UKOPA

United Kingdom Onshore Pipeline Operators' Association

UKOPA Pipeline Fault Database

Product Loss Incidents and Faults Report

(1962 – 2022)

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This report was prepared by G D Goodfellow and Dr C J Lyons for the UKOPA Fault and Risk Working Group comprising data from: Cadent; National Gas; Northern Gas Networks, SGN; Wales & West Utilities; Gas Networks Ireland; E.ON; Essar Oil (UK) Ltd.; INEOS; Ineos FPS; Sabic; Shell; and supported by the Health and Safety Executive.

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1	25/11/2024	30	First Issue

CONTENTS

1. EXECUTIVE SUMMARY

This report presents collaborative pipeline and product loss incident data from onshore Major Accident Hazard Pipelines (MAHPs) operated by National Gas, Cadent, Northern Gas Networks, Scotia Gas Networks, Wales & West Utilities, Gas Networks Ireland, E.ON, Penspen, Essar Oil (UK) Ltd., INEOS, Ineos FPS, Sabic and Shell, covering operating experience up to the end of 2022.

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 for the period from 1962 to 2022 is 0.194 incidents per 1000 km years, which is slightly lower than the previous report covering the period from 1962 to 2021 (0.197 incidents per 1000 km years). The overall trend continues to show a gradual reduction in failure frequency.

The failure frequency over the last 20 years is 0.074 incidents per 1000 km years.

For the last 5 years the failure frequency is 0.042 incidents per 1000 km years, whilst in the previous report this figure was 0.076 incidents per 1000 km years (covering the 5 year period up to the end of 2021).

This report also includes data for part-wall damage and defects, known as fault data; and the statistical distributions (derived from the 1962 to 2016 data) for use in estimating pipeline failure probabilities due to external interference events.

2. INTRODUCTION

2.1 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 (LUP) aspects adjacent to, and operational As Low As Reasonably Practicable (ALARP) assessments on, Major Accident Hazard Pipelines (MAHPs)[1]. 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 carried 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 widely available 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.

2.2 Purpose of the Database

The purpose of the database is to:

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

2.3 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 60 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.

[1] Defined by UK statutory legislation – The Pipelines Safety Regulations 1996 (PSR96) [8]. For pipelines containing natural gas this is those operating at pressures above 8 bar absolute (i.e. > 7 barg)

3. PIPELINE SYSTEM DATA

3.1 Exposure

The total length of MAHPs in operation at the end of 2022 reported by all participating companies (National Gas, Cadent, Northern Gas Networks, SGN, Wales & West Utilities, Gas Networks Ireland, E.ON, Essar Oil (UK) Ltd., INEOS, Ineos FPS, Sabic, Shell, Uniper and Wood) was 23,577 km. The total length of MAHPs in operation to the end of 2021 was 23,574 km.

The total exposure in the period 1952 to the end of 2022 was 1,069,312 km years. The development of this exposure is illustrated in Figure 3.1.

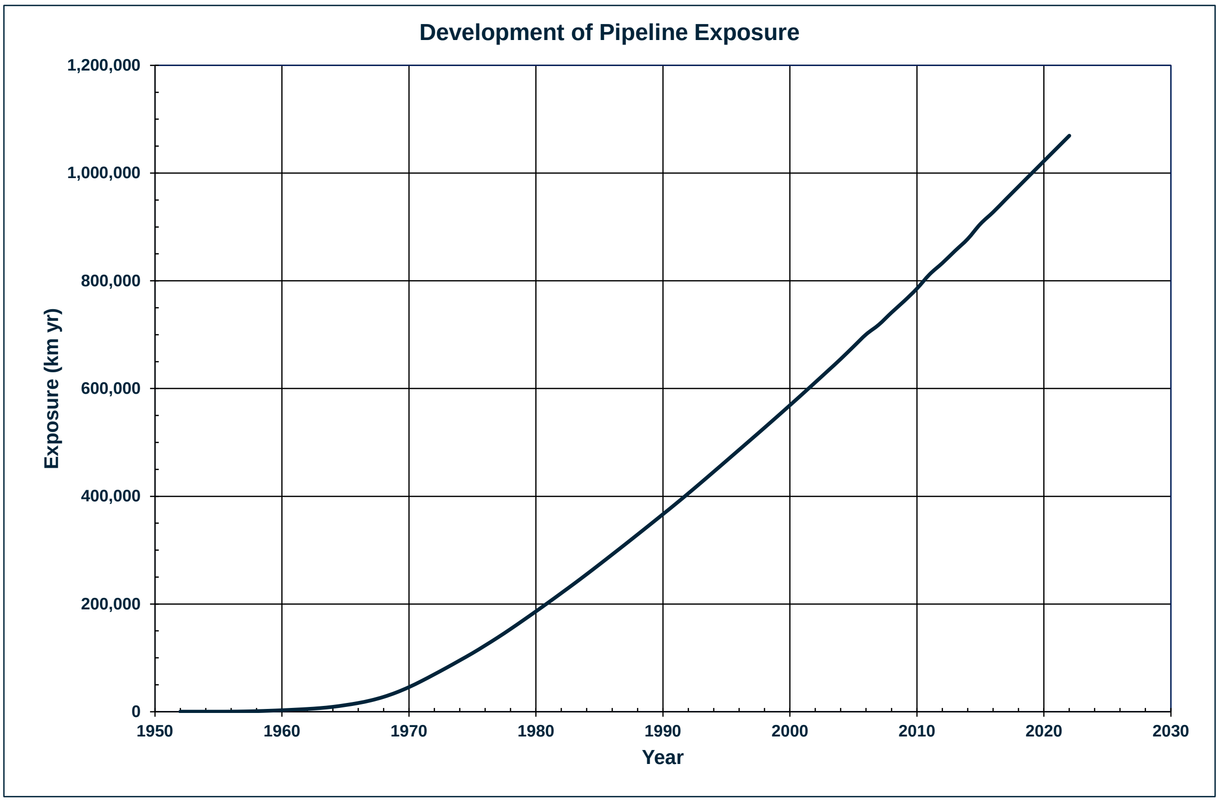

Figure 3.1: MAHP Operating Exposure from 1952 to 2022

Note 1: Pipeline exposure before first recorded incident in 1962 = 3,740 km.yr (included in exposure and incident frequency calculations).
Note 2: Short above ground sections of cross-country pipelines are included in totals.

3.2 Transported Products

The reported lengths (in km) of pipeline in operation at the end of 2022, by transported product, are shown in Table 3.1.

Product	Length (km)	%age of Total
Natural Gas (Dry)	21,816.89	92.5
Ethylene	1,140.94	4.8
Natural Gas Liquids	251.00	1.1
Crude Oil (Spiked)	212.60	0.9
Ethane	38.10	0.2
Propylene	37.00	0.2
Condensate	24.00	0.1
Propane	19.50	0.1
Butane	19.50	0.1
Hydrogen	14.14	0.1
TOTAL	**23,574**	**100.0**

Table 3.1: 2022 Pipeline Operating Lengths

4. 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).

A total of 207 product loss incidents were recorded over the period between 1962 and 2022 compared with 206 product loss incidents documented in the report covering the period to 2021 [1]. No product loss incidents were recorded prior to 1962. An annual breakdown of incidents is illustrated in Figure 4.1.

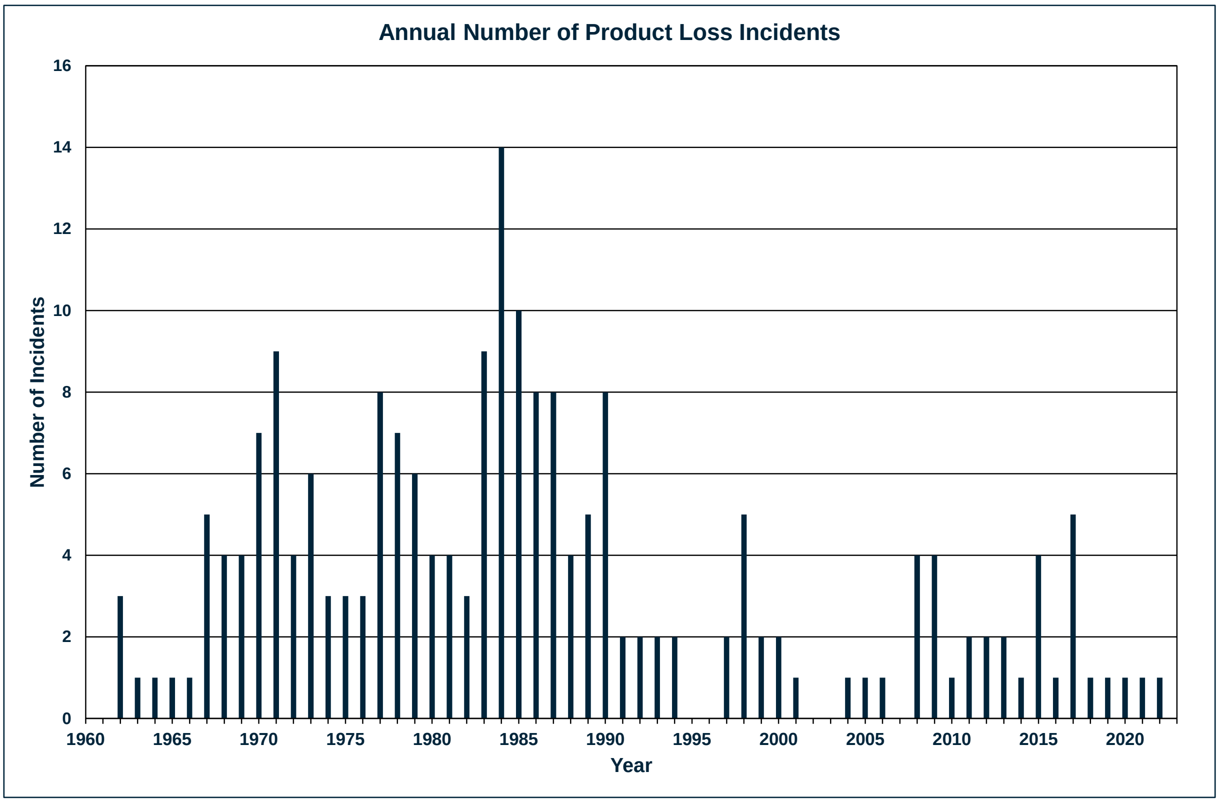

Figure 4.1: Product Loss Incidents per year since 1962

4.1 Differences between 2021 and 2022 Product Loss Statistics

One product loss incident was recorded in 2022: a pinhole leak in the girth weld at a tee. In 2021, one product loss incident was recorded from a girth weld at a bend. The cumulative number of incidents between 1962 and 2022 is shown in Figure 4.2.

