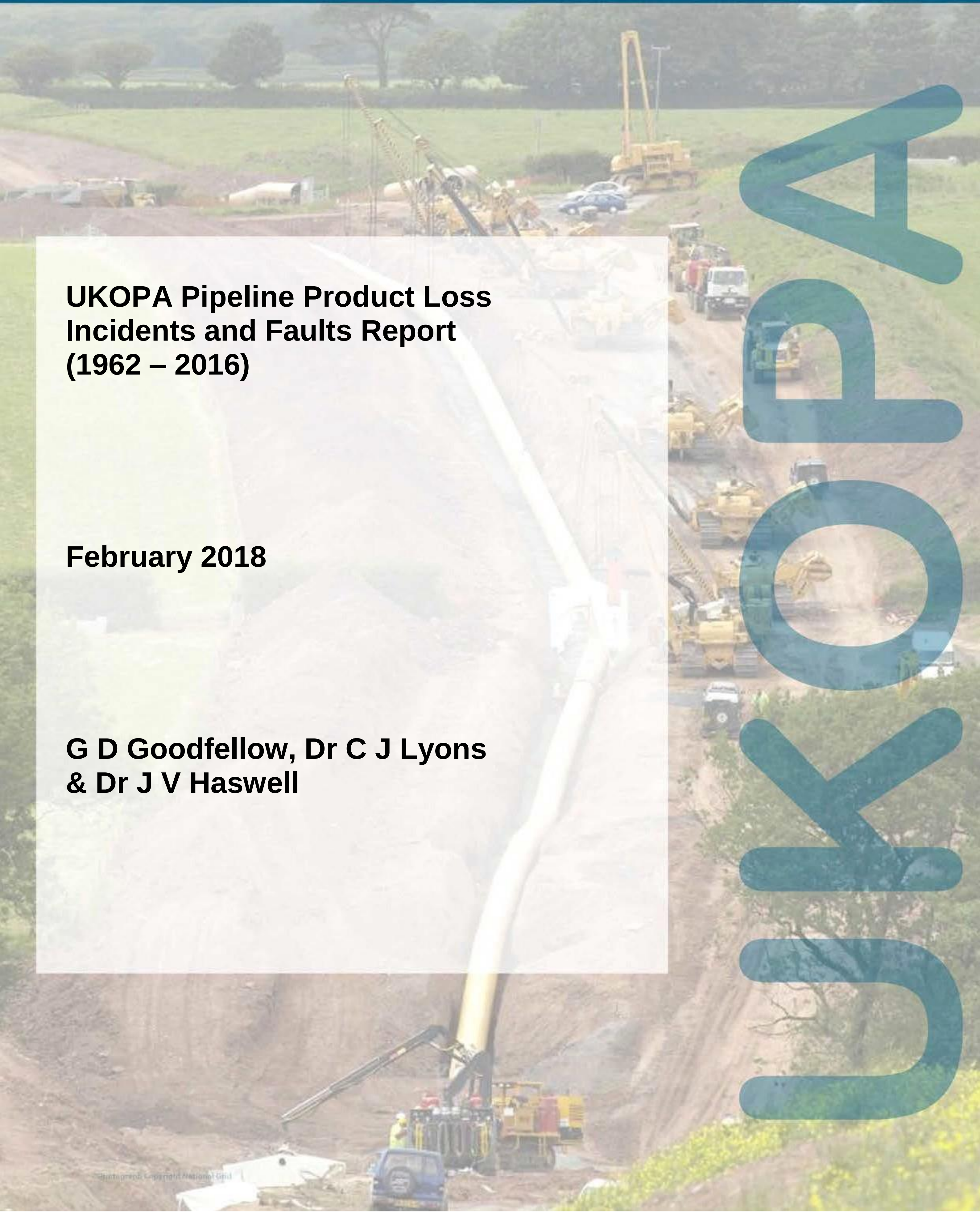
UKOPA

United Kingdom Onshore Pipeline Operators' Association



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UKOPA Pipeline Product Loss Incidents and Faults Report (1962 – 2016)

February 2018

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

UKOPA PIPELINE FAULT DATABASE

Pipeline Product Loss Incidents and Faults Report

(1962 – 2016)

Report of the UKOPA Fault And Risk Work Group

Comprising data from:
National Grid
Scotia Gas Networks
Northern Gas Networks
Wales & West Utilities
BP
INEOS
Sabic
Essar Oil (UK) Limited
Shell
E.ON UK
BPA

and supported by: Health and Safety Executive

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

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Summary

This report presents collaborative pipeline and product loss incident data from onshore Major Accident Hazard Pipelines (MAHPs) operated by National Grid, Scotia Gas Networks, Northern Gas Networks, Wales & West Utilities, BP, INEOS, SABIC, Essar Oil (UK) Ltd, Shell, E.ON UK and BPA, covering operating experience up to the end of 2016.

MAHPs are defined by the UK statutory legislation, The Pipelines Safety Regulations 1996 (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 2016 is 0.212 incidents per 1000 km.year, whilst in the previous report this figure was 0.218 incidents per 1000 km.year (covering the period from 1962 to 2015). The overall trend continues to show a reduction in failure frequency.

The failure frequency over the last 20 years is 0.084 incidents per 1000 km.year.

For the last 5 years the failure frequency is 0.087 incidents per 1000 km.year, whilst in the previous report this figure was 0.108 incidents per 1000 km.year (covering the 5 year period up to the end of 2015).

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 2016 for all participating companies (National Grid, Scotia Gas Networks, Wales & West Utilities, Northern Gas Networks, BP, Essar Oil (UK) Ltd, Shell, INEOS, Sabic, E.ON UK and BPA) was 21,845 km. The total exposure in the period 1952 to the end of 2016 was 927,351 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.

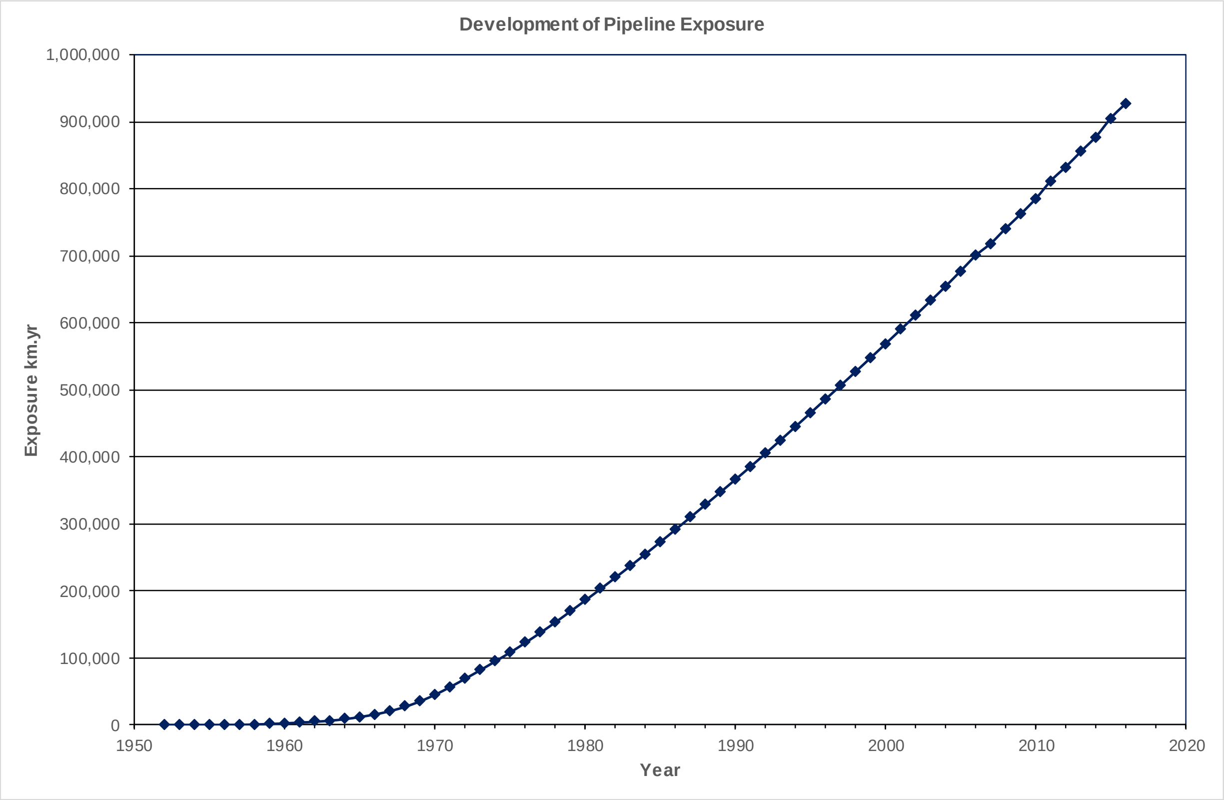

Figure 1: Development of Exposure from 1952 to 2016

* 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 2016, by transported product, are shown in Table 1 below.

Product	Length (km)	%age of Total
Natural Gas (Dry)	20,074	91.9
Ethylene	1,141	5.2
Natural Gas Liquids	251	1.1
Crude Oil (Spiked)	224	1.0
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	**21,845**	**100.0**

Table 1: 2016 Pipeline Operating Lengths

Note: The database includes 543 km of decommissioned pipeline (440 km previously used to transport natural gas, 56 km to transport ethylene, 37 km to transport carbon monoxide, 5 km to transport propane and 5 km to transport 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; and,
- Excluding associated equipment (e.g. valves, compressors) or parts other than the pipeline itself.

A total of 197 product loss incidents were recorded over the period between 1962 and 2016 compared with 196 product loss incidents documented in the report covering the period to 2015. No product loss incidents were recorded prior to 1962. An annual breakdown of incidents is illustrated in Figure 2.

