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United Kingdom Onshore Pipeline Operators' Association

Title:

UKOPA Pipeline Product Loss Incidents and Faults Report (1962-2014)

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UKOPA PIPELINE FAULT DATABASE

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Pipeline Product Loss Incidents and Faults Report

(1962 - 2014)

Report of the UKOPA **F**ault **A**nd **R**isk **W**ork **G**roup

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 Dr J V Haswell & R A McConnell 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 2014.

Major Accident Hazard Pipelines 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 2014 is 0.219 incidents per 1000 km.year, whilst in the previous report this figure was 0.223 incidents per 1000 km.year (covering the period from 1962 to 2013). The overall trend continues to show a reduction in failure frequency.

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

For the last 5 years the failure frequency is 0.078 incidents per 1000 km.year, whilst in the previous report this figure was 0.105 incidents per 1000 km.year (covering the 5 year period up to the end of 2013). The most recent 5 year failure frequency shows a decrease on the previous rate.

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.

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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 relates to the extent of risk zones adjacent to the pipelines.

Regulators and consultants who carry out risk assessments for UK pipelines have generally 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. UKOPA published the first report in November 2000, presenting the first set of incident 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 Major Accident Hazard Pipelines,
- 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,
- provide the means to test design intentions and determine the effect 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 and failure data are extensive, there are pipeline groups (e.g. large diameter, recently constructed pipelines) on which no failures have occurred; however, it is unreasonable to assume that the failure frequency for these pipelines is zero. Similarly, further pipeline groups exist for which the historical failure data are not statistically significant.

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.

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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 assessing failure rates for quantified risk assessments.

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2 Product System Data

2.1 Exposure

The total length of Major Accident Hazard Pipelines* in operation at the end of 2014 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 22,158 km. The total exposure in the period 1952 to the end of 2014 was 877,598 km.yr; the development of this exposure is illustrated in Figure 1.

Exposure of Pipeline before first recorded incident in 1962 = 3740 km.yr (included in exposure and incident frequency calculations).
Above ground sections of cross-country pipelines are included in totals.

Figure 1

Development of Pipeline Exposure
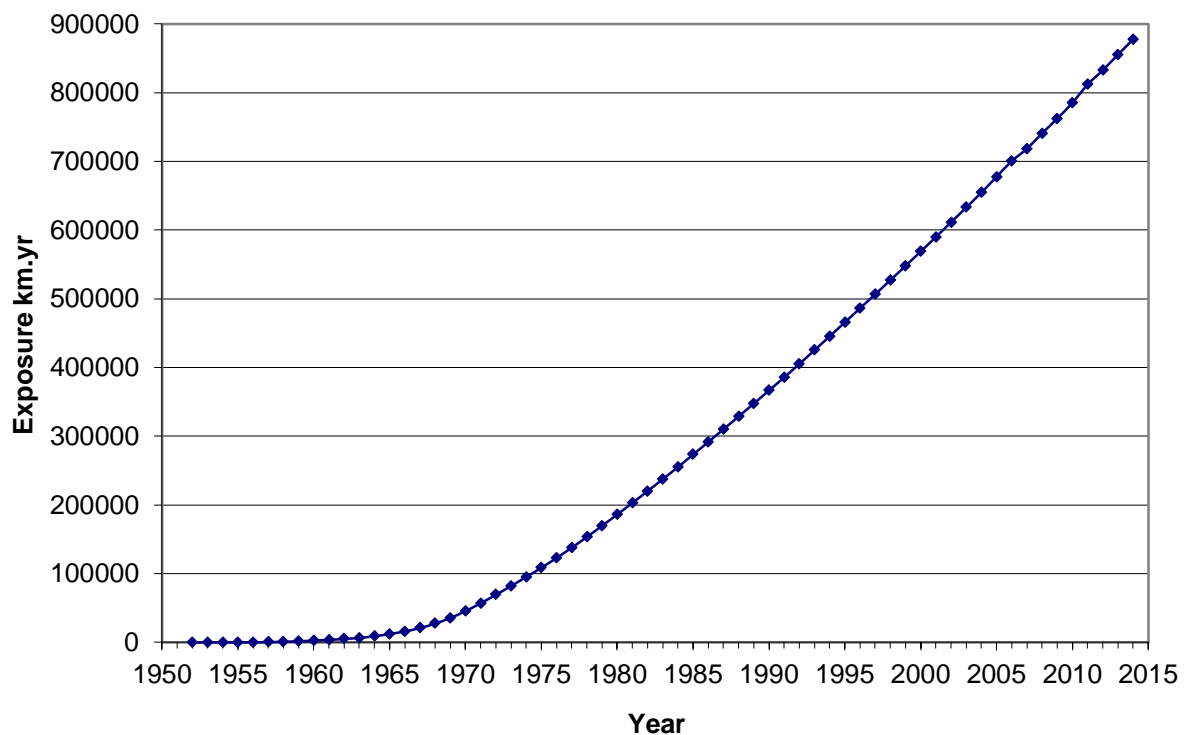
*For definition of Major Accident Hazard Pipelines (MAHPs) – see UK statutory legislation – The Pipelines Safety Regulations 1996 [PSR96], for the full definition – for natural gas the classification is above 8 bar absolute.

