incidents by Wall Thickness

3.6.3 *External Interference by Location or Area Classification*

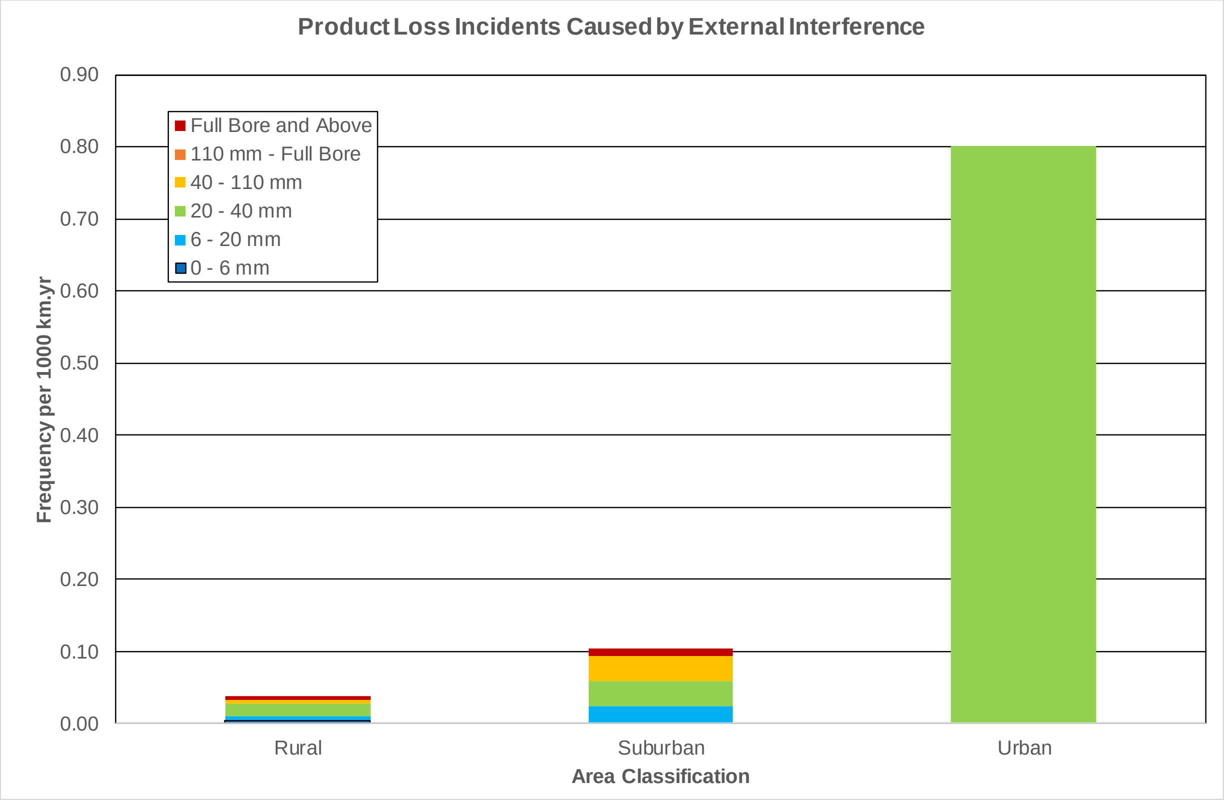


Figure 13: External Interference Product Loss Frequency by Area (or Location) Class and Equivalent Hole Size

Area / Location Classification	Exposure [km.yr]	External Interference Incidents	Frequency [per 1000 km.yr]
Rural	864,328	32	0.038
Suburban	85,673	11	0.105
Urban	1,249	0	0.801
OVERALL	**951,250**	**43**	**0.045**

Table 9: External Interference Incidents by Area Classification

Note: Rural = population density < 2.5 persons per hectare
Suburban = population density > 2.5 persons per hectare and which may be extensively developed with residential properties, and includes data classed as semi-rural
Urban = Central areas of towns or cities with a high population density

3.7 External Corrosion

External corrosion is the other main cause of product loss incidents with 42 recorded failures.

3.7.1 External Corrosion by Wall Thickness

Figure 14 and Table 10 show product loss incident frequencies due to external corrosion by wall thickness class.