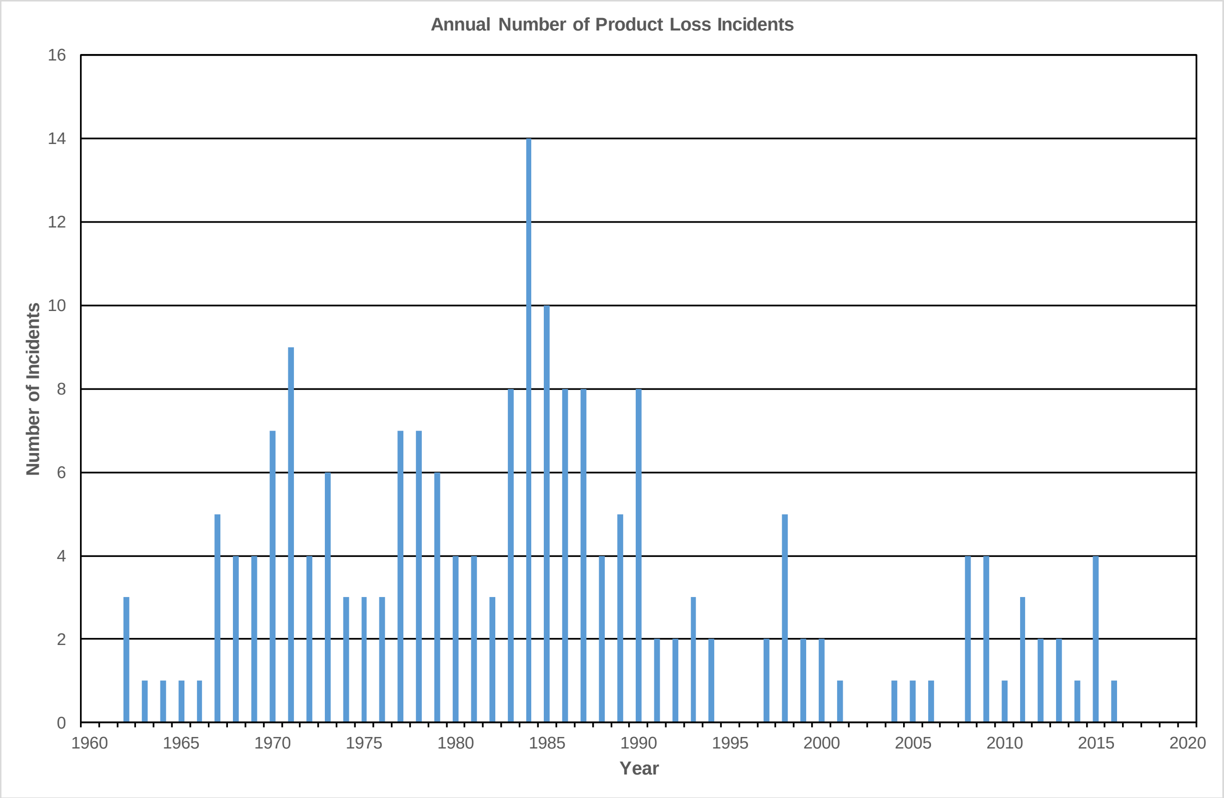

Figure 2: Product Loss Incidents per year since 1962

3.1 Differences between 2015 and 2016 product loss statistics

One product loss incident was recorded in 2016, a small leak at a socket and spigot weld. In comparison, in 2015 there were four product loss incidents recorded, one due to external interference, one due to external corrosion, a leak at a socket and spigot weld and a leak at a syphon flange. The cumulative number of incidents over the period 1962 to 2016 is shown in Figure 3.

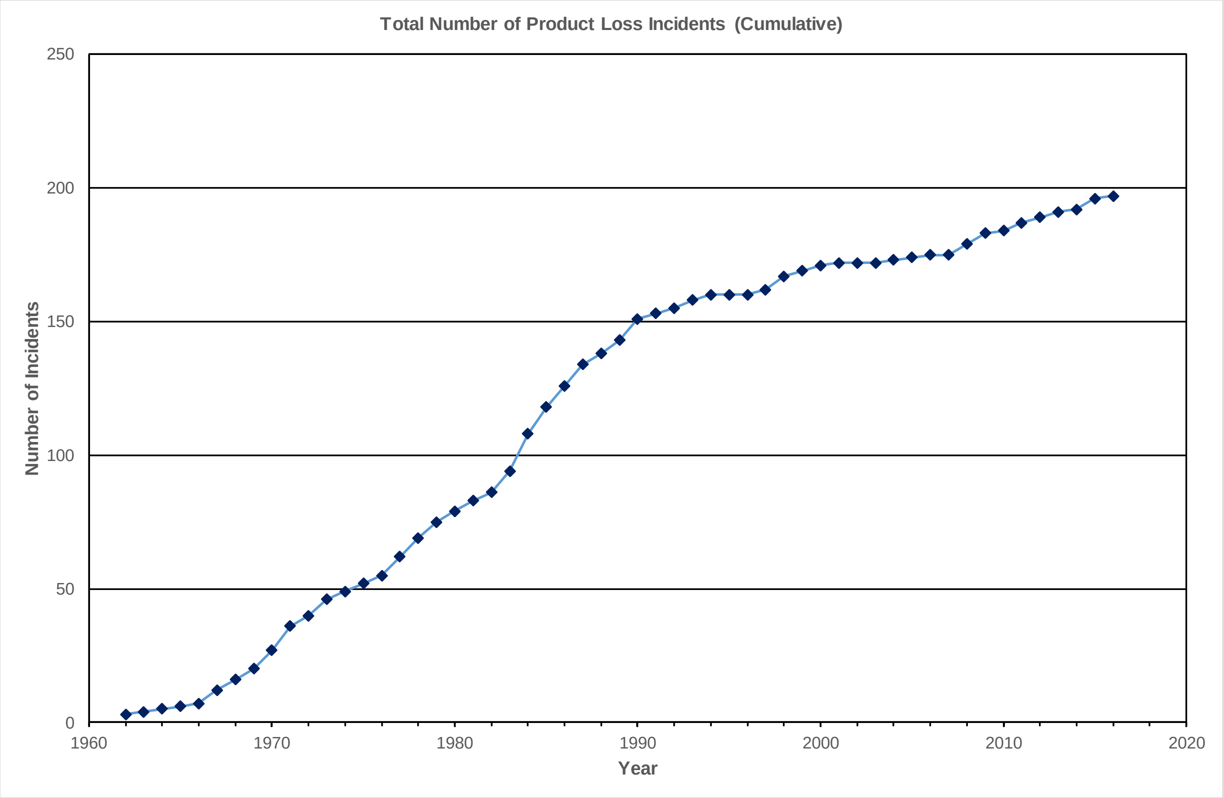

Figure 3: Cumulative Product Loss Incidents since 1962

3.2 Incident Ignition

Only nine out of 197 (4.6%) 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 54 Years

The incident frequency over eleven consecutive 5-year periods up to the end of 2016 is shown in Table 3.

Period	Number of Incidents	Total Exposure [km.yr]	Frequency [Incidents per 1000 km.yr]
1952 – 1961	0	3,740	0.000
1962 – 1966	7	12,245	0.572
1967 – 1971	29	40,942	0.708
1972 – 1976	19	65,961	0.288
1977 – 1981	28	80,055	0.350
1982 – 1986	43	88,689	0.485
1987 – 1991	27	93,951	0.287
1992 – 1996	7	100,593	0.070
1997 – 2001	12	103,830	0.116
2002 – 2006	3	110,457	0.027
2007 – 2011	12	111,460	0.108
2012 – 2016	10	115,428	0.087
TOTAL	**197**	**927,351**	**0.212**

Table 3: 5-Year Incident Frequency

The overall incident frequency by hole size over the period 1962 – 2016 is shown in Table 4.

Equivalent Hole# Size Class	Number of Incidents	Frequency [Incidents per 1000 km.yr]
Full Bore* and Above	8	0.009
110 mm – Full Bore*	3	0.003
40 mm – 110 mm	7	0.008
20 mm – 40 mm	24	0.026
6 mm – 20 mm	32	0.035
0 – 6 mm	121	0.130
Unknown	2	0.002
TOTAL	**197**	**0.212**

Table 4: 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 total exposure for the last 20 years (1997 – 2016) is 441,176 km.yr and the resulting incident frequency is shown in Table 5.

Hole Size Class	**Number of Incidents**	**Frequency [Incidents per 1000 km.yr]**
Full Bore* and Above	1	0.002
110 mm – Full Bore*	0	0.000
40 mm – 110 mm	0	0.000
20 mm – 40 mm	6	0.014
6 mm – 20 mm	6	0.014
0 – 6 mm	24	0.054
Unknown	0	0.000
TOTAL	**37**	**0.084**

Table 5: 20-Year Incident Frequency by Hole Size

The failure frequency over the last 20 years is 0.084 incidents per 1000 km.yr and for the last 5 years (2012 – 2016) is 0.087 incidents per 1000 km.yr.

These compare with the overall failure frequency during the period 1962 – 2016 of 0.212 incidents per 1000 km.yr. An overview of the development of this failure frequency is shown in Figure 4 below.

In order to see the results over recent periods, the moving average for each year is calculated with reference to the incidents from the previous 5 years (2012 – 2016, 2011 – 2015, 2010 – 2014 etc.).