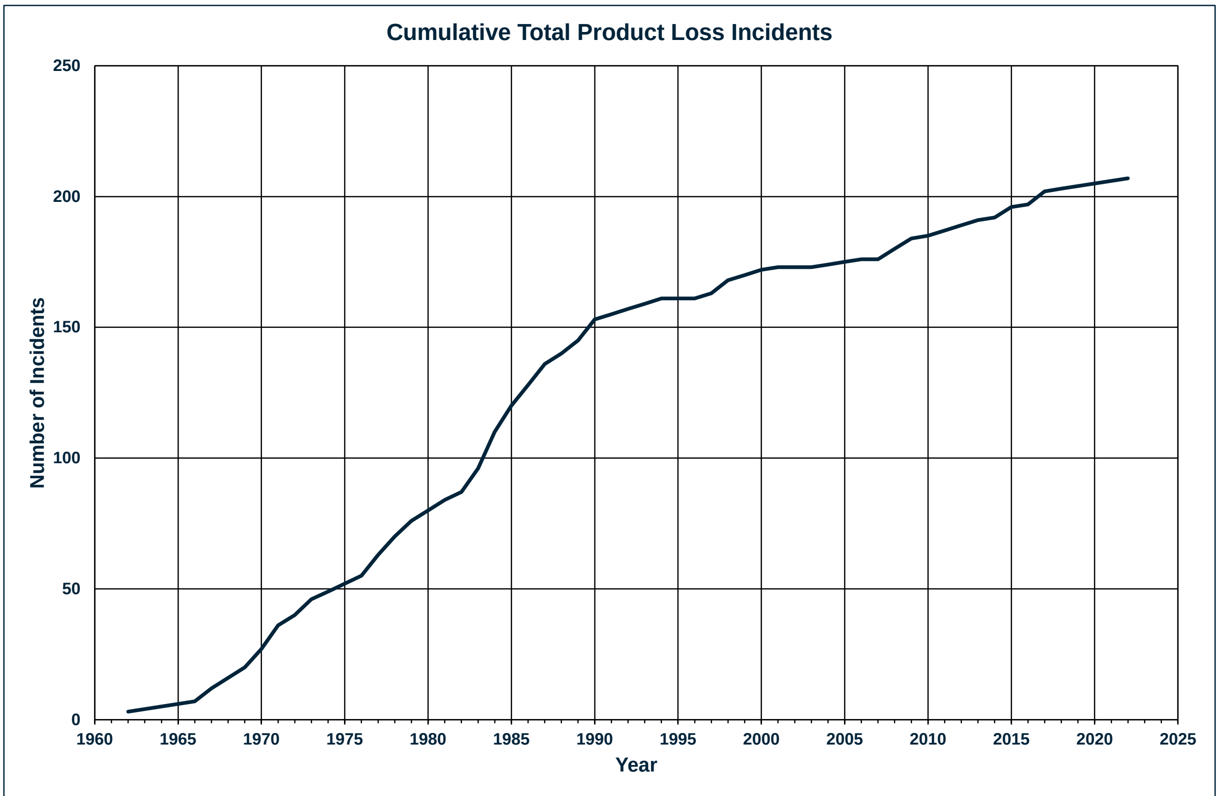

Figure 4.2: Cumulative Product Loss Incidents since 1962

4.2 Incident Ignition

Only 9 out of 207 (4.4%) product loss incidents have resulted in ignition, see Table 4.1.

Affected Component	Cause of Fault	Hole Diameter Range	Year
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 4.1: Ignited Product Loss Incidents

4.3 Incident Frequency

4.3.1 Trends over the past 5, 20 and 60 Years

The incident frequency over consecutive 5-year periods up to the end of 2022 is shown in Table 4.2.

Period	Number of Incidents	Total Exposure (km yr)	Frequency (Incidents per 1000 km yr)
<=1957	0	408.30	
1958 - 1962	3	4,565.34	0.657
1963 - 1967	9	15,930.64	0.565
1968 - 1972	28	48,377.84	0.579
1973 - 1977	23	68,463.16	0.336
1978 - 1982	24	82,362.39	0.291
1983 - 1987	49	89,991.20	0.544
1988 - 1992	21	95,103.09	0.221
1993 - 1997	6	101,421.79	0.059
1998 - 2002	10	104,813.76	0.095
2003 - 2007	3	107,005.99	0.028
2008 - 2012	13	114,330.61	0.114
2013 - 2017	13	118,474.96	0.110
2018 - 2022	5	118,062.23	0.042
TOTAL	**207**	**1,069,312**	**0.194**

Table 4.2: 5-year Incident Frequency

The overall incident frequency by hole size over the period 1962 – 2022 is shown in Table 4.3.

Equivalent Hole Size (θ)[2]	Number of Incidents	Frequency (per 1000 km yr)
θ ≥ Full Bore[3]	6	0.006
110 mm ≤ θ < Full Bore[3]	2	0.002
40 ≤ θ < 110 mm	9	0.008
20 ≤ θ < 40 mm	24	0.022
6 ≤ θ < 20 mm	30	0.028
0 ≤ θ < 6 mm	136	0.127
TOTAL	**207**	**0.194**

Table 4.3: Overall Incident Frequency by Hole Size

[2] 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.
[3] Full Bore ≡ diameter of the pipeline

The total exposure for the last 20 years (2002 – 2022) is 457,874 km years and the resulting incident frequency is shown in Table 4.4.

Equivalent Hole Size (θ)	Number of Incidents	Frequency (per 1000 km yr)
θ ≥ Full Bore	0	0.000
110 mm ≤ θ < Full Bore	0	0.000
40 ≤ θ < 110 mm	1	0.002
20 ≤ θ < 40 mm	4	0.009
6 ≤ θ < 20 mm	3	0.007
0 ≤ θ < 6 mm	26	0.057
TOTAL	**34**	**0.074**

Table 4.4: 20-year Incident Frequency by Hole Size

The failure frequency over the last 20 years (2002 – 2022) is 0.074 incidents per 1000 km yr and for the last 5 years (2018 – 2022) is 0.042 incidents per 1000 km yr.

These compare with the overall failure frequency during the period 1962 – 2022 of 0.194 incidents per 1000 km yr. An overview of the development of this failure frequency is shown in Figure 4.3 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 (2018 – 2022, 2017 – 2021, 2016 – 2020 etc.).

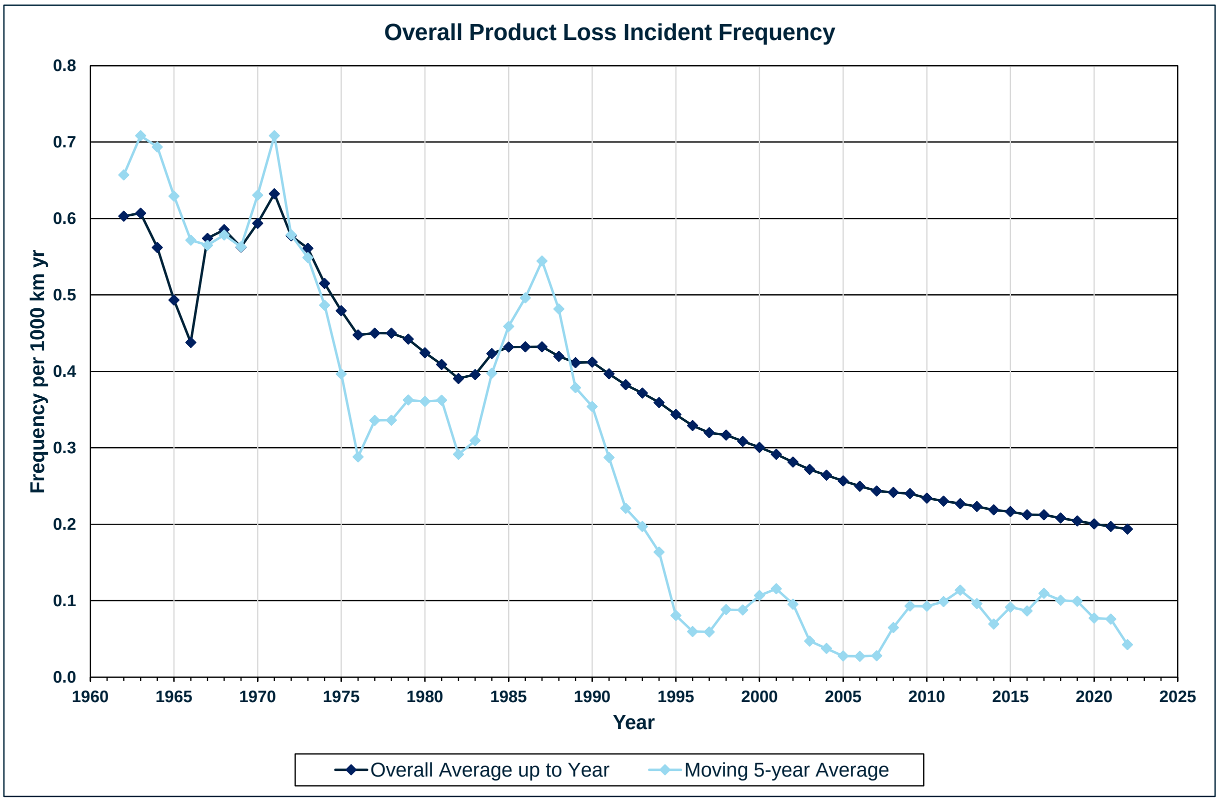

Figure 4.3: Development of overall and 5-year Incident Frequency

4.3.2 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 4.4 and for the 5-year average in Figure 4.5.