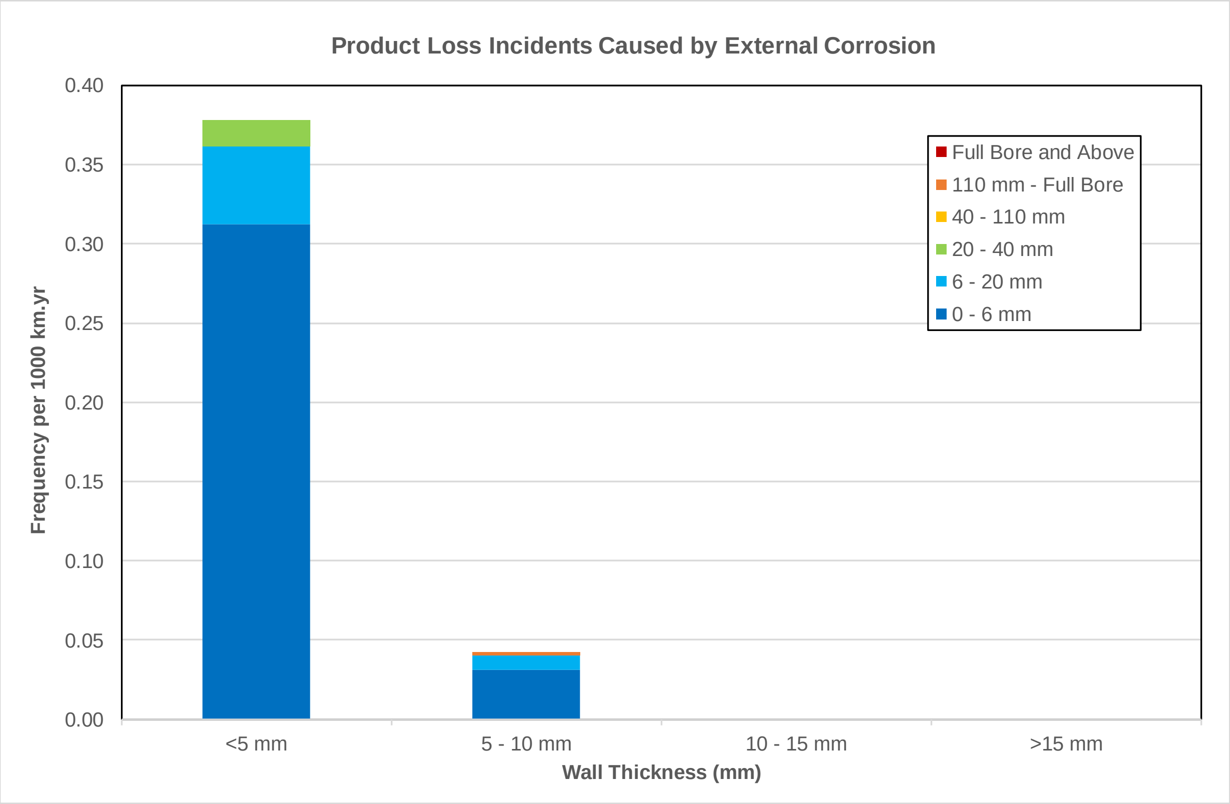


Figure 14: External Corrosion Product Loss Frequency by Wall Thickness and Equivalent Hole Size

Wall Thickness [mm]	Exposure [km.yr]	External Corrosion Incidents	Frequency [per 1000 km.yr]
≤5 mm	60,838	23	0.378
>5 - 10 mm	447,336	19	0.042
>10 - 15 mm	364,310	0	0.000
>15 mm	78,766	0	0.000
OVERALL	**951,250**	**42**	**0.044**