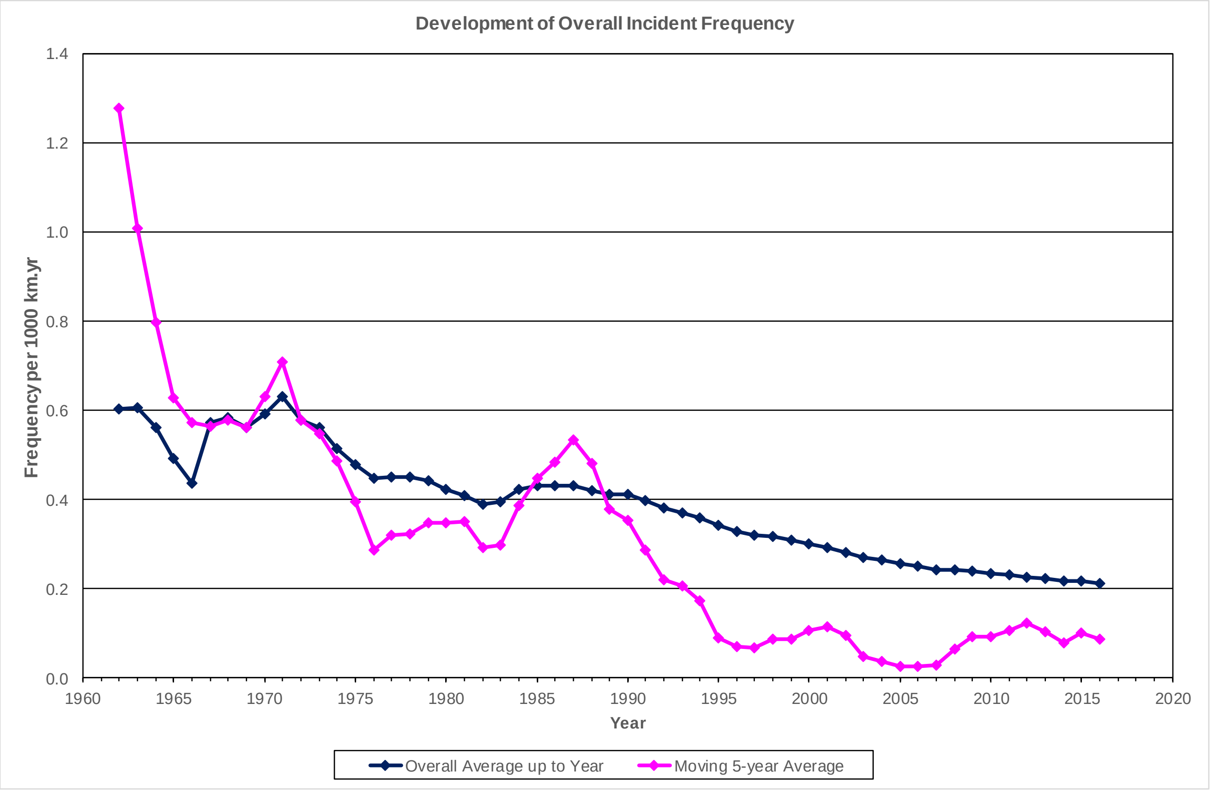

Figure 4: Overall and 5-Year Frequency Development

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 2012 – 2016 is 0.087 per 1000 km.yr +/- 0.055.

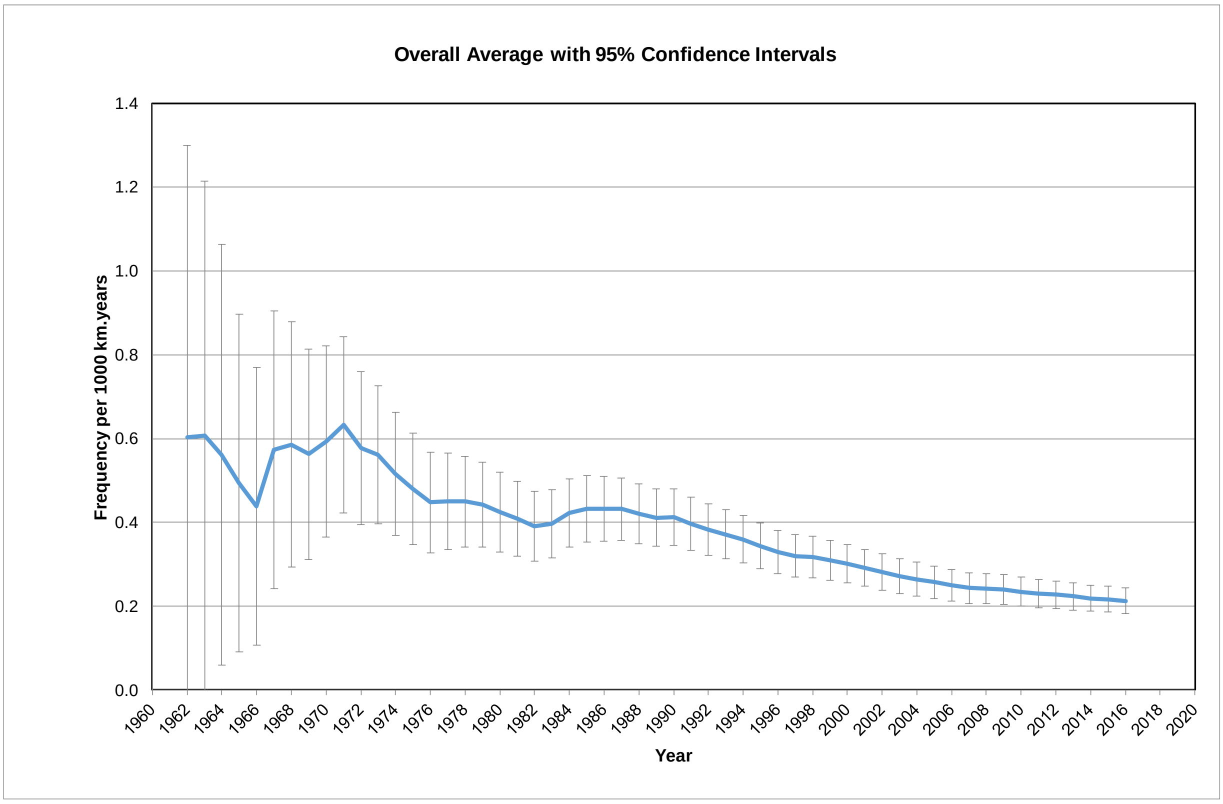

Figure 5: Overall Incident Frequency with 95% Confidence

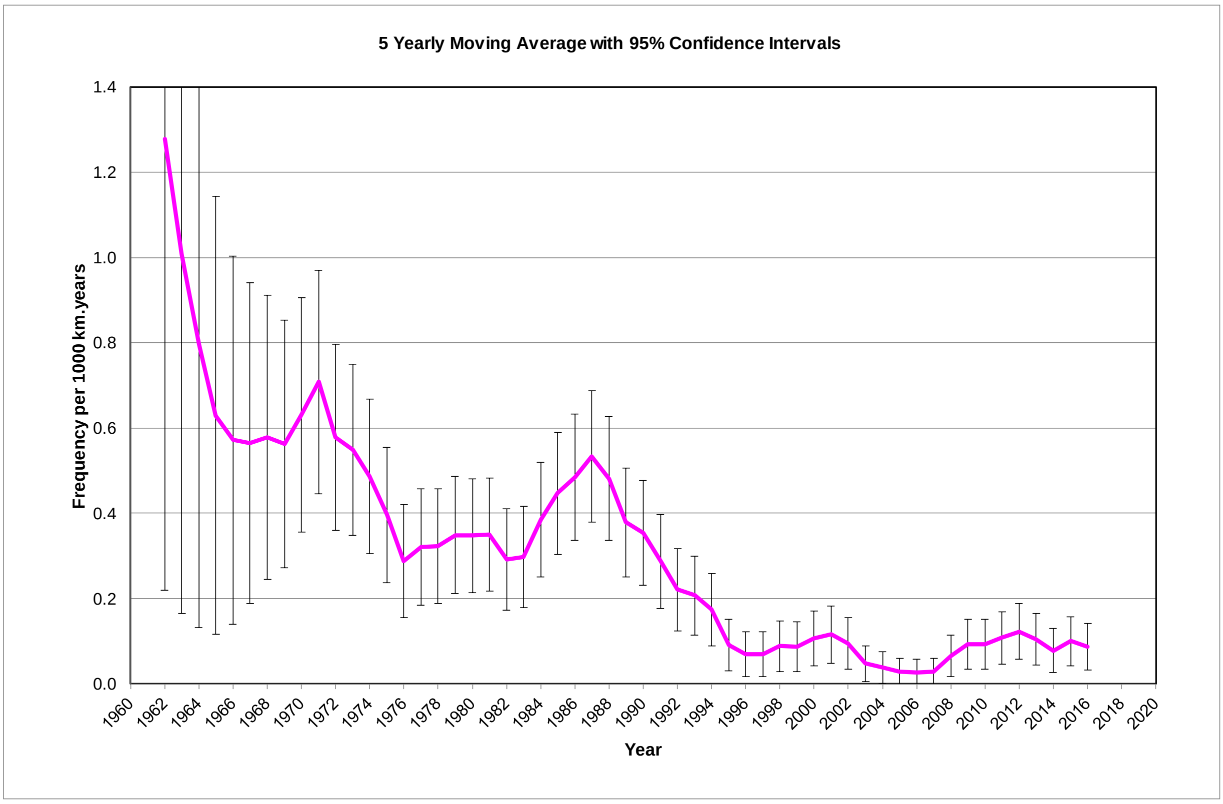

Figure 6: 5-Year Incident Frequency with 95% Confidence

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.