Figure 4.4 shows that the overall frequency for the whole period is 0.194 per 1000 km yr +/- 0.027 and Figure 4.5 shows that the 5-year average failure frequency for 2018 – 2022 is 0.042 per 1000 km yr +/- 0.038.

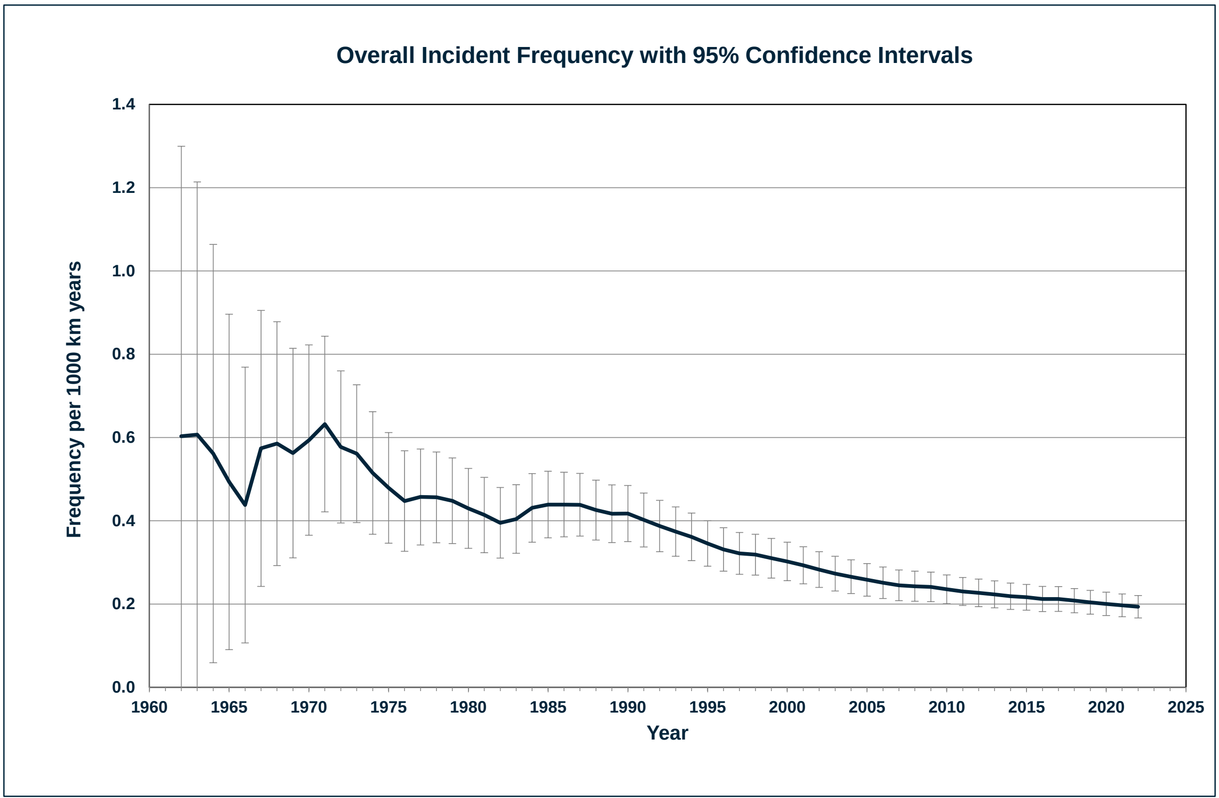

Figure 4.4: Overall Incident Frequency with 95% Confidence Intervals

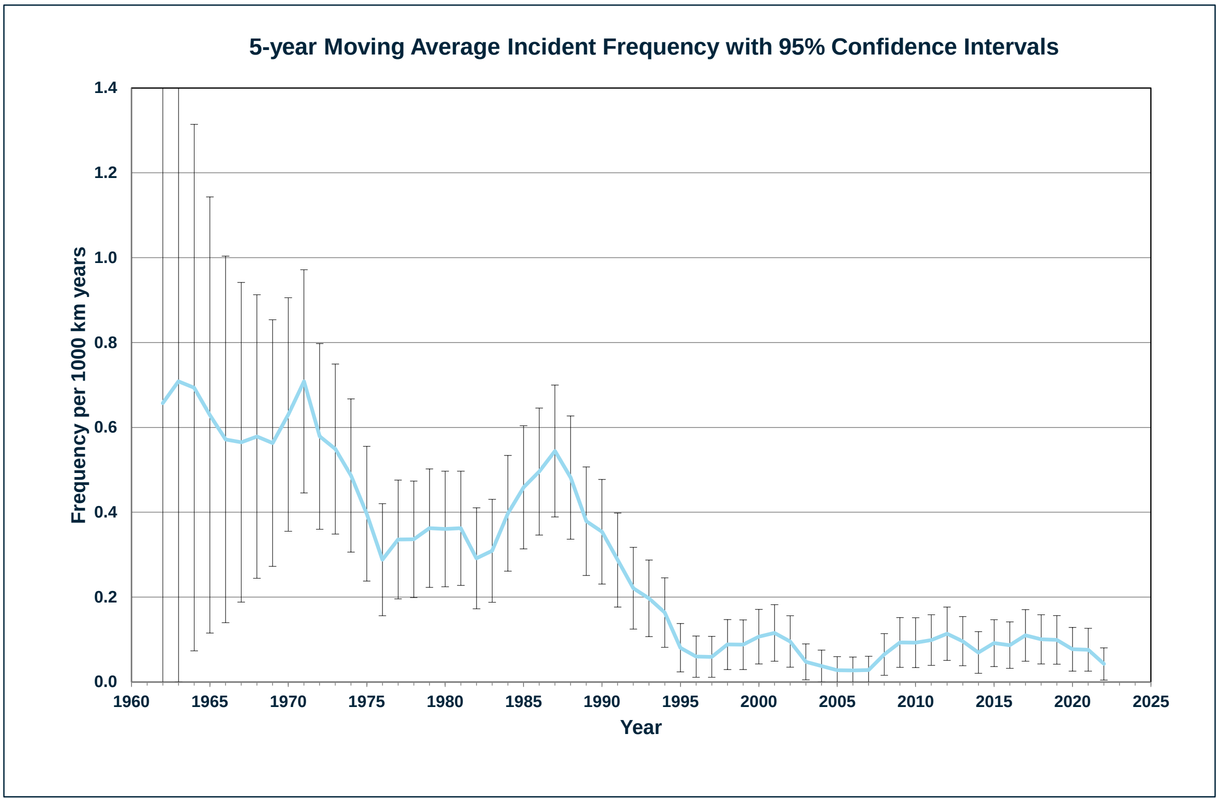

Figure 4.5: 5-year Incident Frequency with 95% Confidence Intervals

4.4 Incident Frequency by Cause

The development of product loss incident frequency by cause is shown in Figure 4.6, and the total number of incidents due to each cause is listed in Table 4.5.

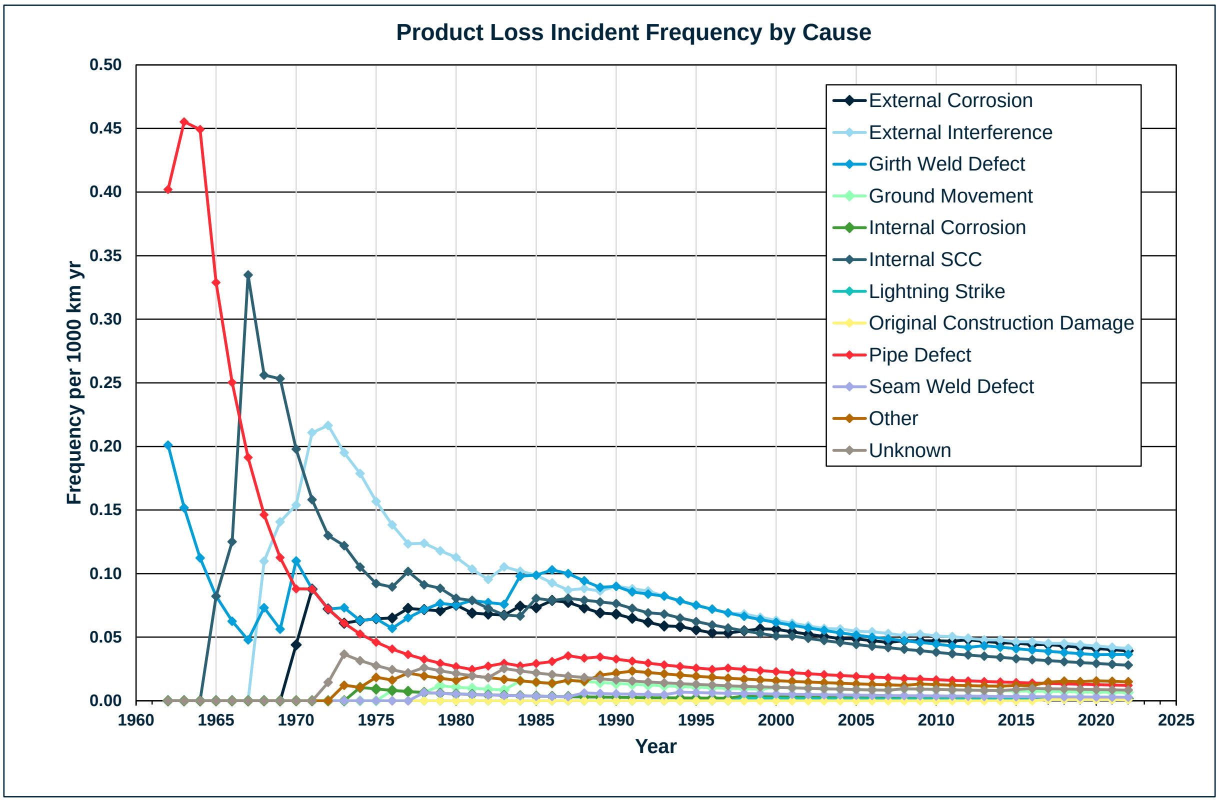

Figure 4.6: Product Loss Incident Frequency by Cause

Product Loss Cause	No. of Incidents	%age of Total
External Corrosion	42	20.3
External Interference	44	21.3
Girth Weld Defect	39	18.8
Ground Movement	7	3.4
Internal Corrosion	2	1.0
Internal SCC	30	14.5
Lightning Strike	1	0.5
Original Construction Damage	1	0.5
Pipe Defect	13	6.3
Seam Weld Defect	3	1.4
Other[4]	16	7.7
Unknown	9	4.3
TOTAL	**207**	**100**

Table 4.5: Product Loss Incidents by Cause

Figure 4.7 shows the product loss incident frequency by cause over the period 1962 – 2022 compared with the frequency over the last 5 years (2018 – 2022).