Table 10: External Corrosion Incidents by Wall Thickness

3.7.2 External Corrosion by Year of Construction

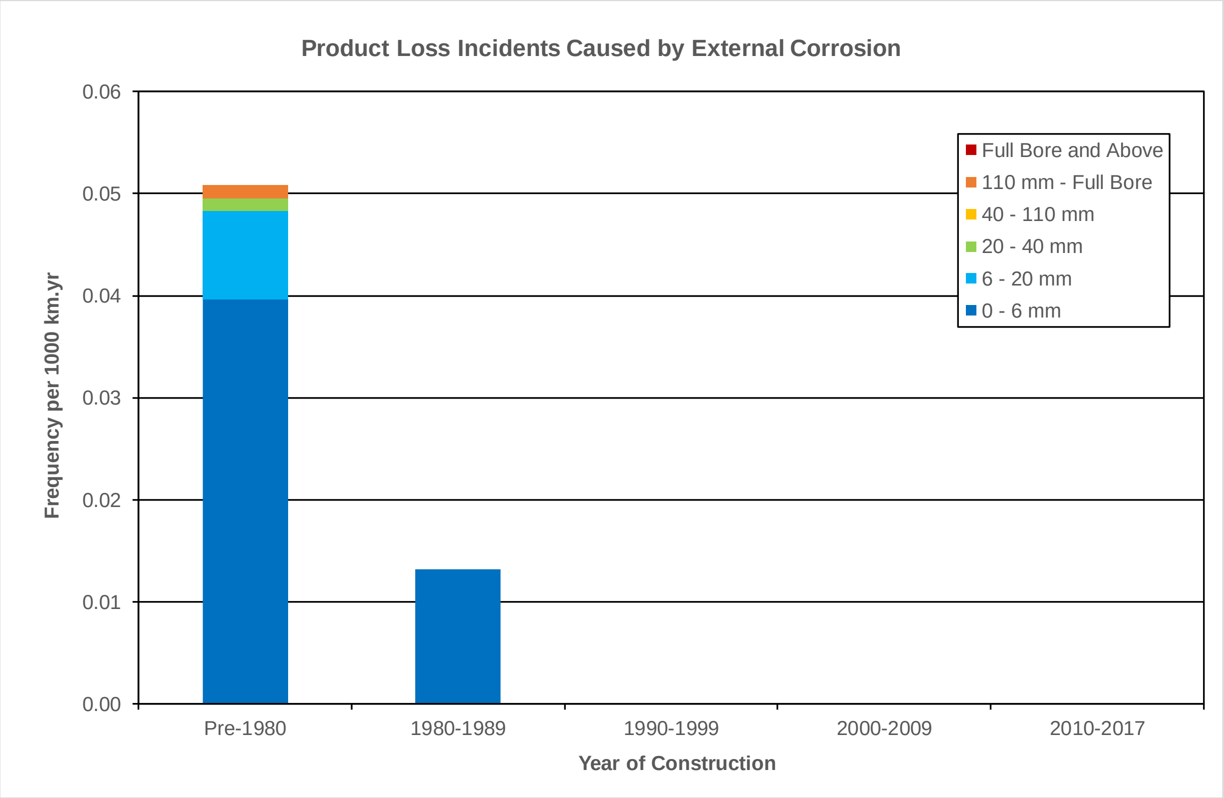


Figure 15: External Corrosion Product Loss Frequency by Year of Construction and Equivalent Hole Size

Construction Year	Exposure [km.yr]	External Corrosion Incidents	Frequency [per 1000 km.yr]
Pre-1980	806,760	41	0.051
1980 – 1989	76,049	1	0.013
1990 – 1999	47,456	0	0.000
2000 – 2009	20,625	0	0.000
2010 – 2017	144	0	0.000
Unknown	216	0	0.000
OVERALL	**951,250**	**42**	**0.044**

Table 11: External Corrosion Incidents by Year of Construction

The reduction in the number of incidents due to external corrosion for pipelines constructed after 1980 is partly associated with the introduction of in-line inspection, which together with appropriate defect acceptance criteria and improved cathodic protection monitoring systems, means that metal loss defects are detected and repaired before developing to through-wall product loss incidents.