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2.2 Transported Products

The lengths (in km) of pipeline in operation at the end of 2014, by transported product, are shown in Table 1 below.

Table 1 - Lengths of Pipeline in Operation

Natural Gas (Dry)	20,388	Propylene	38
Ethylene	1141	Condensate	24
Natural Gas Liquids	251	Propane	20
Crude Oil (Spiked)	224	Butane	20
Ethane	38	**TOTAL**	**22,158**
Hydrogen	14		**kilometres**

Note:- The database includes 855 km of decommissioned pipeline (748 km previously used to transport natural gas, 60 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
- excluding associated equipment (e.g. valves, compressors) or parts other than the pipeline itself

A total of 192 product loss incidents were recorded over the period between 1962 and 2014 compared with 191 product loss incidents documented in the report covering the period to 2013. No product loss incidents were recorded prior to 1962. An annual breakdown of incidents is illustrated in Figure 2.

Figure 2

Annual Number of Product Loss Incidents
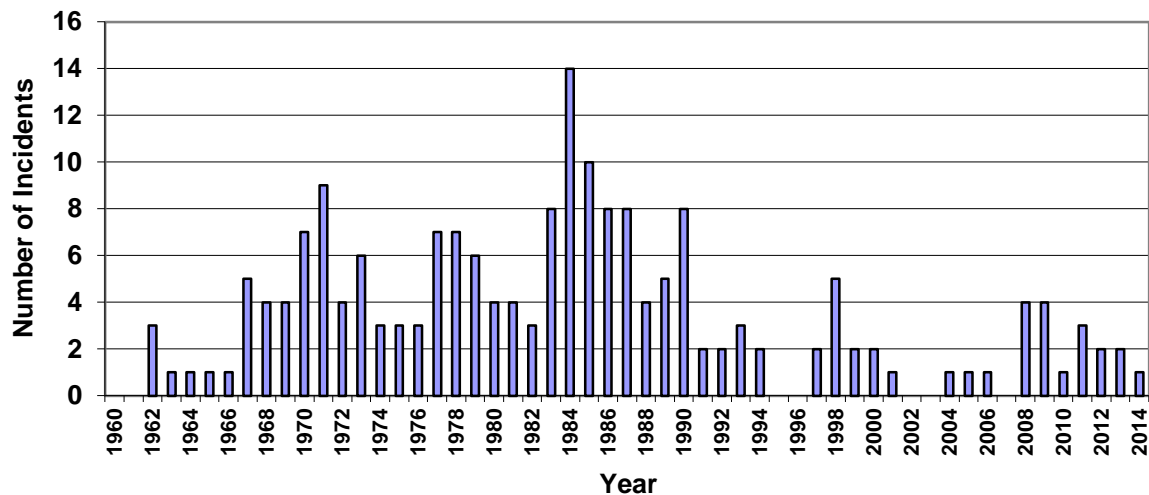
Differences between 2013 and 2014 product loss statistics

One product loss incident was recorded in 2014. This incident was due to external interference, and is still under investigation. The cumulative number of incidents over the period 1962 to 2014 is shown in Figure 3.