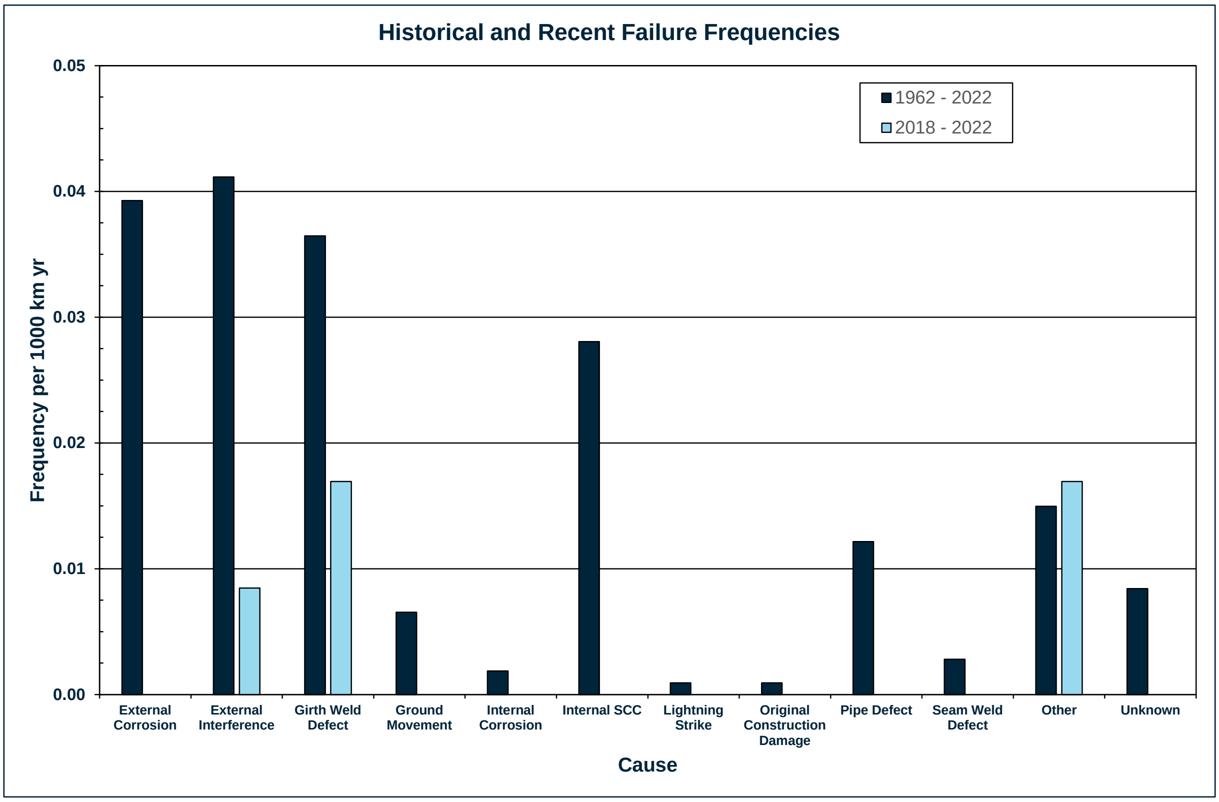

Figure 4.7: Overall and 5-year Product Loss Incident Frequency by Cause

[4] See Section 4.9 for further details.

An overview of the product loss incident frequency by cause and size of leak in the period 1962 to 2022 is shown in Figure 4.8.

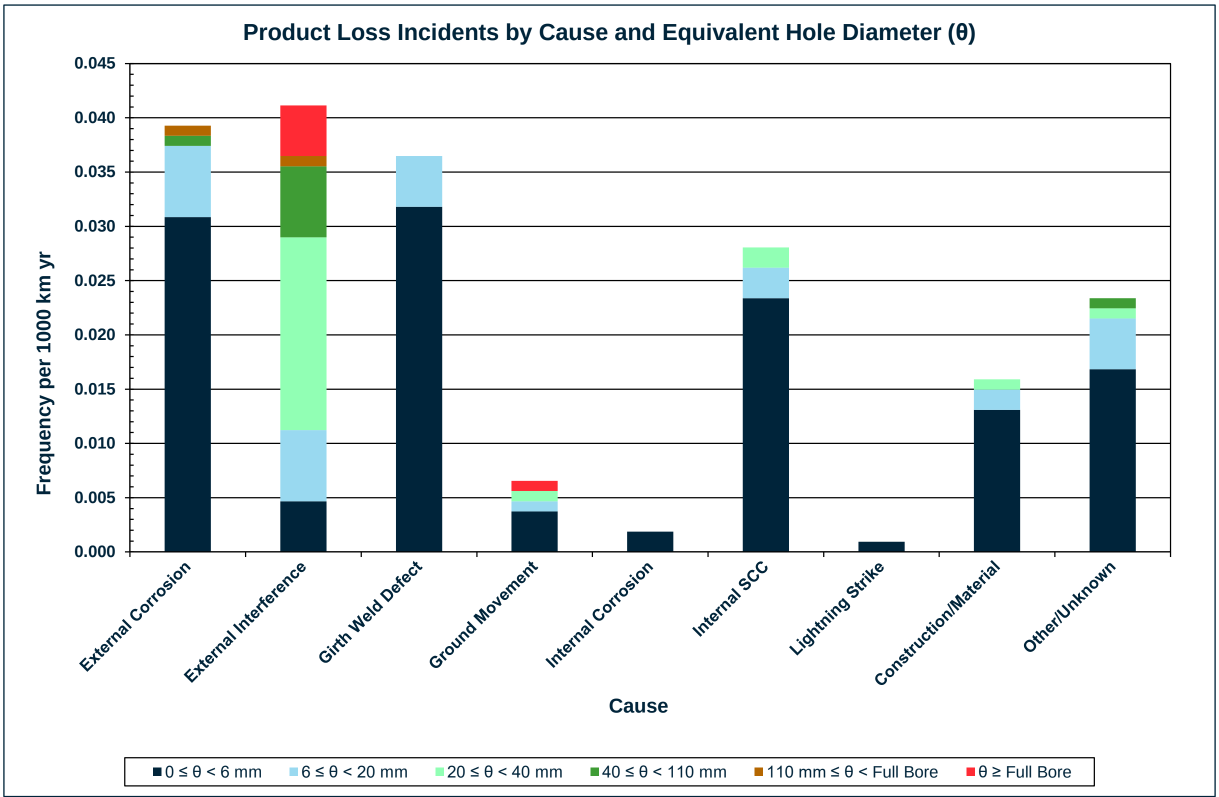

Figure 4.8: Product Loss Incident Frequency by Cause and Size of Leak

Note 1: Construction/Material = Seam Weld Defect + Pipe Defect + Pipe Mill Defect + Original Construction Damage
Note 2: Full Bore ≡ diameter of pipeline

4.5 Girth Weld Defects

Girth weld defects are the third highest cause of product loss in the database. Figure 4.9 shows that 39 leaks due to girth weld defects were recorded in pipelines constructed before 1985, 36 of which were in pipelines constructed before 1972. All 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.

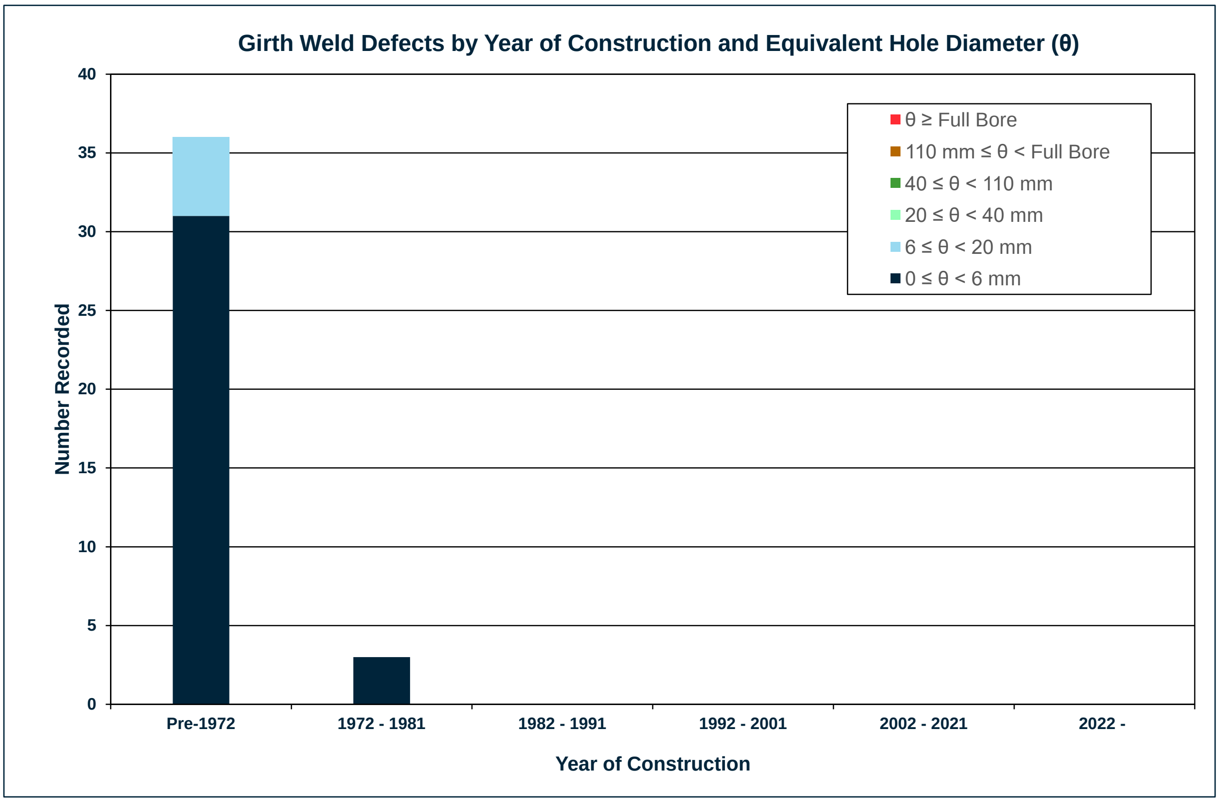

Figure 4.9: Girth Weld Defects

4.6 External Interference

External interference is the most common cause of product loss incidents with 44 recorded incidents attributable to this cause.