3.7.3 *External Corrosion by External Coating Type*

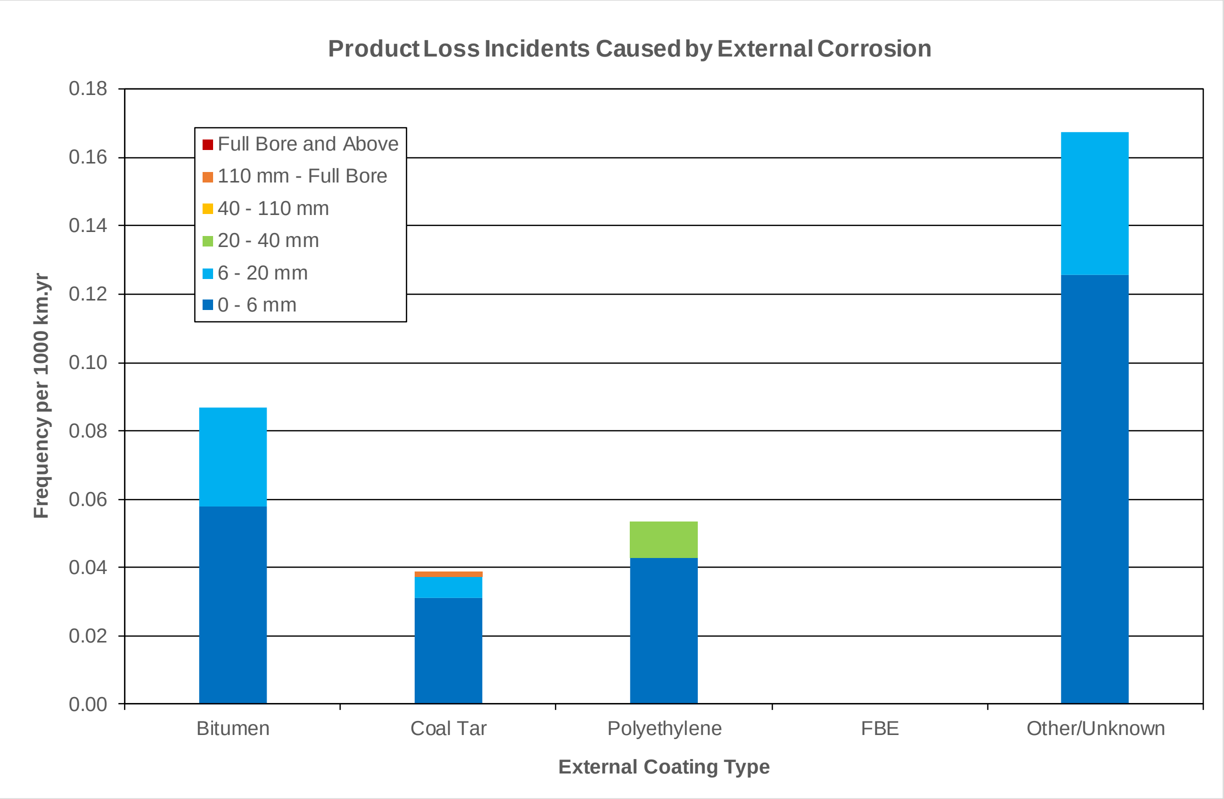


Figure 16: External Corrosion Product Loss Frequency by External Coating and Equivalent Hole Size

External Coating	Exposure [km.yr]	External Corrosion Incidents	Frequency [per 1000 km.yr]
Bitumen	34,609	3	0.087
Coal Tar	671,136	26	0.040
Polyethylene	93,209	5	0.055
FBE	104,574	0	0.000
Other/Unknown	47,721	8	0.173
OVERALL	**951,250**	**42**	**0.044**

Table 12: External Corrosion Incidents by External Coating Type

3.8 Pipeline Failures Classified as “Other”

Pipeline failures due to causes other than those defined as:

- External interference
- Corrosion
- Material and construction
- Ground movement (or other environmental load)

are generally classified as “Other”.

The UKOPA product loss data contains the following incidents under this category:

Other Cause	**Incidents**
Internal cracking due to wet towns gas	30
Pipe / Fitting Weld	4
Socket & Spigot Weld	4
Leaking Clamps	3
Electric Cable Arc Strike	1
Lightning Strike	1
Syphon Flange	1
Threaded Joint	1
TOTAL	**45**

Table 13: Pipeline Failures classified as Other

The UKOPA product loss data indicates that “Other” causes account for approximately 22% of the total failure rate.

91% (41 out of 45) of the incidents recorded in this category relate to pipelines constructed before 1970, and are not relevant to pipelines designed, constructed and operated in accordance with current pipeline standards. Further details on failures caused by internal cracking due to wet towns gas can be found in Section 3.9.

3.9 Pipeline Failures Caused by Internal Cracking

A significant proportion of the failures classified as “Other” (30 out of 45 = 67%) were caused by internal cracking (stress corrosion cracking [SCC]) in pipelines which had seen wet towns gas (pre-natural gas) service. All these failures were in pipelines constructed before 1977, when the conversion to natural gas service was completed, and 93% (28 out of 30) were in pipelines constructed before 1972.