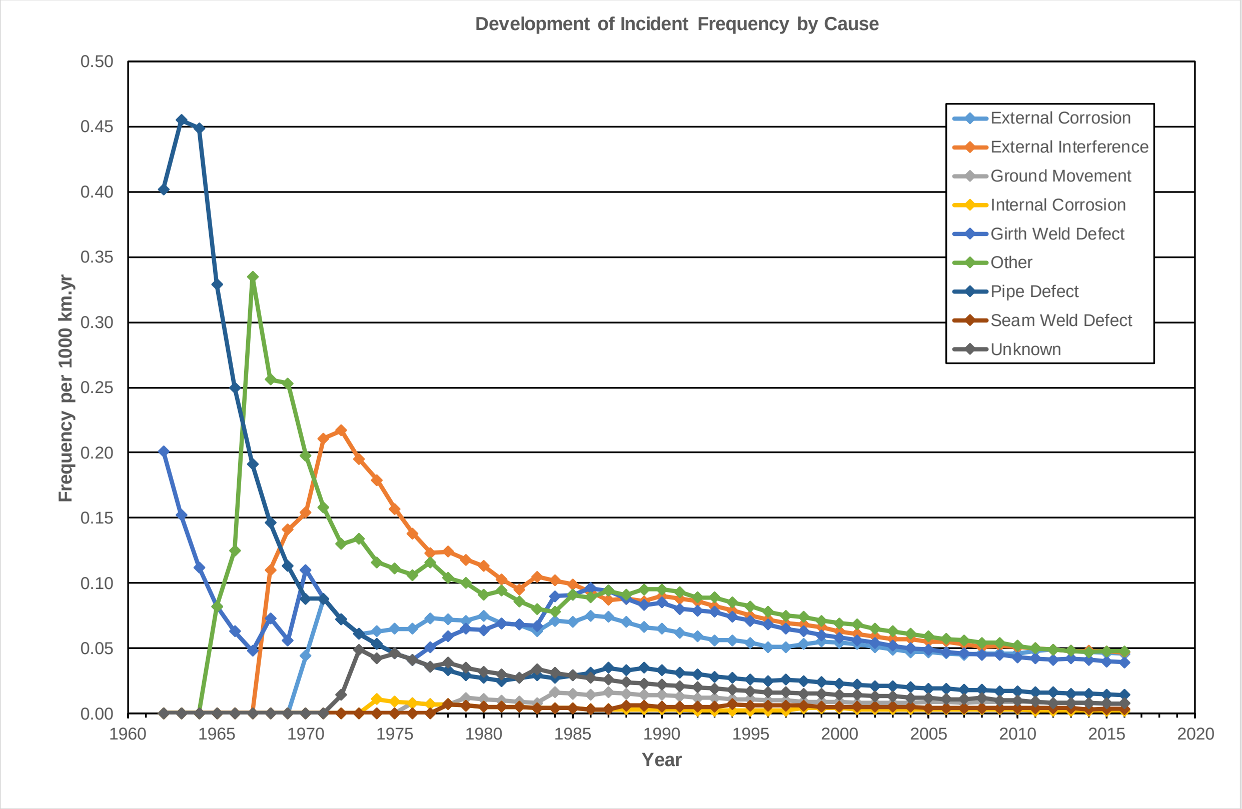

Figure 7: Product Loss Incident Frequency by Cause

Product Loss Cause	No. of Incidents	%age of Total
External Corrosion	42	21.3
External Interference	43	21.8
Ground Movement	7	3.6
Internal Corrosion	2	1.0
Girth Weld Defect	36	18.3
Pipe Defect	13	6.6
Seam Weld Defect	3	1.5
Other	44	22.3
Unknown	7	3.6
TOTAL	**197**	**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 over the period 1962 – 2016 compared with the frequency over the last 5 years (2012 – 2016).

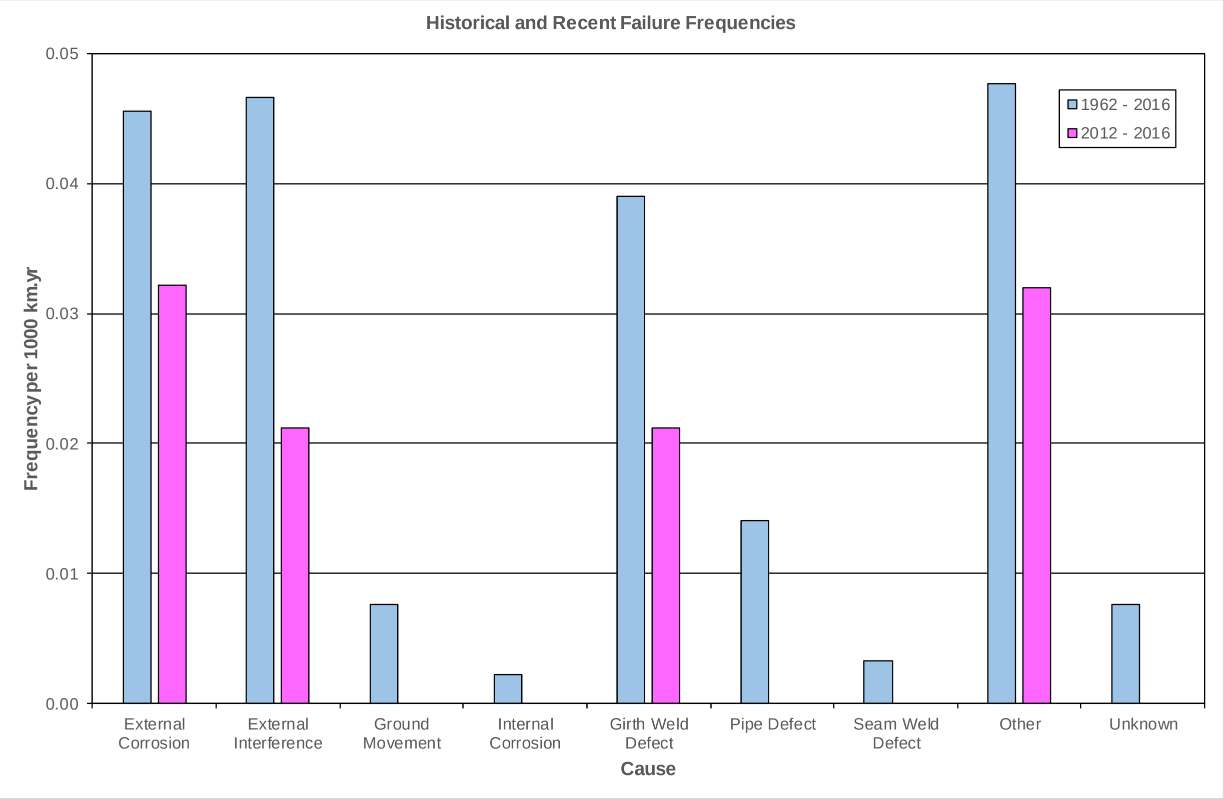

Figure 8: Product Loss Incident Frequency by Cause

An overview of the product loss incident frequency by cause and size of leak in the period 1962 to 2016 is shown in Figure 9.

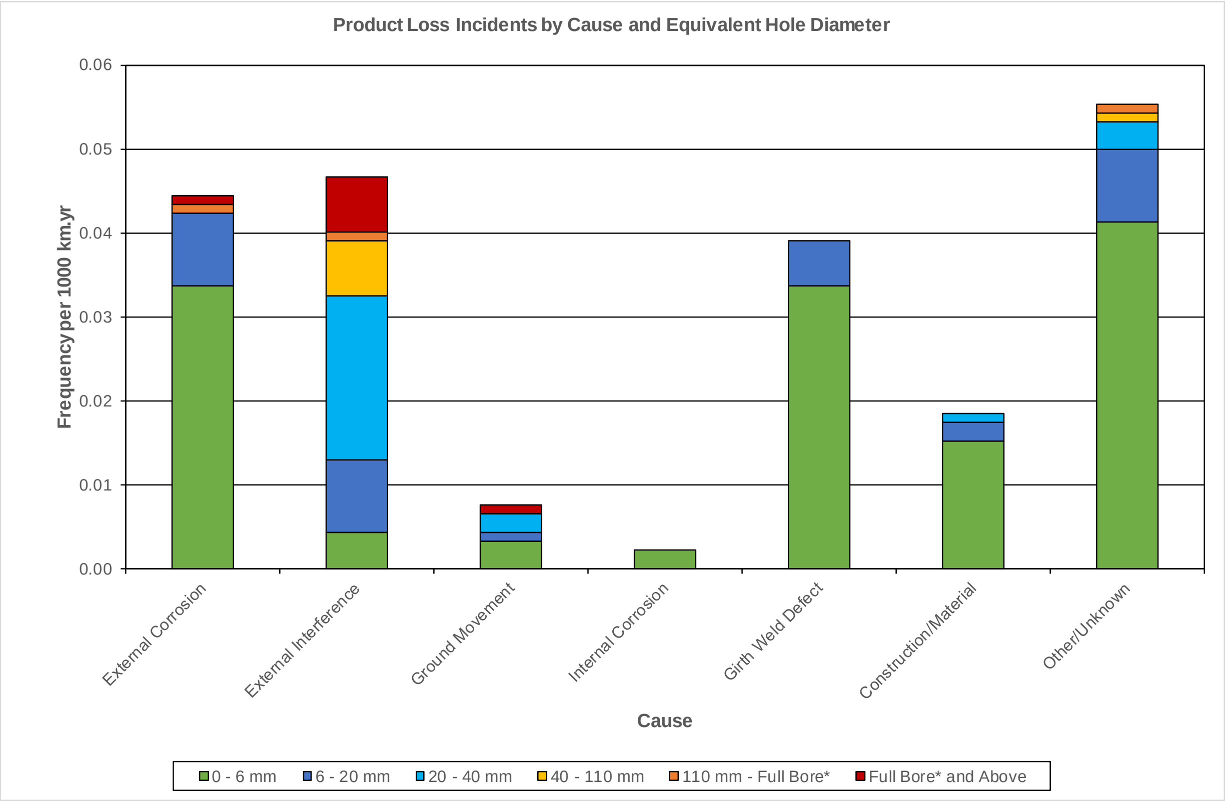

Figure 9: Product Loss Incident Frequency by Cause and Size of Leak

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 36 leaks due to girth weld defects were recorded in pipelines constructed before 1985, 35 of which were in pipelines constructed before 1972.

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.

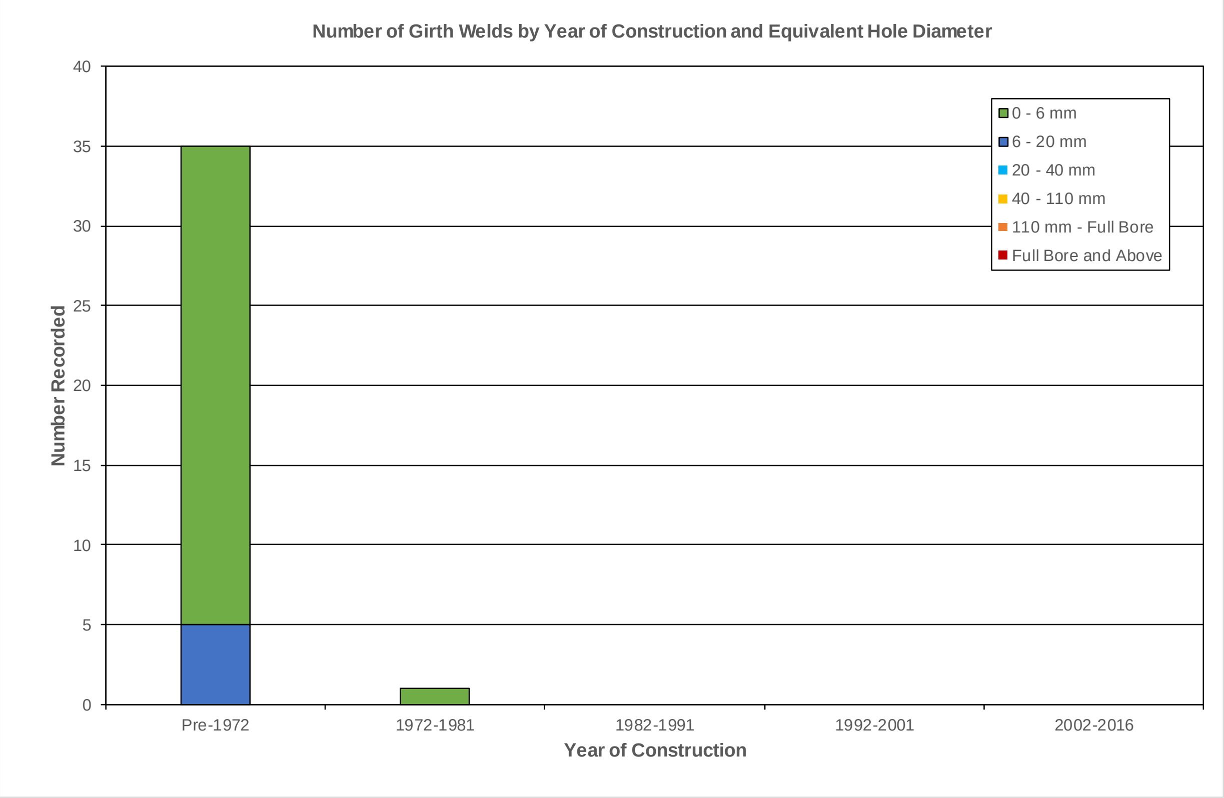

Figure 10: Girth Weld Defects

3.6 External Interference

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 diameter class and by hole size and the total frequencies by diameter class are shown Table 7.