4.6.1 External Interference by Diameter

Figure 4.10 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 in Table 4.6.

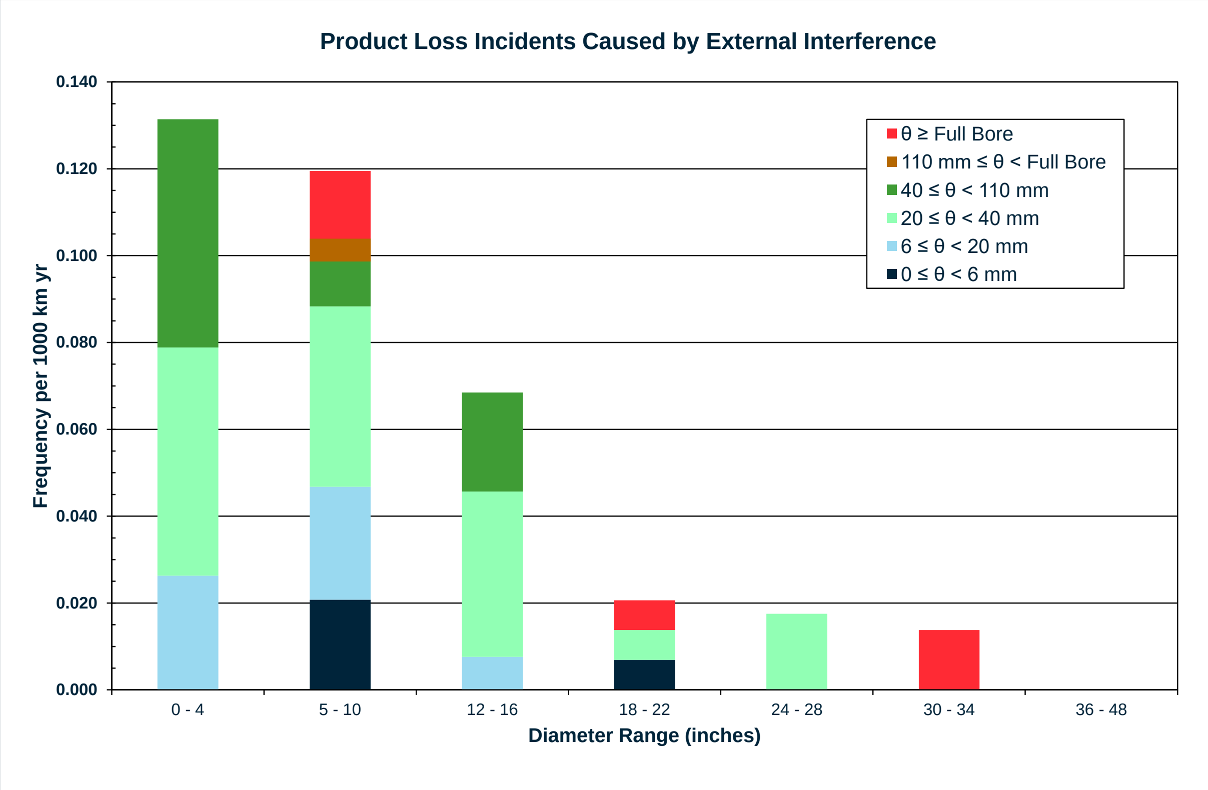

Figure 4.10: External Interference Product Loss Frequency by Diameter and Equivalent Hole Size (θ)

Diameter Class (inches)	Exposure (km yr)	No. of External Interference Incidents	Frequency (Incidents per 1000 km yr)
0 – 4	38,049	5	0.131
5 – 10	192,480	23	0.119
12 – 16	131,404	9	0.068
18 – 22	145,337	3	0.021
24 – 28	171,117	3	0.018
30 – 34	72,693	1	0.014
36 – 48	316,695	0	0.000
Unknown	1,537	0	0.000
TOTAL	**1,069,312**	**44**	**0.041**

Table 4.6: External Interference Incidents by Diameter Class

4.6.2 External Interference by Measured Wall Thickness

The relationship between product loss incidents caused by external interference and wall thickness is shown in Figure 4.11 and Table 4.7 below.

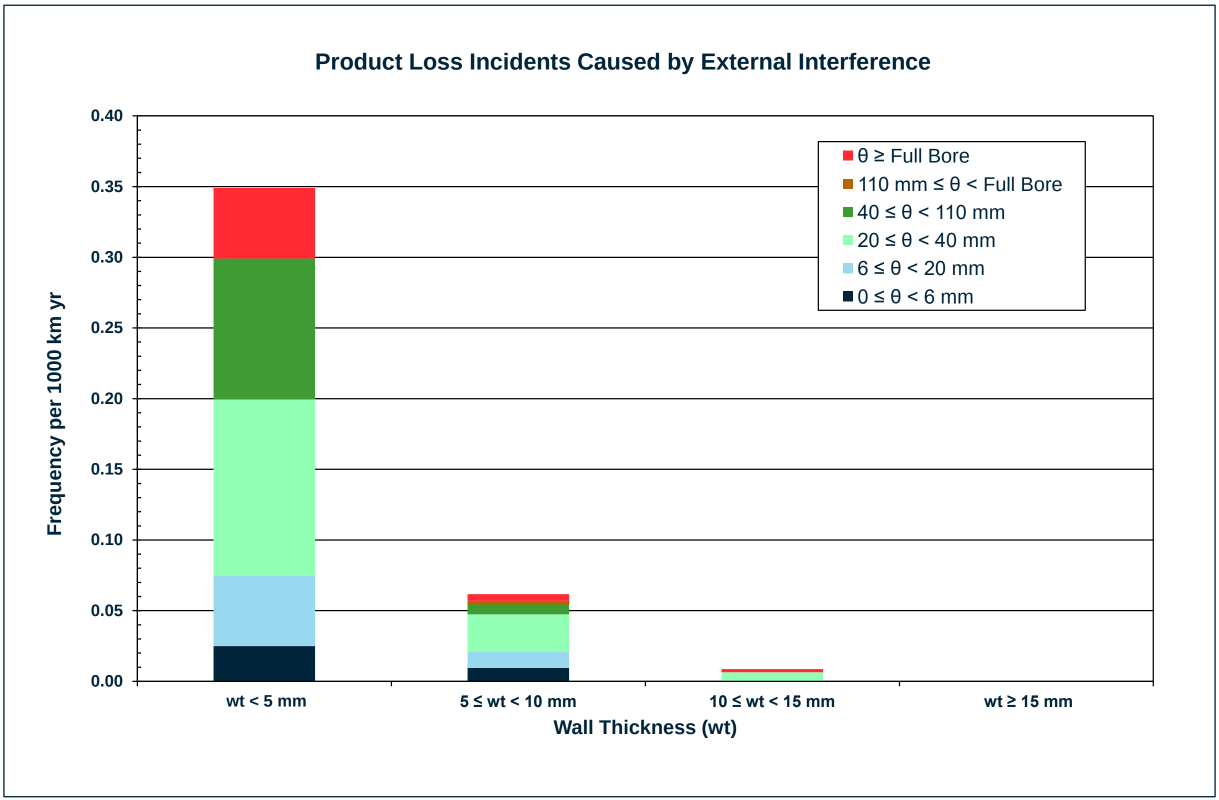

Figure 4.11: External Interference Product Loss Frequency by Wall Thickness (wt) and Equivalent Hole Size (θ)

Note 1: 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)	No. of External Interference Incidents	Frequency (Incidents per 1000 km yr)
wt < 5	40,114	14	0.349
5 ≤ wt < 10	421,467	26	0.062
10 ≤ wt < 15	462,982	4	0.009
wt ≥ 15	130,891	0	0.000
Unknown	13,858	0	0.000
TOTAL	**1,069,312**	**44**	**0.041**

Table 4.7: External Interference Incidents by Wall Thickness (wt)

4.6.3 External Interference by Area or Location Classification

The relationship between product loss incidents caused by external interference and location or area class is shown in Figure 4.12 and Table 4.8 below.