Figure 3

Total Number of Product Loss Incidents (Cumulative)

3.1 Incident Ignition

There were 9 out of 192 (4.7%) product loss incidents that resulted in ignition. Table 2 below provides more detail:
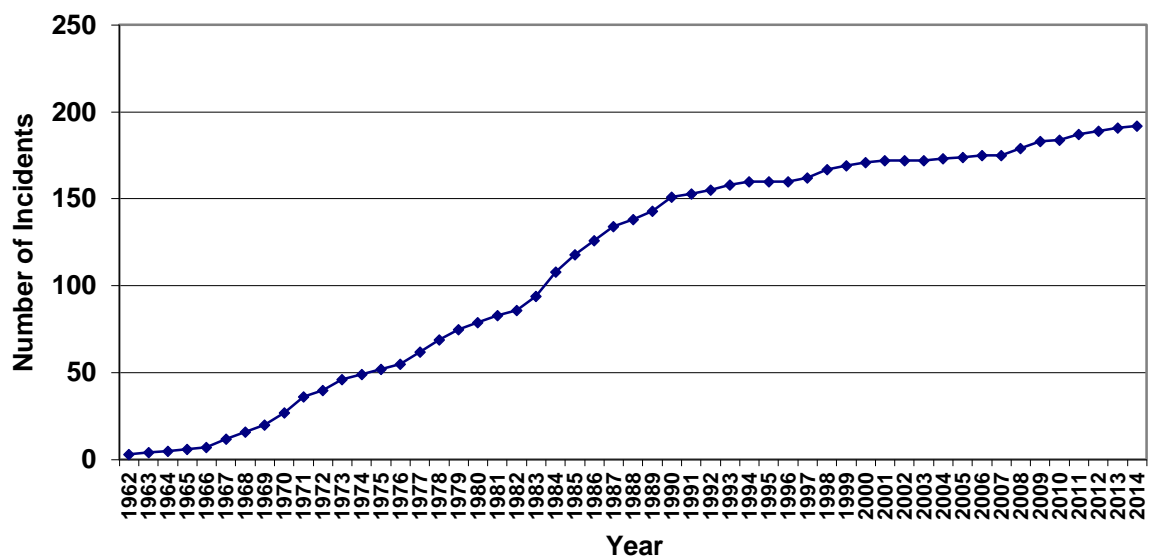
Table 2 – Incidents that Resulted in Ignition

Affected Component	Cause Of Fault	Hole Diameter Class
Pipe	Seam Weld Defect	0 - 6 mm
Pipe	Ground Movement	Full Bore and Above (18" Diameter Pipe)
Pipe	Girth Weld Defect	6 - 20 mm
Pipe	Unknown	6 - 20 mm
Pipe	Pipe Defect	0 - 6 mm
Pipe	Unknown	40 - 110 mm
Pipe	Lightning Strike	0 - 6 mm
Bend	Internal Corrosion	0 - 6 mm
Bend	Pipe Defect	6 - 20 mm

3.2 Incident Frequency

3.2.1 Trends over the Past 5, 20 and 49 Years

The incident frequency over eight consecutive 5-year periods up to the end of 2014 is shown in Table 3.

Table 3 - 5 Year Incident Frequency

Period	Number of Incidents	Total Exposure [km.yr]	Frequency [Incidents per 1000 km.yr]
1965 - 1969	15	26638.54	0.563
1970 - 1974	29	59597.87	0.487
1975 – 1979	26	74485.60	0.349
1980 - 1984	33	85534.15	0.386
1985 - 1989	35	92406.33	0.379
1990 - 1994	17	97839.50	0.174
1995 - 1999	9	102527.26	0.088
2000 - 2004	4	106799.21	0.037
2005 - 2009	10	107617.92	0.093
2010 – 2014	9	115248.38	0.078

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The overall incident frequency by hole size over the period 1962 - 2014 is shown in Table 4.

Table 4

Equivalent Hole[#] Size Class	Number of Incidents	Frequency [Incidents per 1000 km.yr]
Full Bore* and Above	7	0.008
110mm – Full Bore*	4	0.003
40mm – 110mm	7	0.008
20mm – 40mm	23	0.026
6mm – 20mm	31	0.035
0 – 6mm	118	0.134
Unknown	2	0.002
Total	192	0.219

* 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 1995-2014 is 429,801 km.years and the resulting incident frequency is shown in Table 5.

Table 5

Hole Size Class	Number of Incidents	Frequency [Incidents per 1000 km.yr]
Exposure	1995-2014	429801
Full Bore* and Above	0	0
110mm – Full Bore*	1	0.023
40mm – 110mm	0	0.000
20mm – 40mm	5	0.012
6mm – 20mm	5	0.012
0 – 6mm	21	0.049
Unknown	0	0.000
Total	32	0.074

The failure frequency over the last 20 years is therefore 0.074 incidents per 1000 km.years and for the last 5 years (2010-2014) is 0.078 incidents per 1000 km.yr.