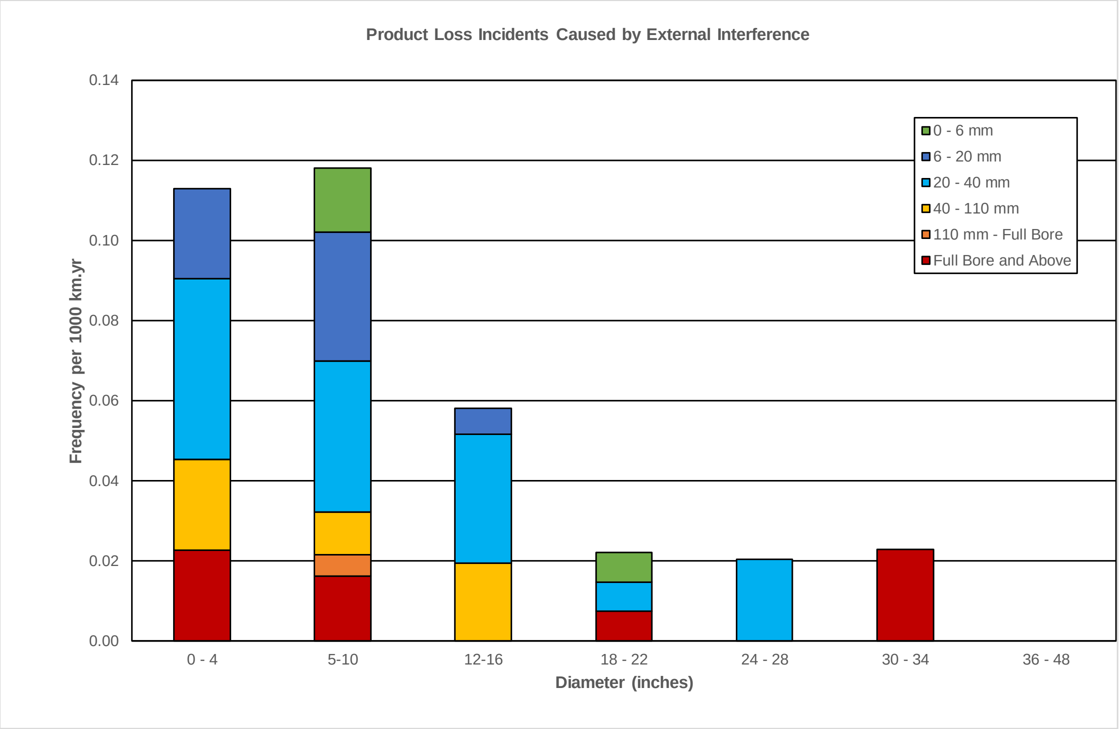

Figure 11: External Interference Product Loss Frequency by Diameter and Equivalent Hole Size

Diameter [inches]	Exposure [km.yr]	External Interference Incidents	Frequency [per 1000 km.yr]
0 - 4	44,243	5	0.113
5 - 10	186,294	22	0.118
12 - 16	155,228	9	0.058
18 - 22	136,557	3	0.022
24 - 28	147,156	3	0.020
30 - 34	43,826	1	0.023
36 - 48	208,648	0	0.000
TOTAL	921,995	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.

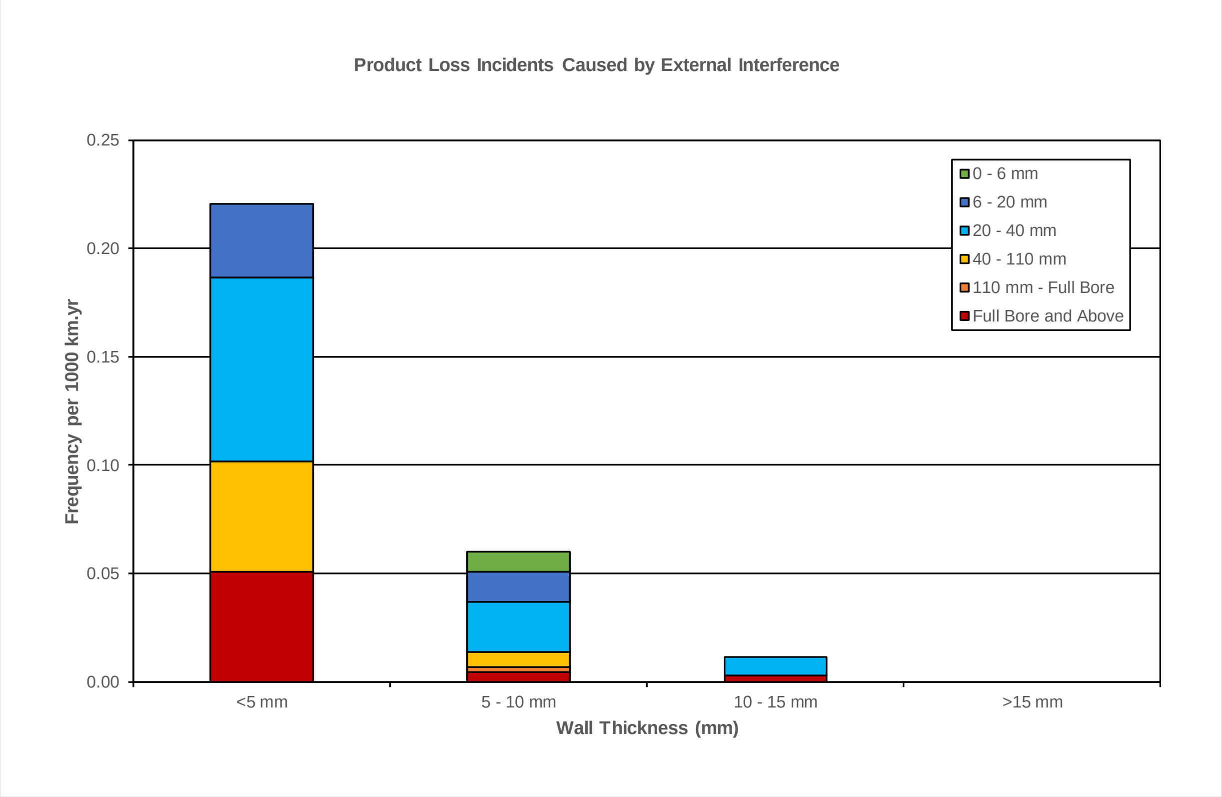

Figure 12: External Interference Product Loss Frequency by Wall Thickness and Equivalent Hole Size

Note: *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	58,933	13	0.221
6 - 10 mm	433,332	26	0.060
11 - 15 mm	352,906	4	0.011
>15 mm	76,300	0	0.000
TOTAL	**921,995**	**43**	**0.047**

Table 8: External Interference Incidents by Wall Thickness

3.6.3 *External Interference by Area Classification*

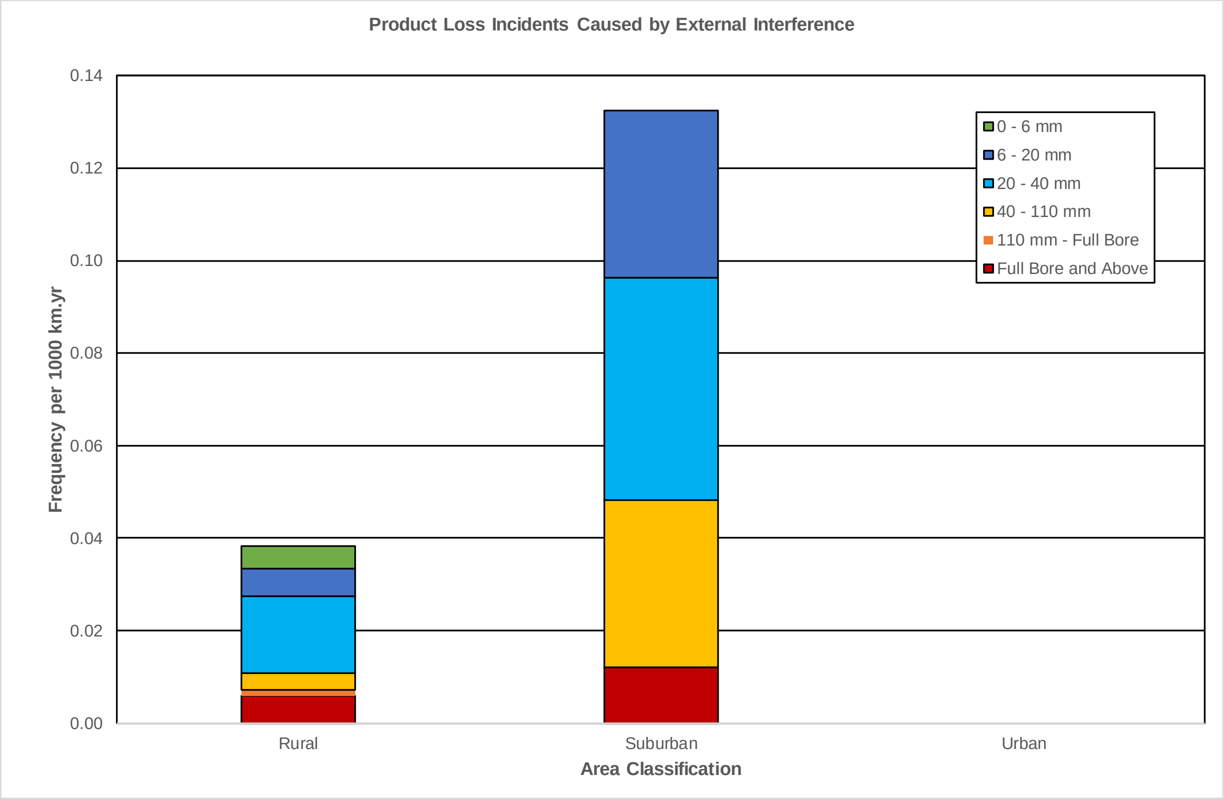

Figure 13: External Interference Product Loss Frequency by Area (or Location) Class and Equivalent Hole Size