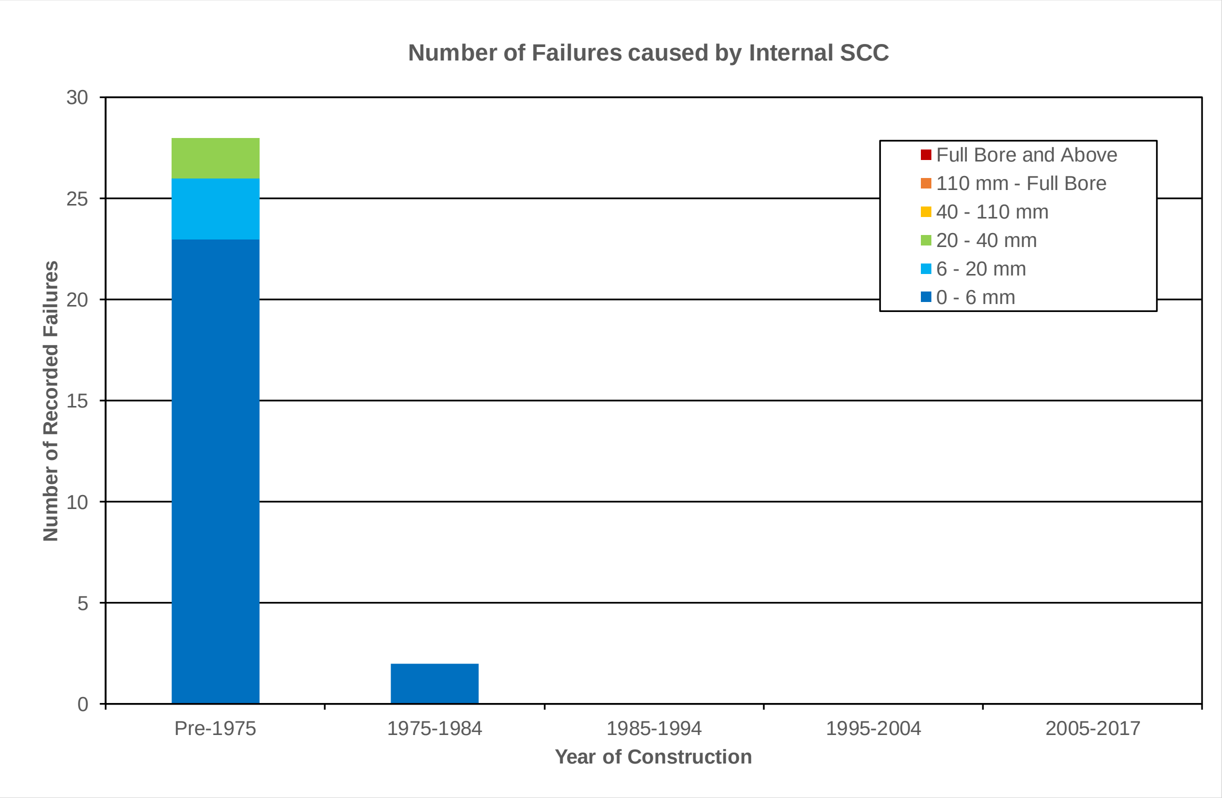


Figure 17: Failures caused by Internal SCC by Year of Construction and Equivalent Hole Diameter