These compare with the failure frequency during the period 1962-2014 of 0.219 incidents per year per 1000 km.yr. An overview of the development of this failure frequency over the period 1962 to 2014 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 (2010-2014, 2009-2013, 2008-2012 etc.).

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Figure 4

Development of Overall Incident Frequency
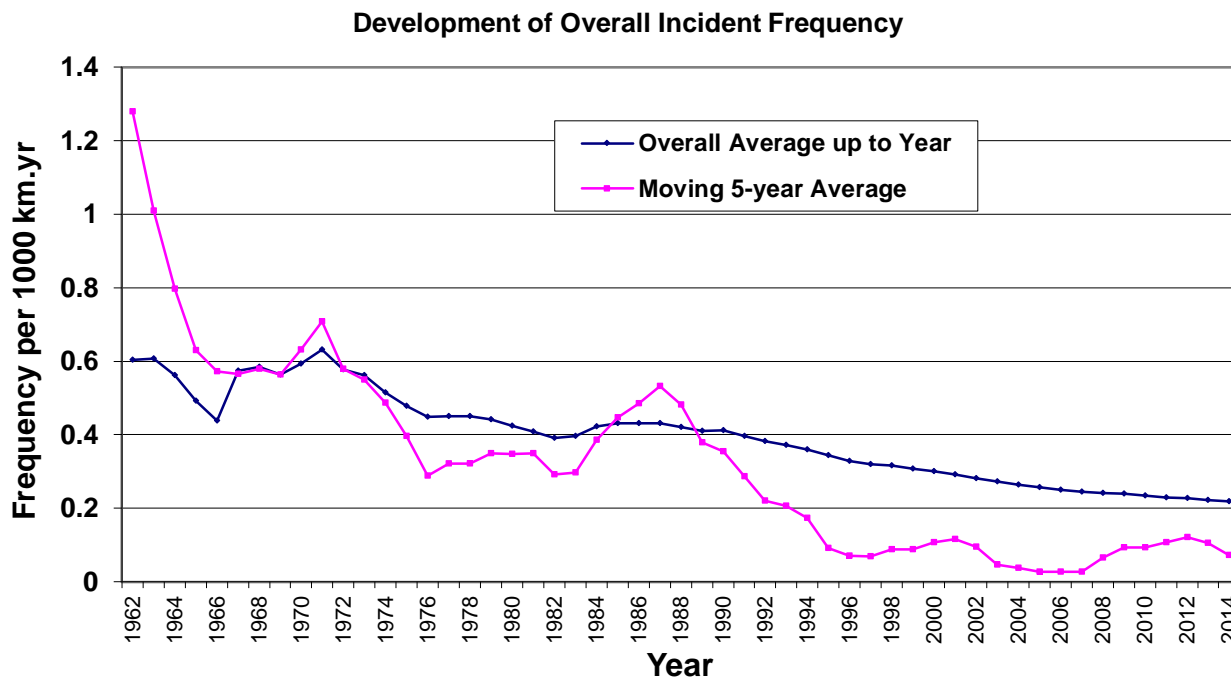
3.2.2 Confidence Intervals

Confidence intervals take uncertainty into account. The greater the exposure, the smaller the confidence interval which shows that uncertainty decreases as more operating experience is gained. To calculate the confidence intervals, the population is assumed to have a known distribution.