Area Classification	Exposure [km.yr]	External Interference Incidents	Frequency [per 1000 km.yr]
Rural	837,709	32	0.038
Suburban	83,034	11	0.132
Urban	1,211	0	0.000
TOTAL	**921,995**	**43**	**0.047**

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 Class

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

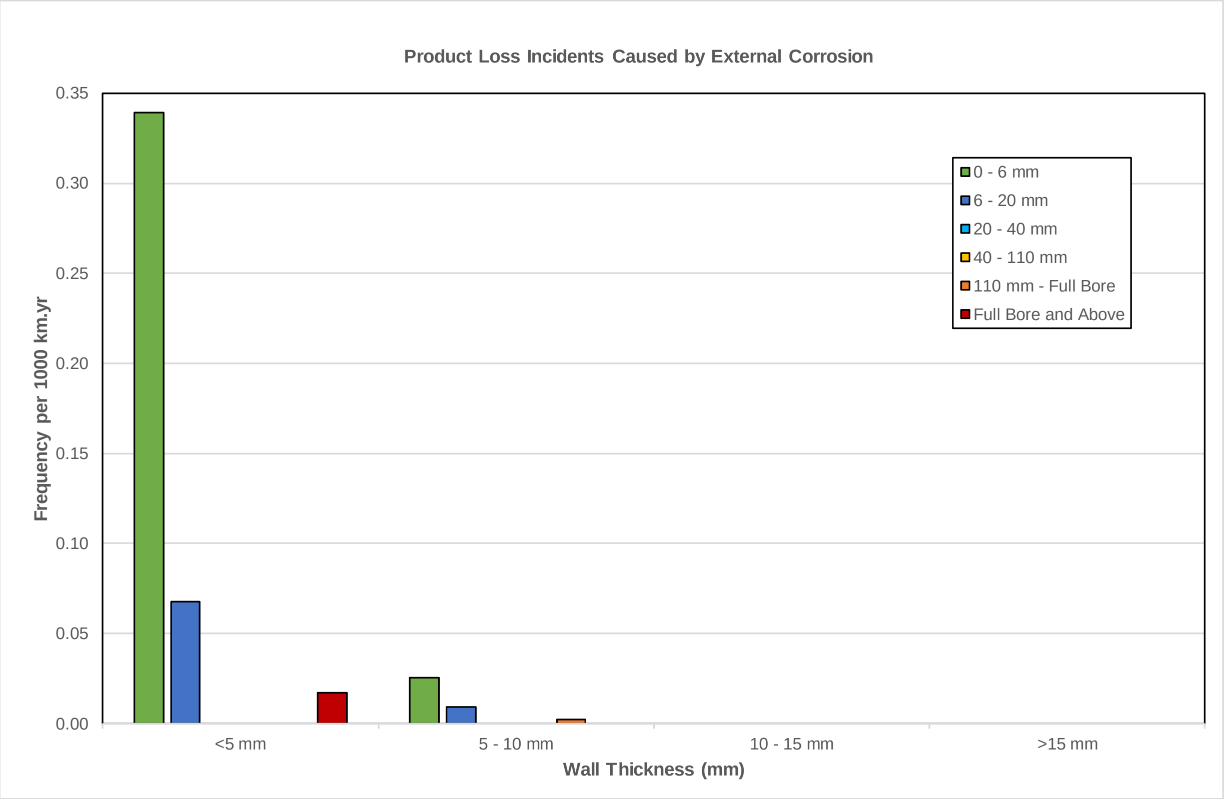

Figure 14: External Corrosion Product Loss Frequency by Wall Thickness and Equivalent Hole Size

Wall Thickness [mm]	Exposure [km.yr]	External Corrosion Incidents	Frequency [per 1000 km.yr]
<5 mm	58,933	24	0.407
6 - 10 mm	433,332	16	0.037
11 - 15 mm	352,906	0	0.000
>15 mm	76,300	0	0.000
TOTAL	**921,995**	**41**	**0.044**

Table 10: External Corrosion Incidents by Wall Thickness

Note: One corrosion leak wall thickness size is unknown.

3.7.2 External Corrosion by Year of Construction

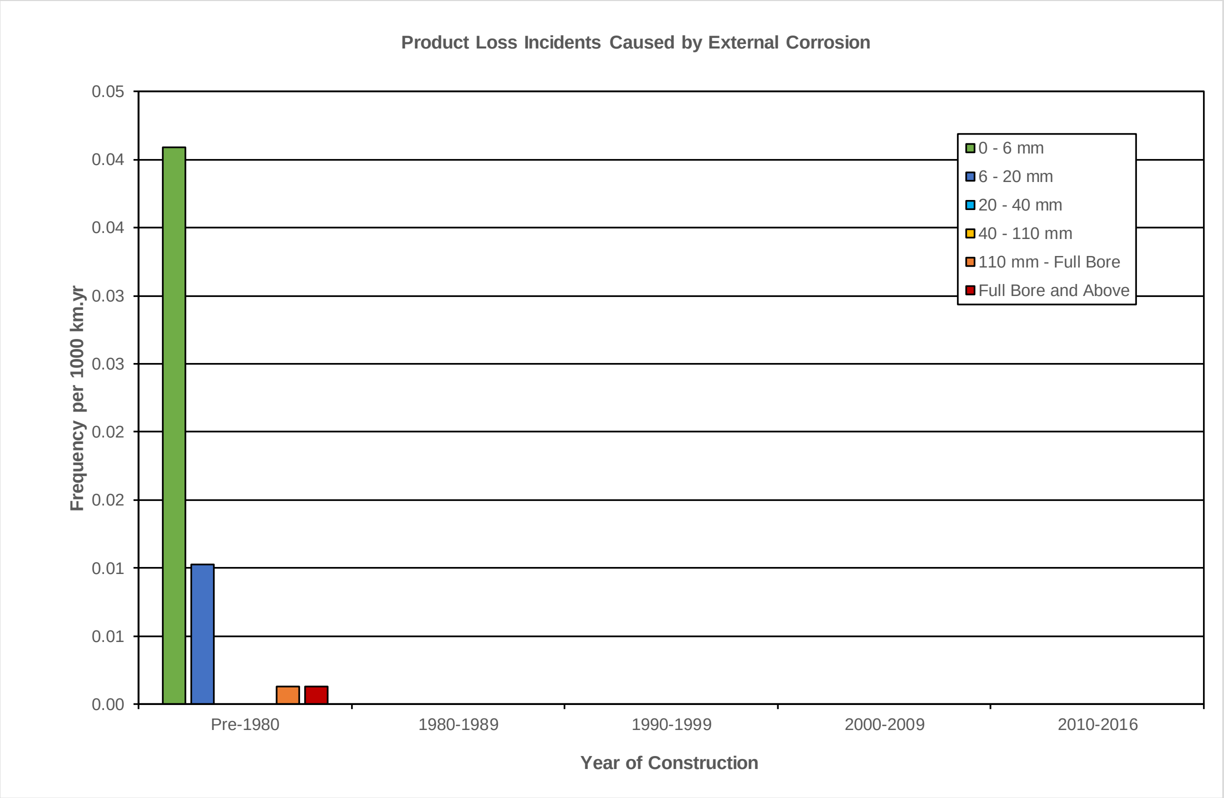

Figure 15: External Corrosion Product Loss Frequency by Year of Construction and Equivalent Hole Size

Construction Year	Exposure [km.yr]	External Corrosion Incidents	Frequency [per 1000 km.yr]
Pre-1980	781,914	42	0.054
1980 – 1989	73,707	0	0.000
1990 – 1999	45,995	0	0.000
2000 – 2009	19,990	0	0.000
2010 – 2014	140	0	0.000
TOTAL	**921,995**	**42**	**0.046**