3.10 Detection of Pipeline Failures

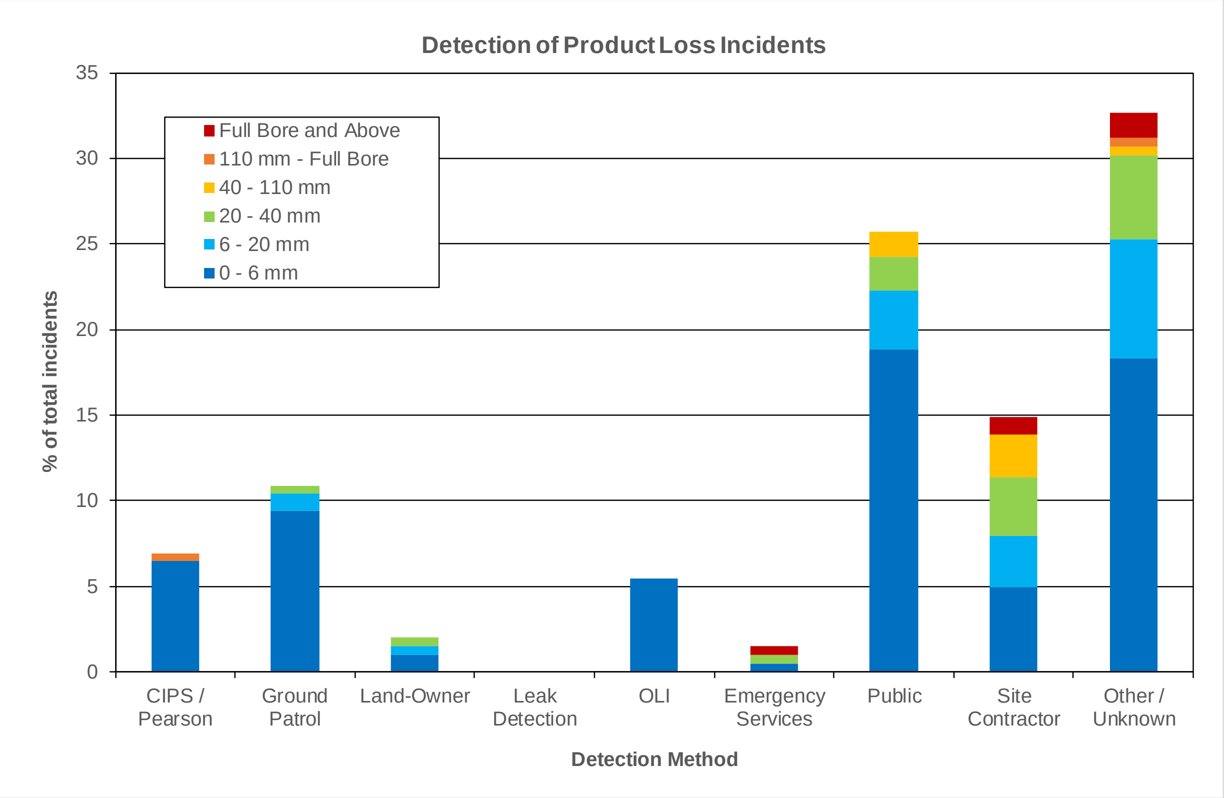


Figure 18: Detection of Product Loss Incidents by Equivalent Hole Diameter

Note: Not all pipelines can be inspected by In-Line Inspection and leak detection systems are not applicable to all pipeline networks.

4 Fault Data

4.1 Pipeline Damage Data

A Fault is a feature relating to a specific event, incident or location that has been subject to field investigation, excavation and measurement and may consist of several individual part-wall defects, e.g. multiple dents and gouges from the teeth of an excavator.

Any features that are inferred by other measurements such as intelligent pig in-line inspections, monitoring the performance of cathodic protection systems, etc. and have not been verified in the field are not included in the UKOPA database. However, pipeline defects comprising of coating damage or grinding marks confirmed by field inspection are included.

The total number of Faults recorded for the period 1962 – 2017 was 3,586. The main causes of the Faults are shown in Figure 19.