Failure events generally follow a random distribution so it is assumed that a Poisson distribution can be applied. The 95% confidence intervals for the overall average failure frequency are shown in Figure 5, and for the 5-year average in Figure 6.
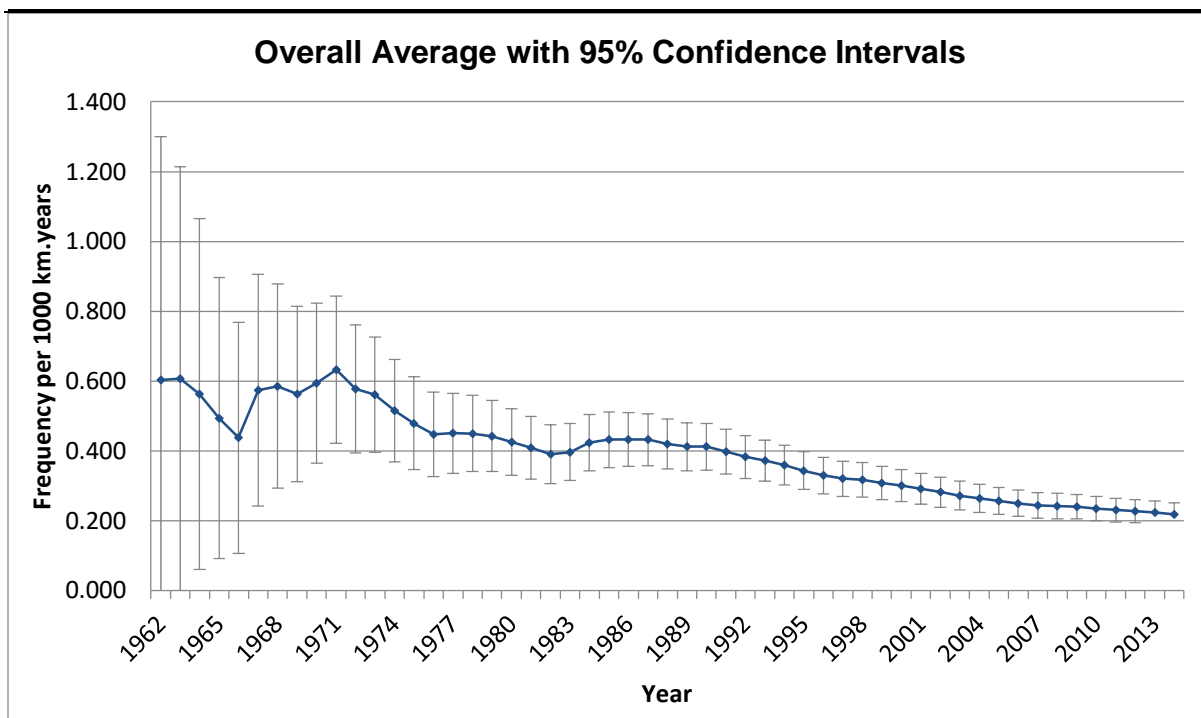
Figure 5

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Overall Average with 95% Confidence Intervals

Figure 5 shows that the overall frequency for the whole period is 0.219 per 1000 km.years +/- 0.032.

Figure 6

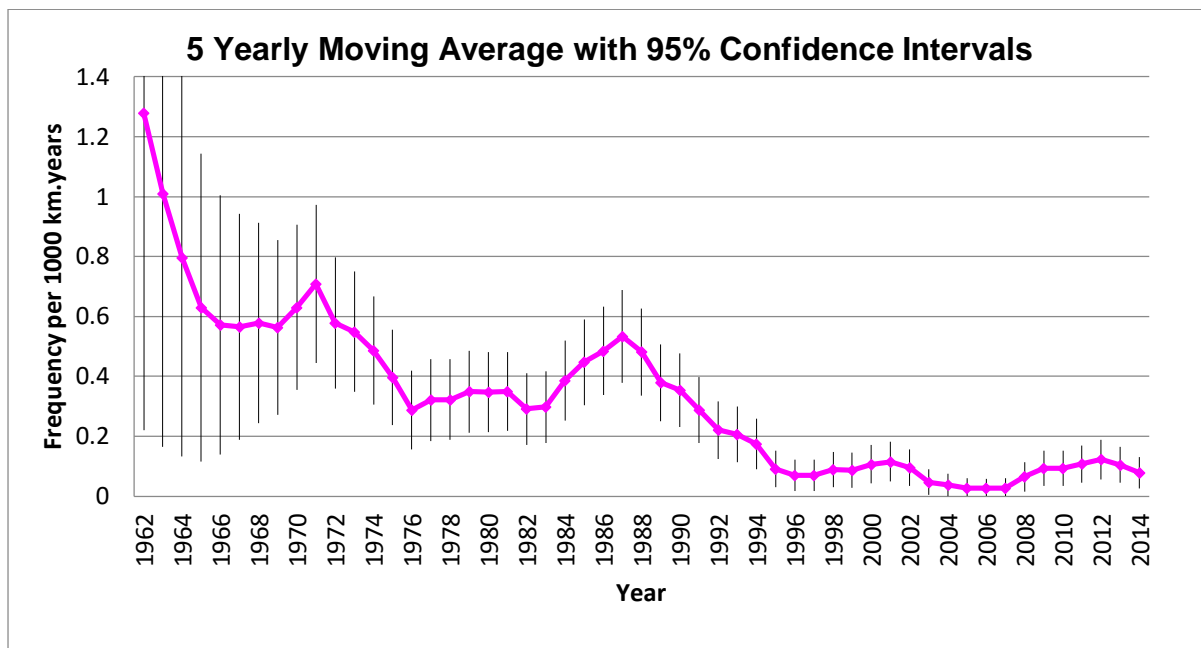**5 Yearly Moving Average with 95% Confidence Intervals**