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

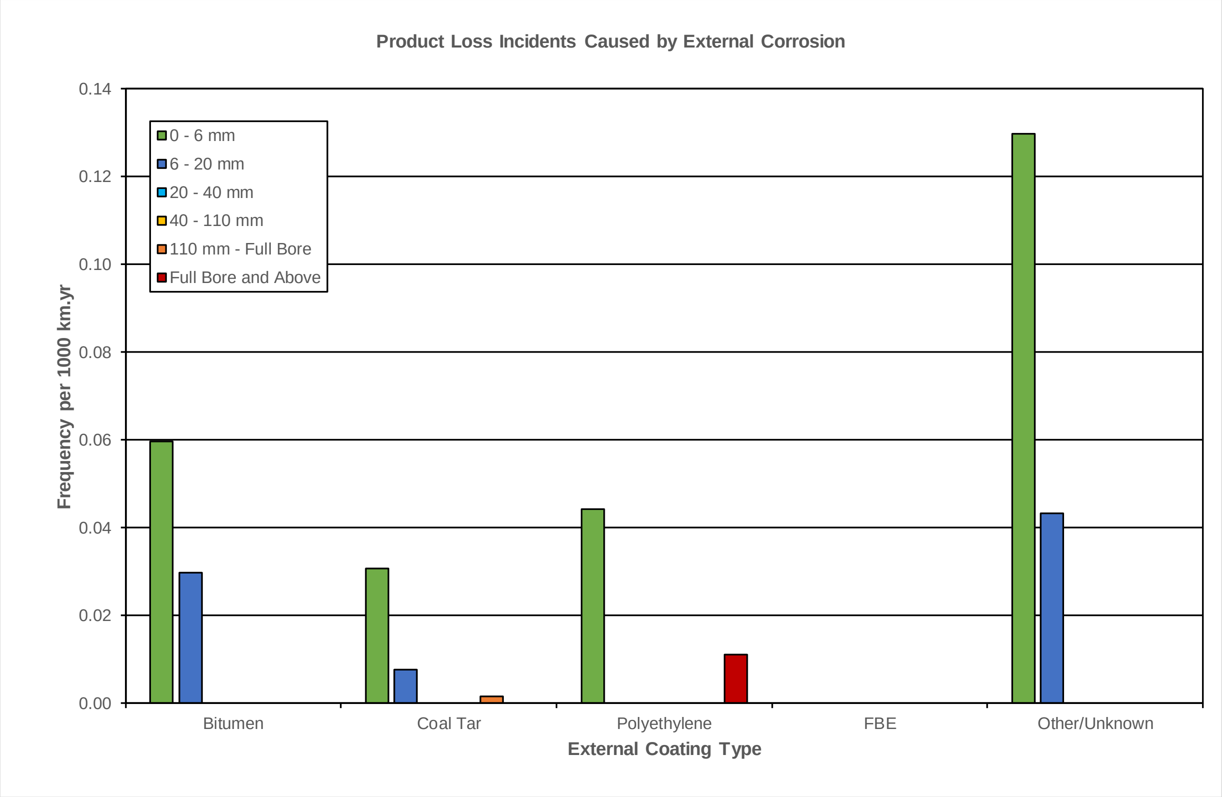

Figure 16: External Corrosion Product Loss Frequency by External Coating and Equivalent Hole Size

External Coating	Exposure [km.yr]	External Corrosion Incidents	Frequency [per 1000 km.yr]
Bitumen	33,543	3	0.089
Coal Tar	650,466	26	0.040
Polyethylene	90,338	5	0.055
FBE	101,354	0	0.000
Other/Unknown	46,252	8	0.173
TOTAL	**921,995**	**42**	**0.046**

Table 12: External Corrosion Incidents by External Coating Type

3.7.4 External Corrosion by Type of Backfill

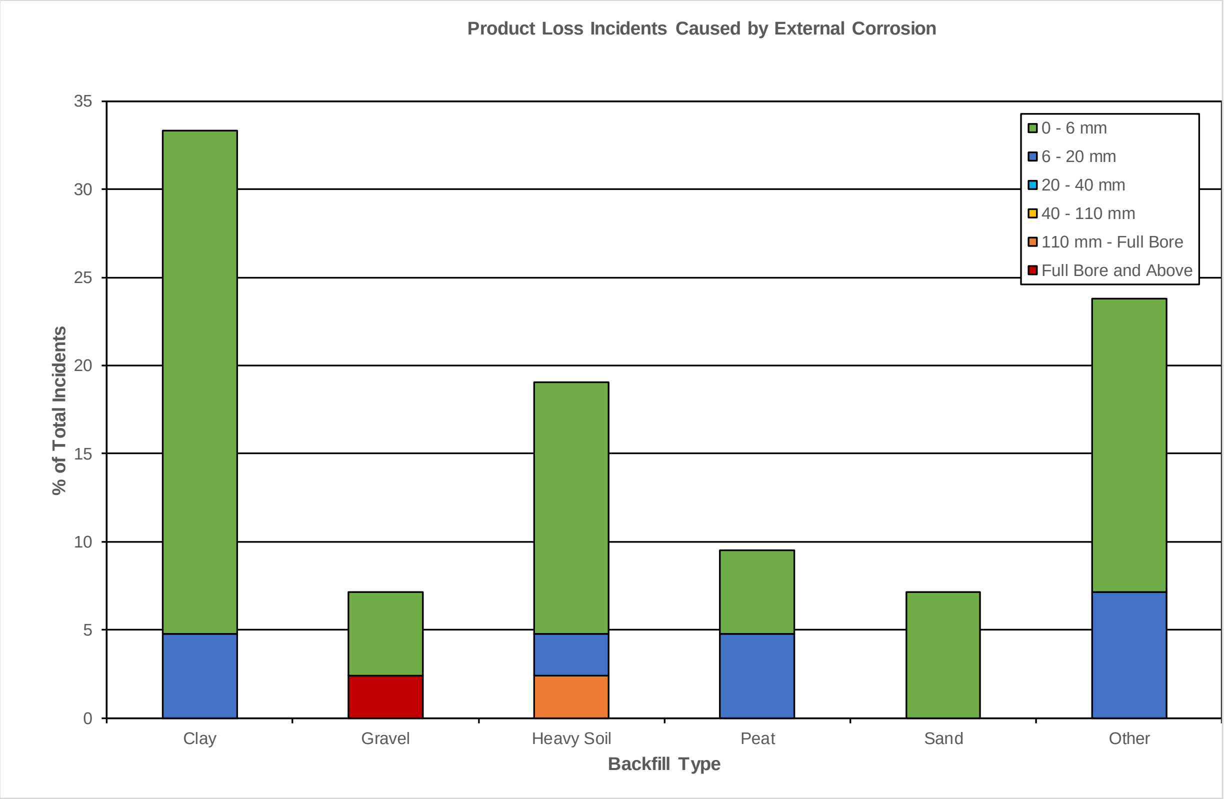

Figure 17: External Corrosion Product Loss Incidents by Type of Backfill

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 town gas	30
Pipe-Fitting Welds	4
Leaking Clamps	3
Lightning	1
Soil stress	1
Threaded Joint	1
Electric Cable Arc Strike	1
Socket & Spigot weld	2
Syphon Flange	1
TOTAL	**44**

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.

84% (37 out of 44) 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 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 44 = 68%) 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.

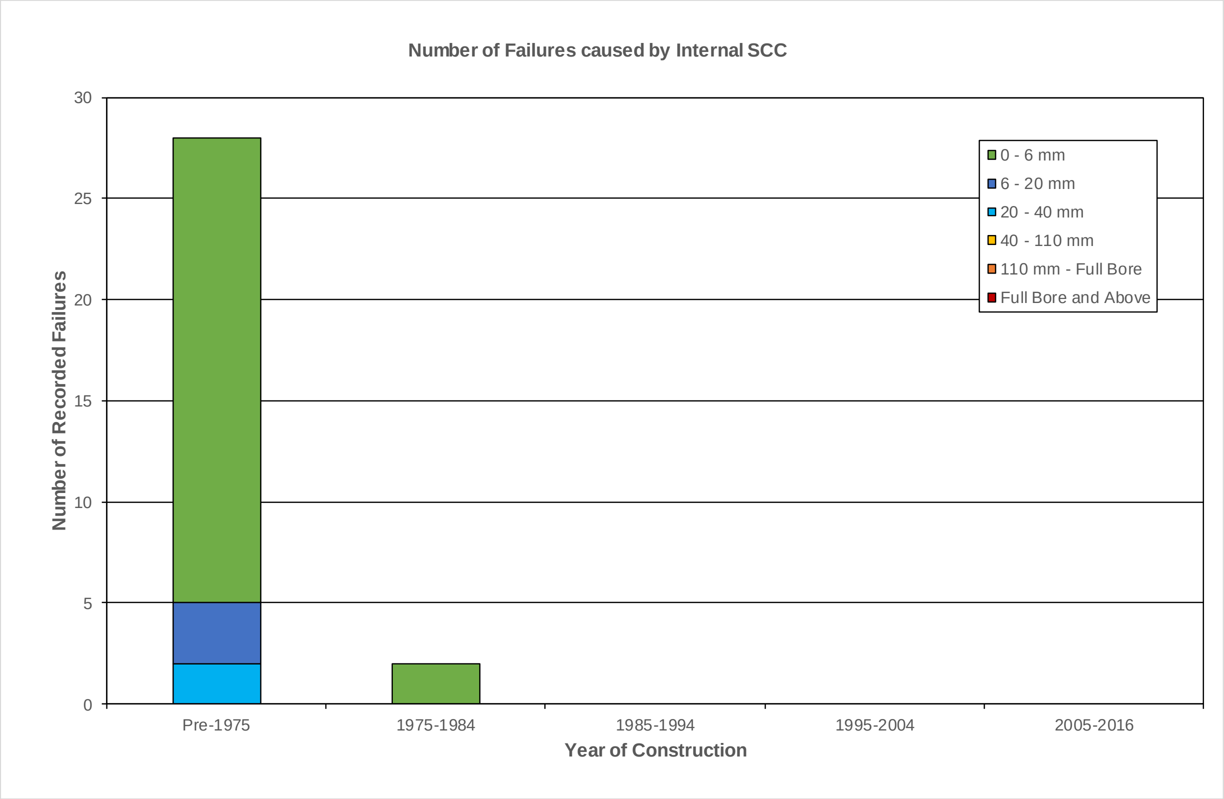

Figure 18: Failures caused by Internal SCC by Year of Construction and Equivalent Hole Diameter