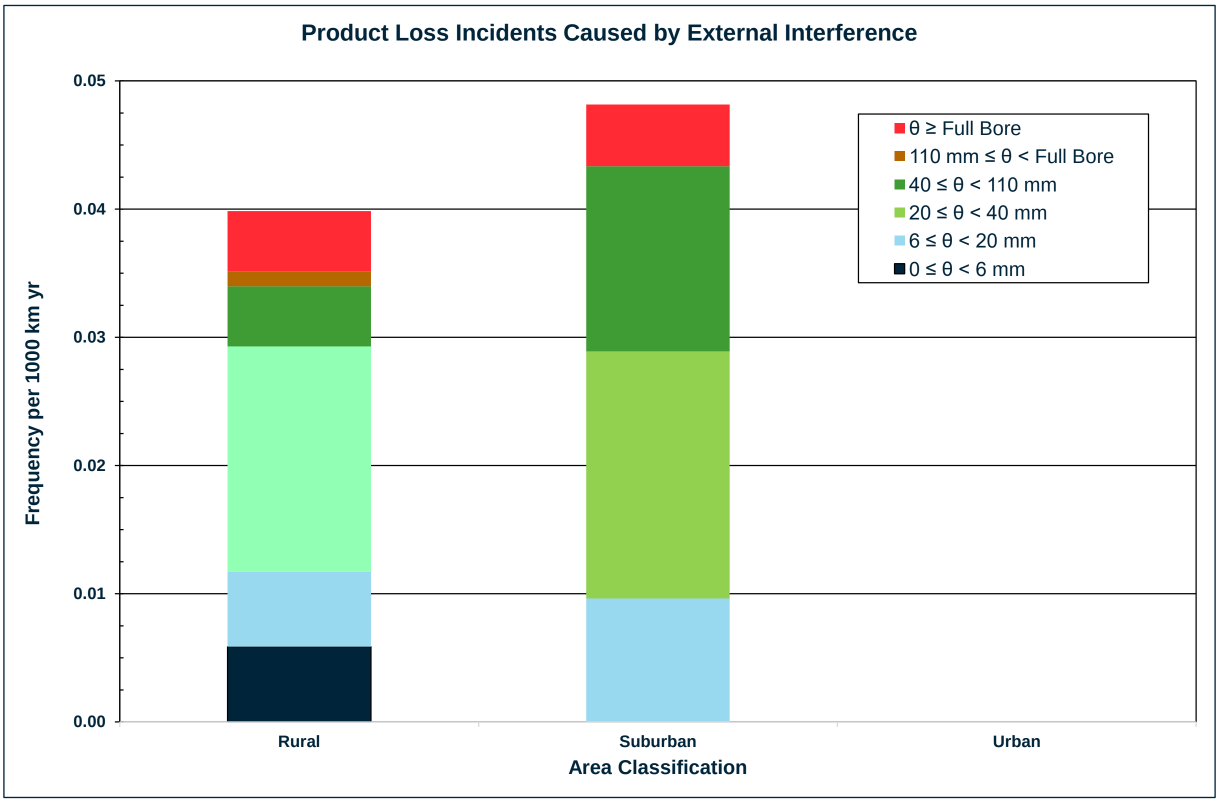

Figure 4.12: External Interference Product Loss Frequency by Area (or Location) Class and Equivalent Hole Size (θ)

Area Class	Exposure (km yr)	No. of External Interference Incidents	Frequency (Incidents per 1000 km yr)
Rural	853,266	34	0.040
Suburban	207,603	10	0.048
Urban	7,561	0	0.000
Other/Unknown	883	0	0.000
TOTAL	**1,069,312**	**44**	**0.041**

Table 4.8: External Interference by Area Class

Note 1: 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 classified by operators as semi-rural
Urban = central areas of towns or cities[5] with a high population density

[5] MAHPs transporting natural gas are not allowed to operate in Urban (Type T) areas.

4.7 External Corrosion

External corrosion is the second highest cause of product loss incidents, just behind external interference, with 42 recorded failures.

4.7.1 External Corrosion by Wall Thickness

Figure 4.13 and Table 4.9 show the relationship product loss incident frequencies due to external corrosion and wall thickness.

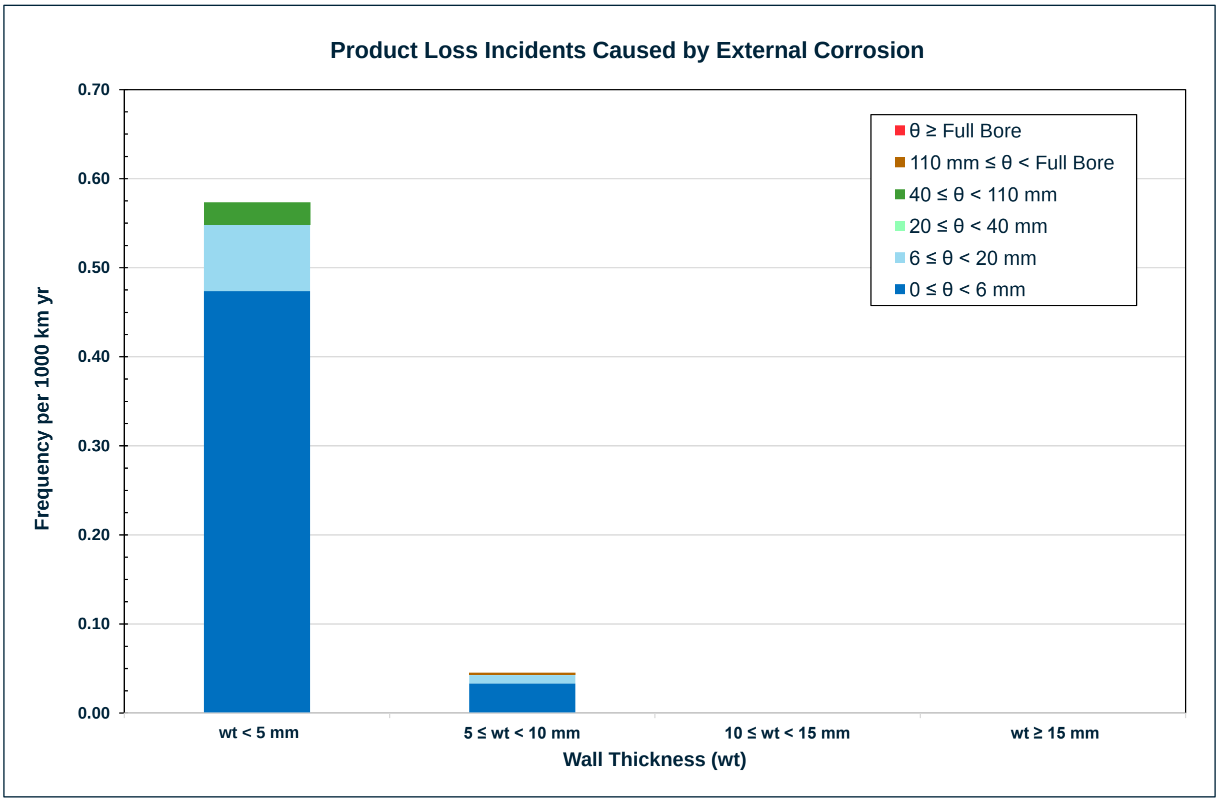

Figure 4.13: External Corrosion Product Loss Frequency by Wall Thickness and Equivalent Hole Size (θ)

Note 1: The largest wall thickness for a product loss incident caused by external corrosion to date is 10 mm

Wall Thickness (mm)	Exposure (km yr)	No. of External Corrosion Incidents	Frequency (Incidents per 1000 km yr)
wt < 5	40,114	23	0.573
5 ≤ wt < 10	421,467	19	0.045
10 ≤ wt < 15	462,982	0	0.000
wt ≥ 15	130,891	0	0.000
Unknown	13,858	0	0.000
TOTAL	**1,069,312**	**42**	**0.039**

Table 4.9: External Corrosion Incidents by Wall Thickness (wt)

4.7.2 External Corrosion by Year of Construction

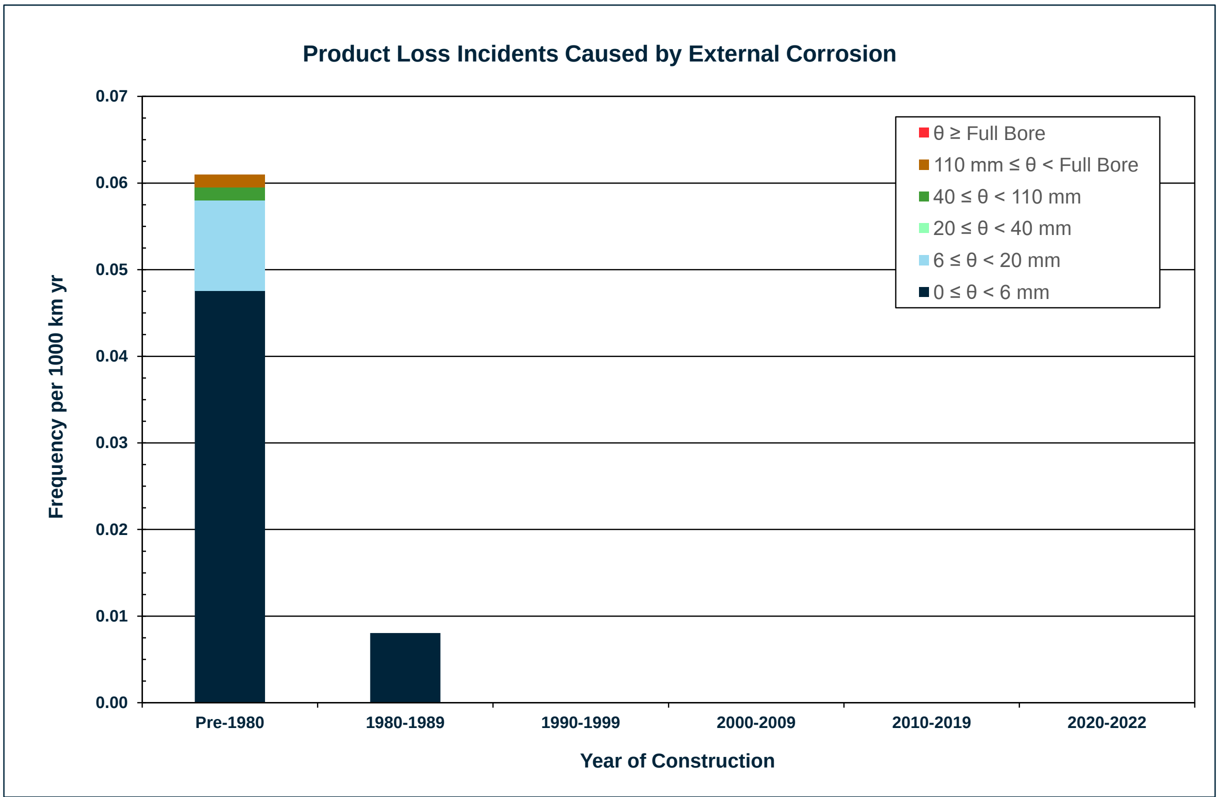

Figure 4.14: External Corrosion Product Loss Frequency by Year of Construction and Equivalent Hole Size (θ)

Construction Year	Exposure (km yr)	No. of External Corrosion Incidents	Frequency (Incidents per 1000 km yr)
Pre-1980	672,639	41	0.061
1980 – 1989	124,075	1	0.008
1990 – 1999	104,175	0	0.000
2000 – 2009	138,180	0	0.000
2010 – 2019	14,040	0	0.000
2020 – 2022	223	0	0.000
Unknown	15,980	0	0.000
TOTAL	**1,069,312**	**42**	**0.039**

Table 4.10: 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.