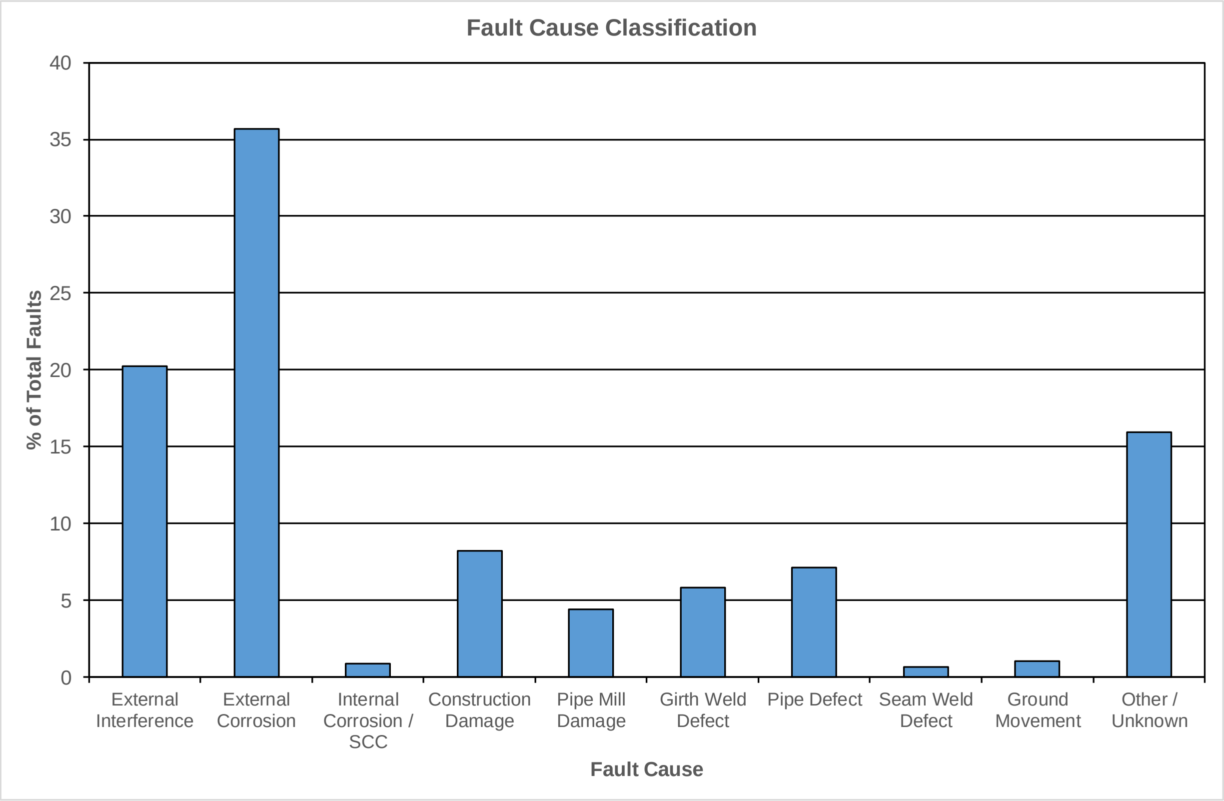


Figure 19: Fault Cause Classification

4.2 Part-Wall Defect Data

One of the main benefits of collecting Fault data is to record of the size of part-wall defects which are measured and recorded in the database. Many faults have several defects and as a result the database contains 6,108 defects recorded in the period 1962 – 2017.

Classification of defect data is shown in Figure 20.