3.10 Detection of Pipeline Failures

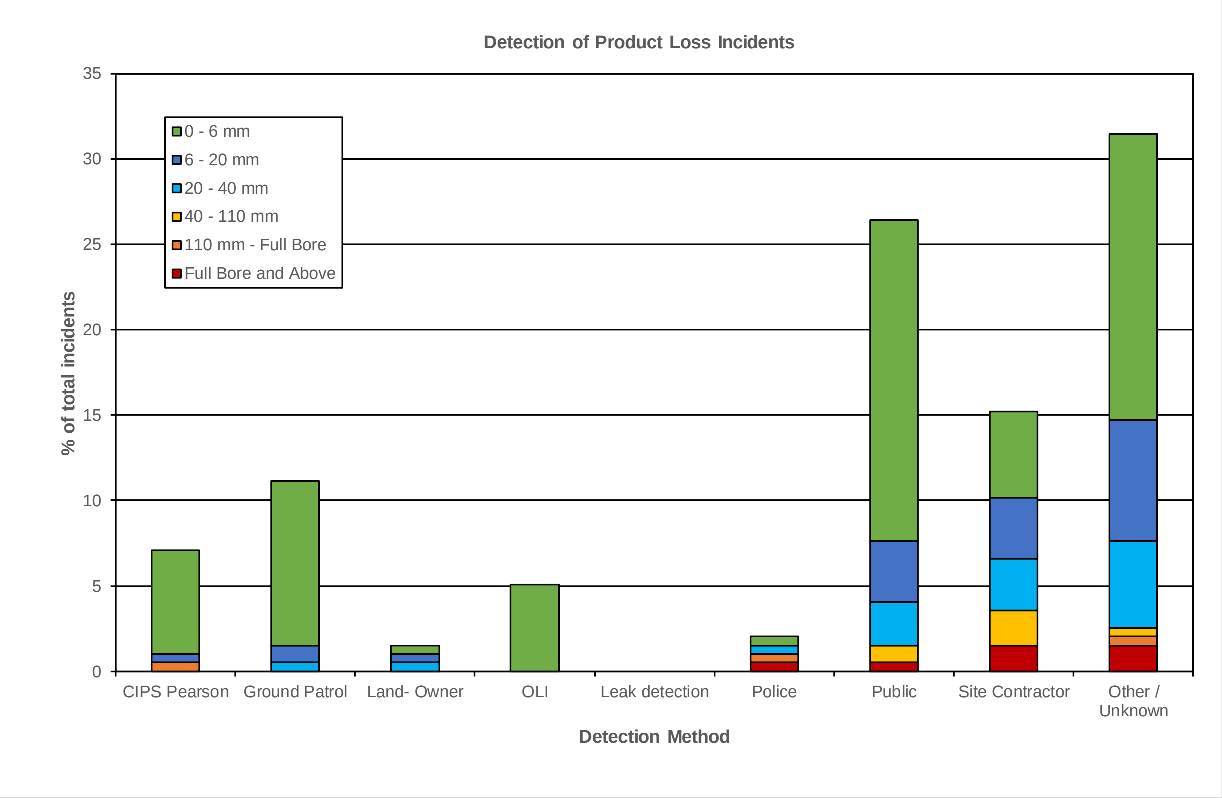

Figure 19: Detection of Product Loss Incidents by Equivalent Hole Diameter

Note: Not all pipelines can be inspected by In-Line Inspection.
Leak detection systems are not applicable to all pipelines and 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 – 2016 was 3756. The main causes of the Faults are shown in Figure 20.

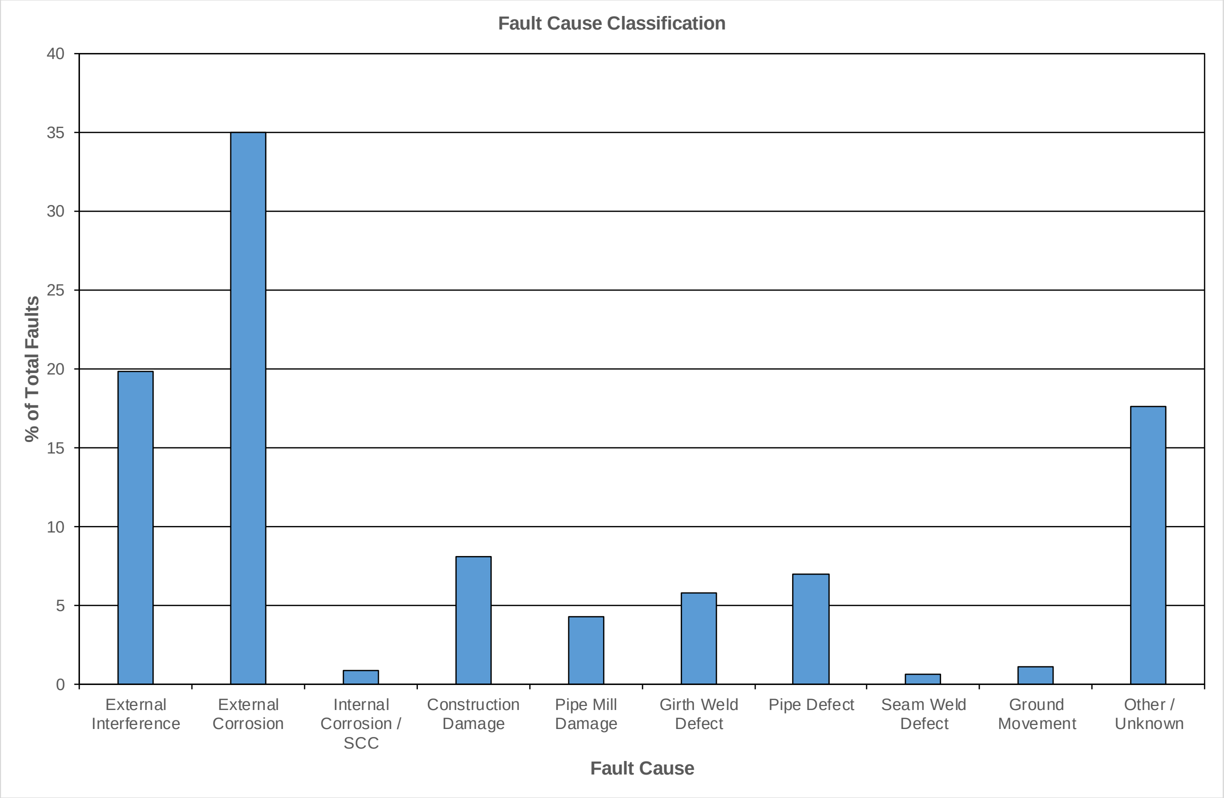

Figure 20: Fault Cause Classification

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 5967 defects recorded in the period 1962 – 2016.

Classification of defect data is shown in Figure 21.

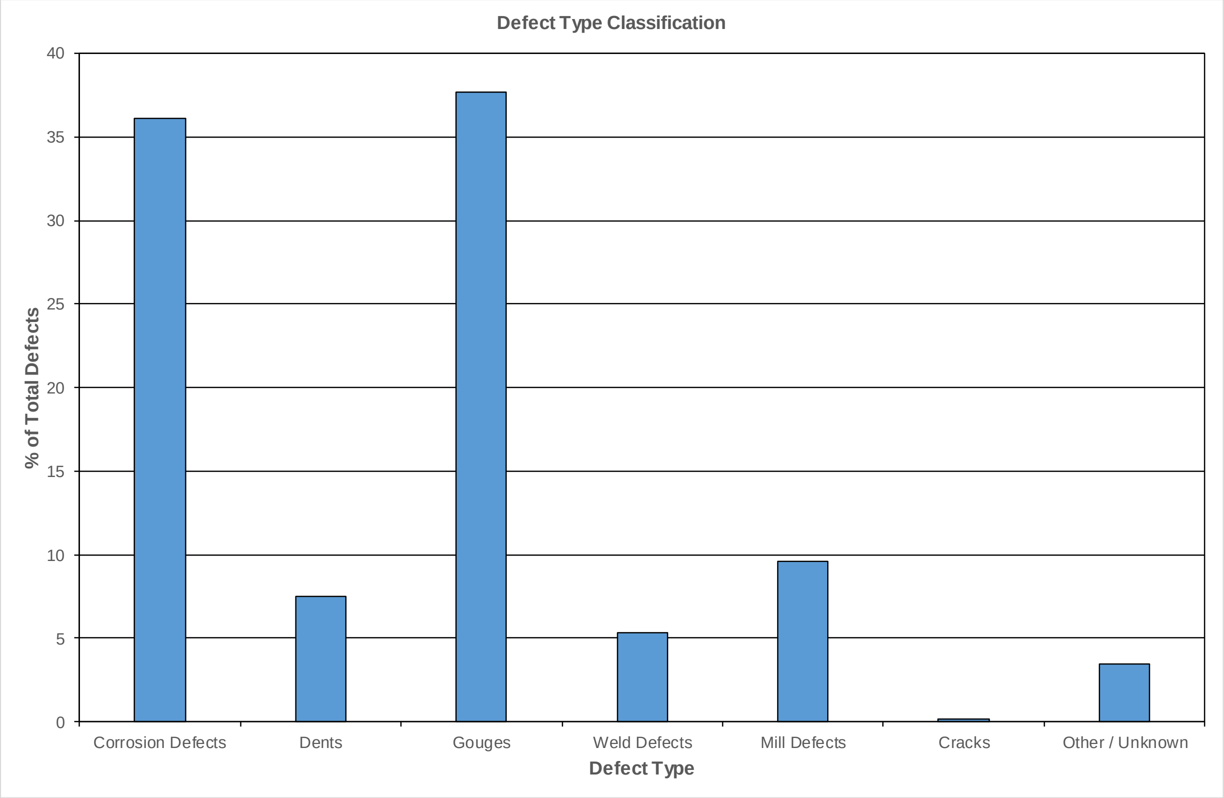

Figure 21: Defect Type Classification

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, recognized 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 [2], [3], [4] & [5] use 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 (dent, gouge and dent-gouge combinations), the size of the damage and the number and location of the incidents. The external interference damage data recorded up to and including 2010 in the UKOPA database has been analyzed to determine the best fit Weibull distribution parameters for gouge length, gouge depth and dent depth [6].

The Weibull distribution parameters for the data up to and including 2010 are given in Table 14.

Distribution Parameters	Gouge Length	Gouge Depth	Dent Depth
Weibull Shape (α)	0.573	0.674	1.018
Weibull Scale (β) mm	125.4	0.916	9.382

Table 14: Weibull Distribution Parameters for Damage Data up to 2010

These parameters allow pipeline failure probabilities to be derived for external interference events. An estimate of “hit rate” (i.e. frequency of damage incidents) is also required to obtain pipeline failure frequencies. “Hit rate” is dependent on specific pipeline parameters including location (rural-suburban), depth of cover, and frequency of external interference events for the pipeline population. The hit rate in rural areas associated with the above damage distribution parameters is 1.255 per 1000 km.yr.

Note: Weibull distributions were identified as appropriate distributions in historic work carried out to develop the FFREQ predictive model.

An update to the UKOPA damage parameters, including data up to 2016, is currently in progress and will be published in 2018.

5 References

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

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

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

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

[5] 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.

[6] G Goodfellow, S Turner, J Haswell, R Espiner, *An Update to the UKOPA Pipeline Damage Distributions,* IPC2012-90247, 9th International Pipeline Conference, Calgary, 2012.