4.7.3 External Corrosion by Type of External Coating

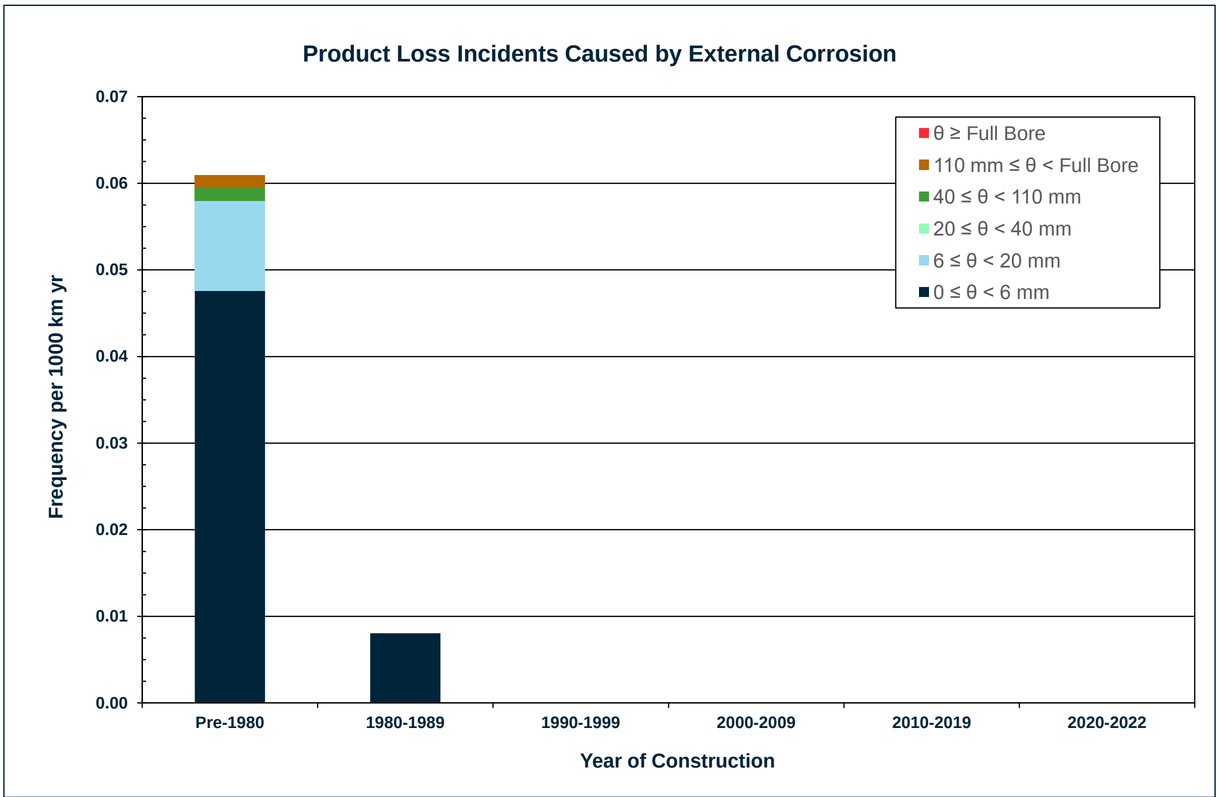

Figure 4.15: External Corrosion Product Loss Frequency by External Coating and Equivalent Hole Size (θ)

External Coating	Exposure (km yr)	No. of External Corrosion Incidents	Frequency (Incidents per 1000 km yr)
Bitumen	12,596	3	0.238
Coal Tar	538,612	26	0.048
Polyethylene (PE)	150,424	5	0.033
Fusion Bonded Epoxy (FBE)	245,173	0	0.000
Other/Unknown	122,506	8	0.065
TOTAL	**1,069,312**	**42**	**0.039**

Table 4.11: External Corrosion Incidents by External Coating

4.8 Internal Stress Corrosion Cracking

30 product loss incidents were caused by internal stress corrosion cracking (SCC) in pipelines which had seen wet towns gas service prior to the introduction of natural gas in the UK. All thirty 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.

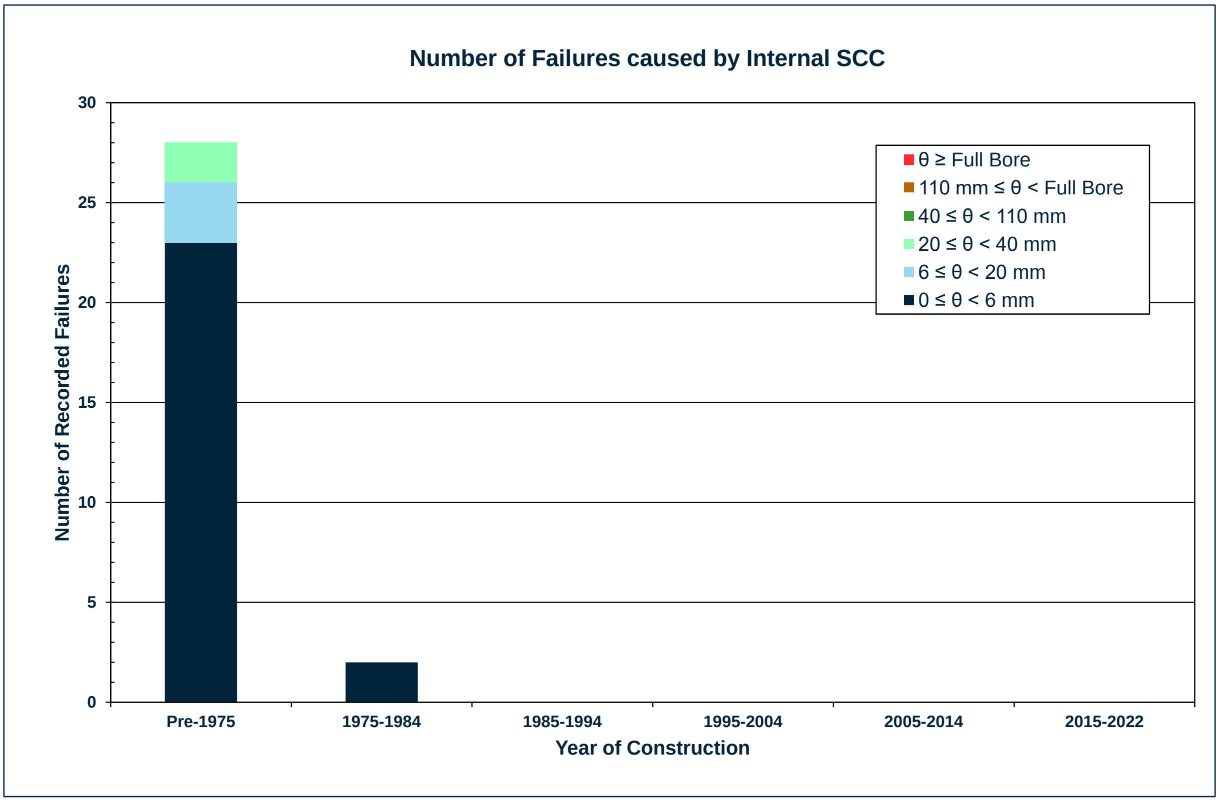

Figure 4.16: Internal SCC Product Loss Incidents by Year of Construction and Equivalent Hole Diameter (θ)

4.9 Product Loss Incidents Classified as 'Other'

Pipeline failures due to causes other than those defined as:

- External Interference
- Corrosion & Stress Corrosion Cracking (SCC)
- Material and Construction related
- Ground movement (or other environmental load)

are generally classified as "Other" with more detail provided in the comments field,

The UKOPA product loss data contains 16 incidents recorded under this category with a range of causes:

Other Cause	No. of Incidents
Pipe / Fitting Weld	4
Socket & Spigot Weld	4
Leaking Clamps	3
Electric Cable Arc Strike	1
Stopple Tee Flange	2
Syphon Flange	1
Threaded Joint	1
TOTAL	**16**

Table 4.12: Product Loss Incidents Classified as Other

It should be noted that the majority of product loss incidents in recent years have been associated with attachments to the pipeline, rather than failures of the pipe itself.