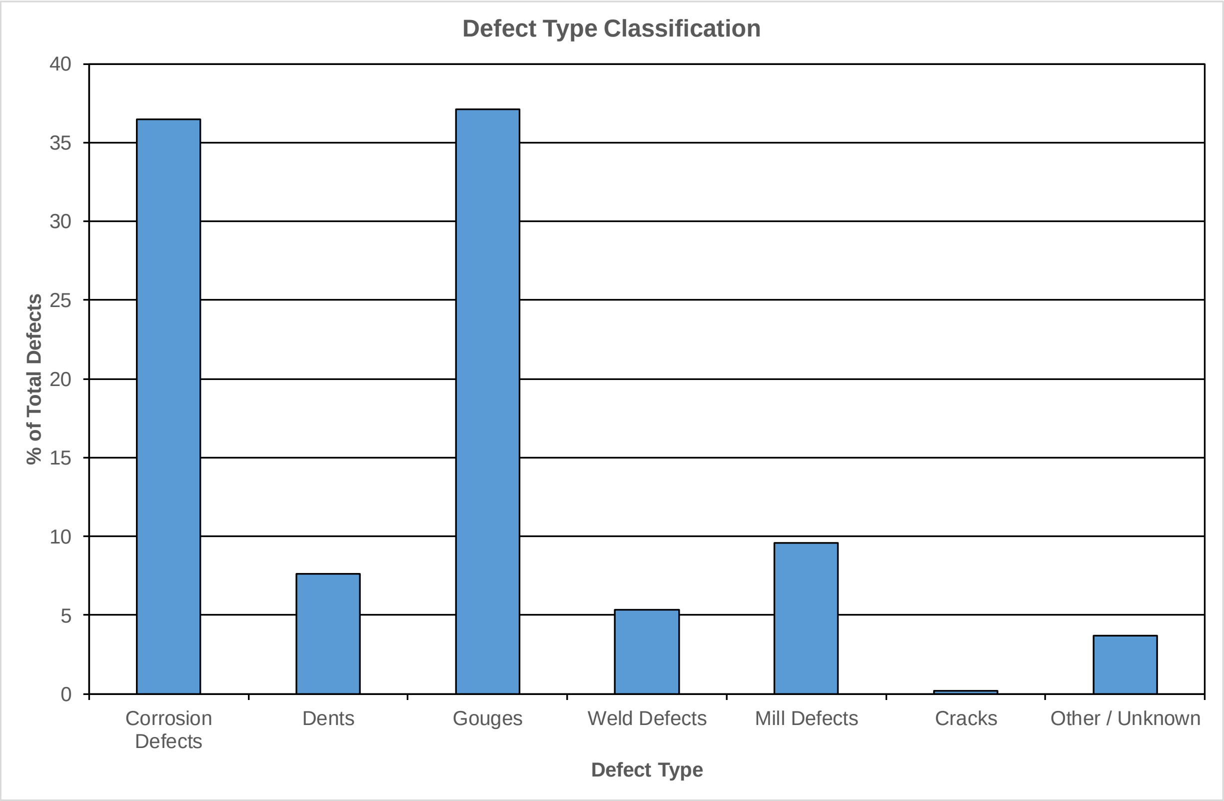


Figure 20: Defect Type Classification

4.3 Statistical Distributions of Defect Dimensions

Pipeline damage due to external interference occurs in the form of gouges, dents or dent-gouge combinations. This type of damage is random in nature, and as operational failure data are sparse, recognised engineering practice requires that a predictive model is used to calculate leak and rupture failure frequencies for specific pipelines. Predictive models such as those described in references [3], [4], [5], [6], & [7] use gouge and dent-gouge fracture mechanics models to predict the pipeline probability of failure, which is also dependent upon the pipeline geometry, material properties and operating pressure.

The UKOPA database includes reports of external interference incidents, including the type of damage, the size of the damage and the number and location of the incidents. The external interference damage data, recorded up to and including 2016, has been analysed to determine the best fit distribution parameters for the following key parameters [7]:

- ‘Plain’ Gouge Length;
- ‘Plain’ Gouge Depth;
- ‘Gouge in Dent’ Gouge Length;
- ‘Gouge in Dent’ Gouge Depth; and,
- Dent Force.

The distribution parameters for the data, up to and including 2016, are given in Table 14.

Fault Type	Fault Parameter	Distribution Type	Distribution Parameters	
‘Plain’ Gouge	Length (mm)	Lognormal	**μ**	**σ**
			4.351	1.360
	Depth (mm)	Lognormal	**μ**	**σ**
			-0.645	1.161
‘Gouge in Dent’	Length (mm)	Lognormal	**μ**	**σ**
			4.059	0.996
	Depth (mm)	Weibull	**α**	**β (mm)**
			1.15	1.51
Dent	Force (kN)	Lognormal	**μ**	**σ**
			3.969	0.516

Table 14: Distribution Parameters for Damage Data up to 2016

These parameters allow pipeline failure probabilities to be derived for external interference events using recommended models [7]. An estimate of the “hit rate” (i.e. the frequency of external interference incidents), which is also dependent on location class (rural/suburban) and depth of cover, is required to obtain pipeline failure frequencies. The hit rate in rural areas associated with the above damage distribution parameters is 1.099 per 1000 km.yr.

5 References

[1] SI 1996 No. 825, *The Pipelines Safety Regulations 1996, as amended.*

[2] G. D. Goodfellow, C. J. Lyons and J. V. Haswell, "UKOPA Pipeline Product Loss Incidents and Faults Reports (1962 - 2016)," UKOPA/17/002, Issue 1.1, February 2018.

[3] I Corder, "The Application of Risk Techniques to the Design and Operation of Pipelines," in *Proceedings of International Conference on Pressure Systems: Operation and Risk Management*, Institution of Mechanical Engineers, London, UK, pp 113-125, 1995.

[4] C. Lyons, J. V. Haswell, P. Hopkins, R. Ellis and N. Jackson, "A Methodology for the Prediction of Pipeline Failure Frequency due to External Interference," IPC2008-64375, Proceedings of IPC2008, 7th International Pipeline Conference, Calgary, 2008.

[5] A. Cosham, J. V. Haswell and N. Jackson, "Reduction Factors for the Probability of Failure of Mechanical Damage due to External Interference," IPC2008-64345, Proceedings of IPC2008, 7th International Pipeline Conference, Calgary, 2008.

[6] P. Seevam, C. Lyons, P. Hopkins and M. Toft, "Modelling of Dents and Gouges and the Effect on the Failure Probability of Pipelines," IPC2008-64061, Proceedings of IPC2008, 7th International Pipeline Conference, Calgary, 2008.

[7] G. Goodfellow, C. Lyons, S. Turner, F. Gray and S. Joyce, "An Update to the Recommended UKOPA External Interference Frequency Prediction Model & Pipeline Damage Distributions," IPC2018-78767, Proceedings of the 2018 12th International Pipeline Conference, IPC 2018, Calgary, 2018.