4.10 Detection of Product Loss Incidents

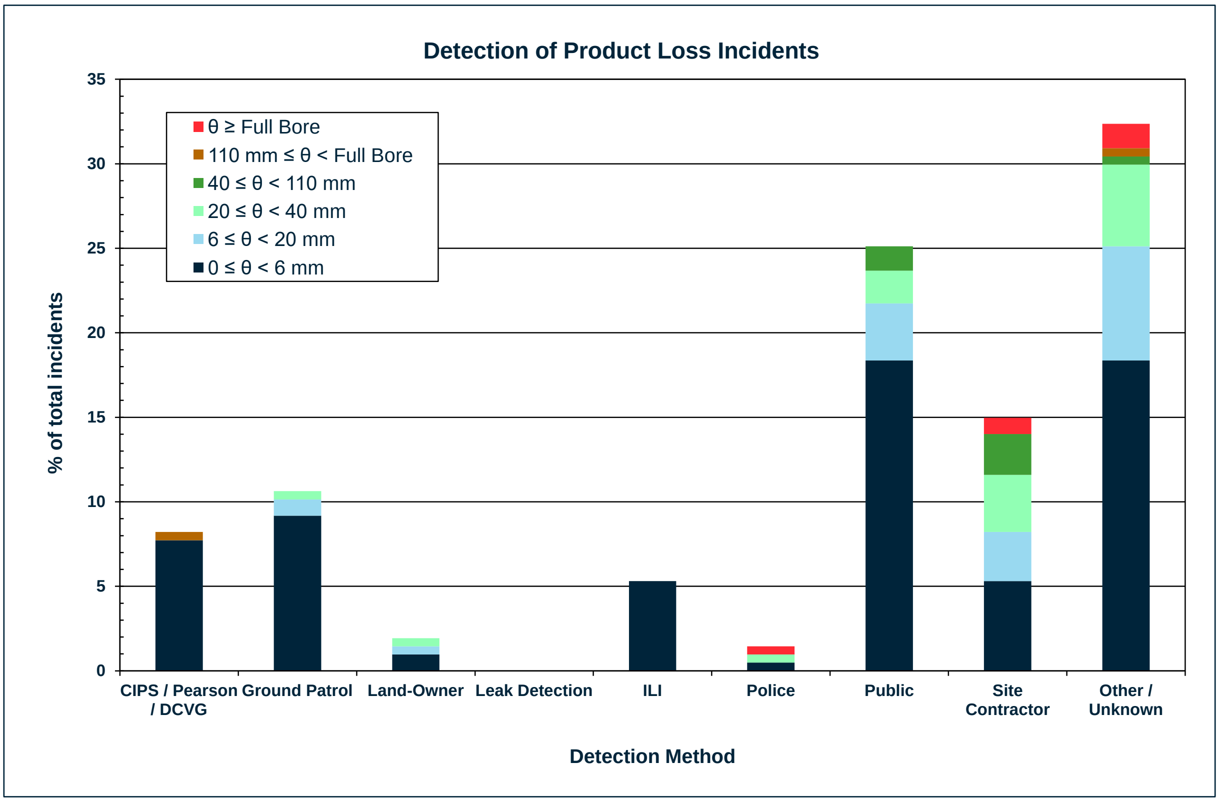

Figure 4.17: Detection of Product Loss Incidents by Equivalent Hole Diameter

Note 1: Not all pipelines can be inspected by In-Line Inspection (ILI) and leak detection systems are not applicable to all pipelines and pipeline networks.

5. FAULT 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 – 2022 was 3,937 compared to 3,895 for the period 1962 – 2021. The main causes of the Faults are shown in Figure 5.1.

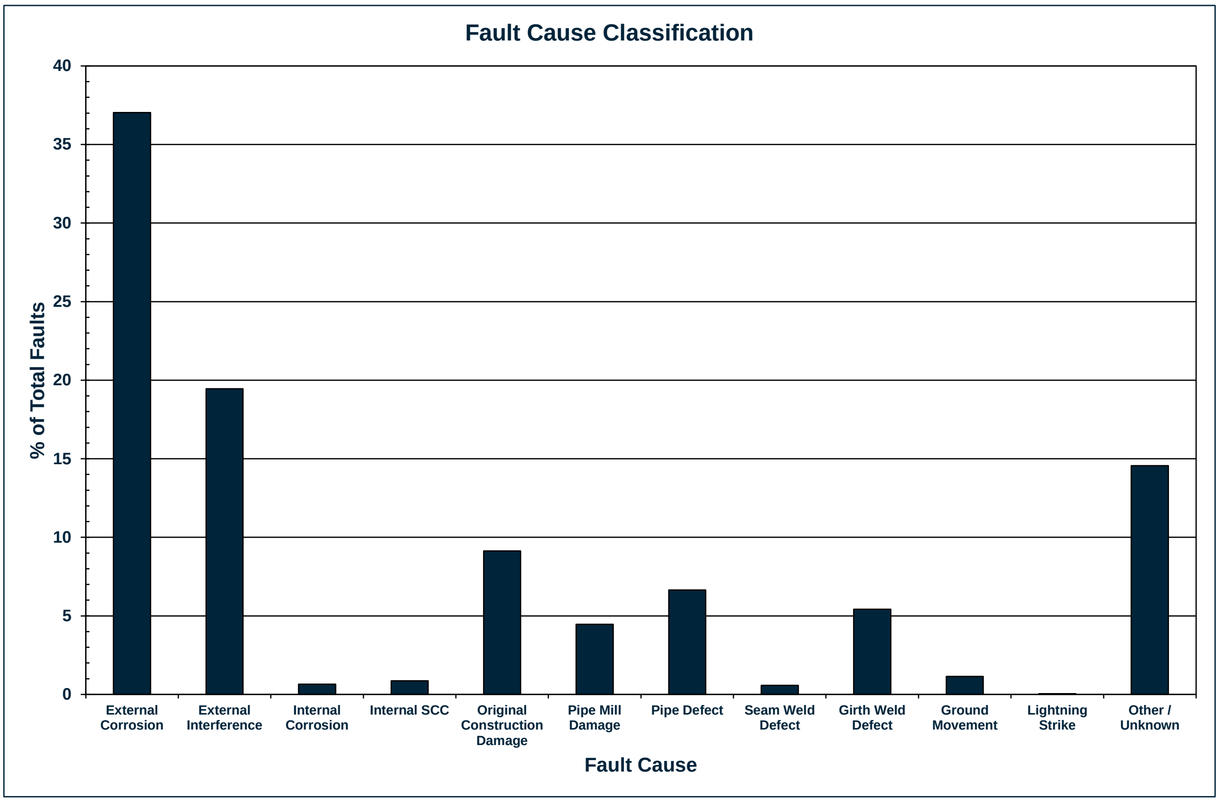

Figure 5.1: Fault Cause Classification

5.1 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 6,629 defects recorded in the period 1962 – 2022 compared to 6,552 in the period 1962 – 2021. The classification of defect data is shown in Figure 5.2.

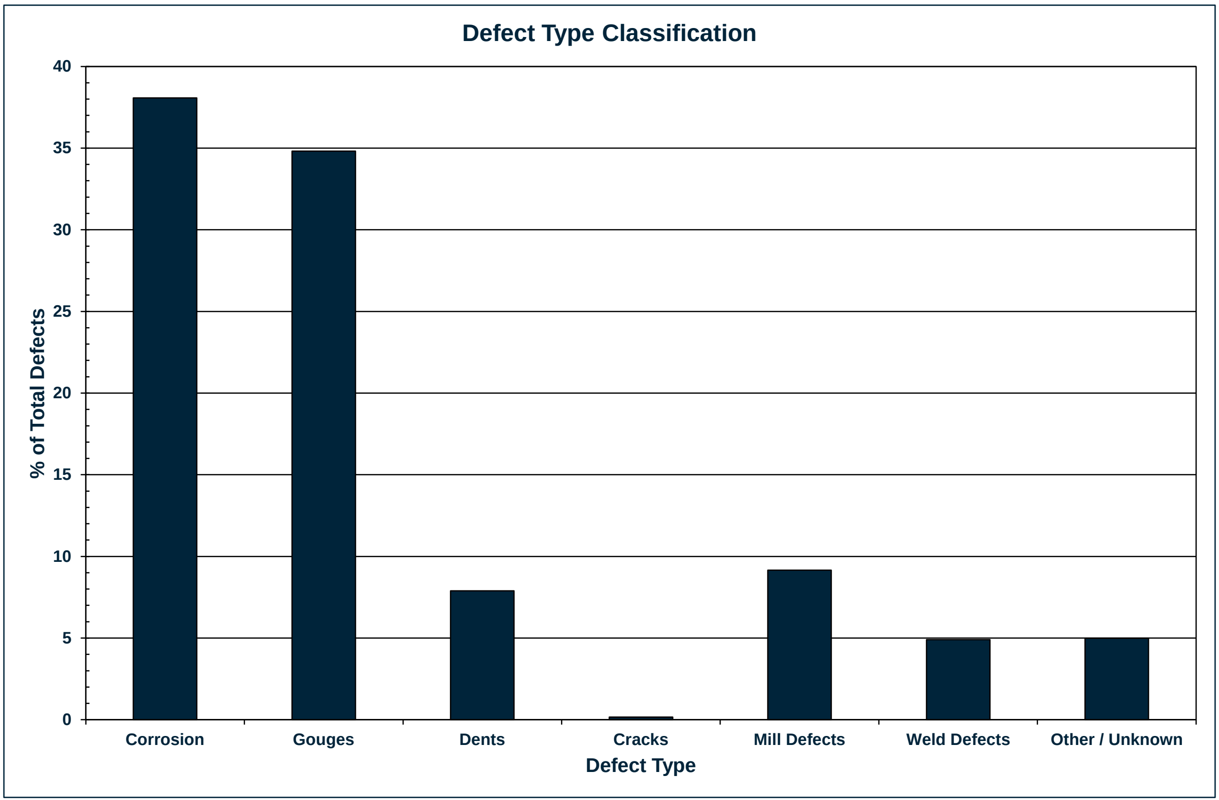

Figure 5.2: Defect Type Classification

5.2 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 [2, 3, 4, 5, 6, 7], use standard pipeline industry 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 from 1962 and up to and including 2016, has been analysed to determine the best fit distribution parameters for the following key parameters [6, 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 1962 – 2016 data are given in Table 5.1.

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	Denting Force (kN)	Lognormal	**μ**	**σ**
			3.969	0.516

Table 5.1: Distribution Parameters for Damage Data (1962 – 2016)

These parameters allow pipeline failure probabilities to be derived for external interference events using recommended models [6, 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.

The next update of the distribution parameters is scheduled to be undertaken following receipt of the 2026 data.

6. REFERENCES

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