Figure 6 shows that the 5-year average failure frequency for 2010-2014 is 0.078 per 1000 km.years +/- 0.052.

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3.3 Incident Frequency by Cause

The development of product loss incident frequency by cause is shown in Figure 7.

Figure 7

Development of Incident Frequency by Cause
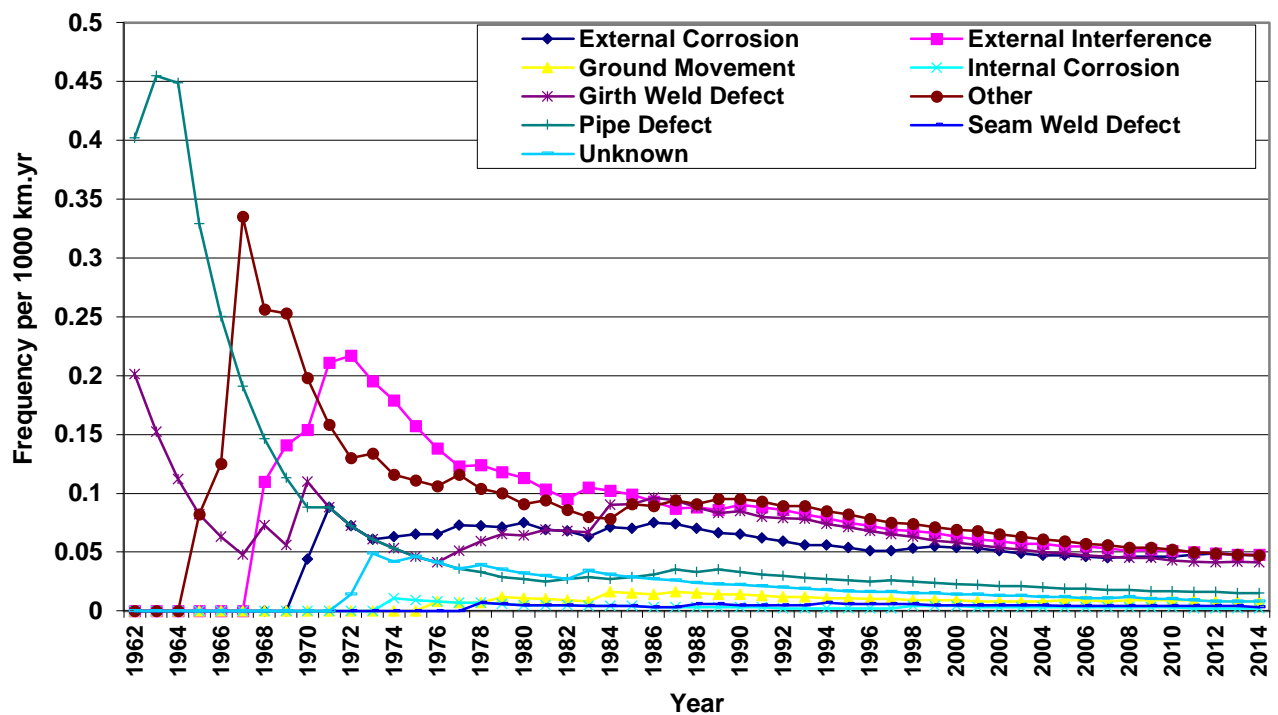
Table 6 – Product Loss Incidents by Cause

Product Loss Cause	No. of Incidents
Girth Weld Defect	36
External Interference	42
Internal Corrosion	2
External Corrosion	41
Unknown	7
Other	41
Pipe Defect	13
Ground Movement	7
Seam Weld Defect	3
Total	**192**

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
Total	**41**

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Figure 8 shows the product loss incident frequency by cause over the period 1962-2014 compared with the frequency over the last 5 years (2010-2014).

Figure 8

Historical and Recent Failure Frequencies
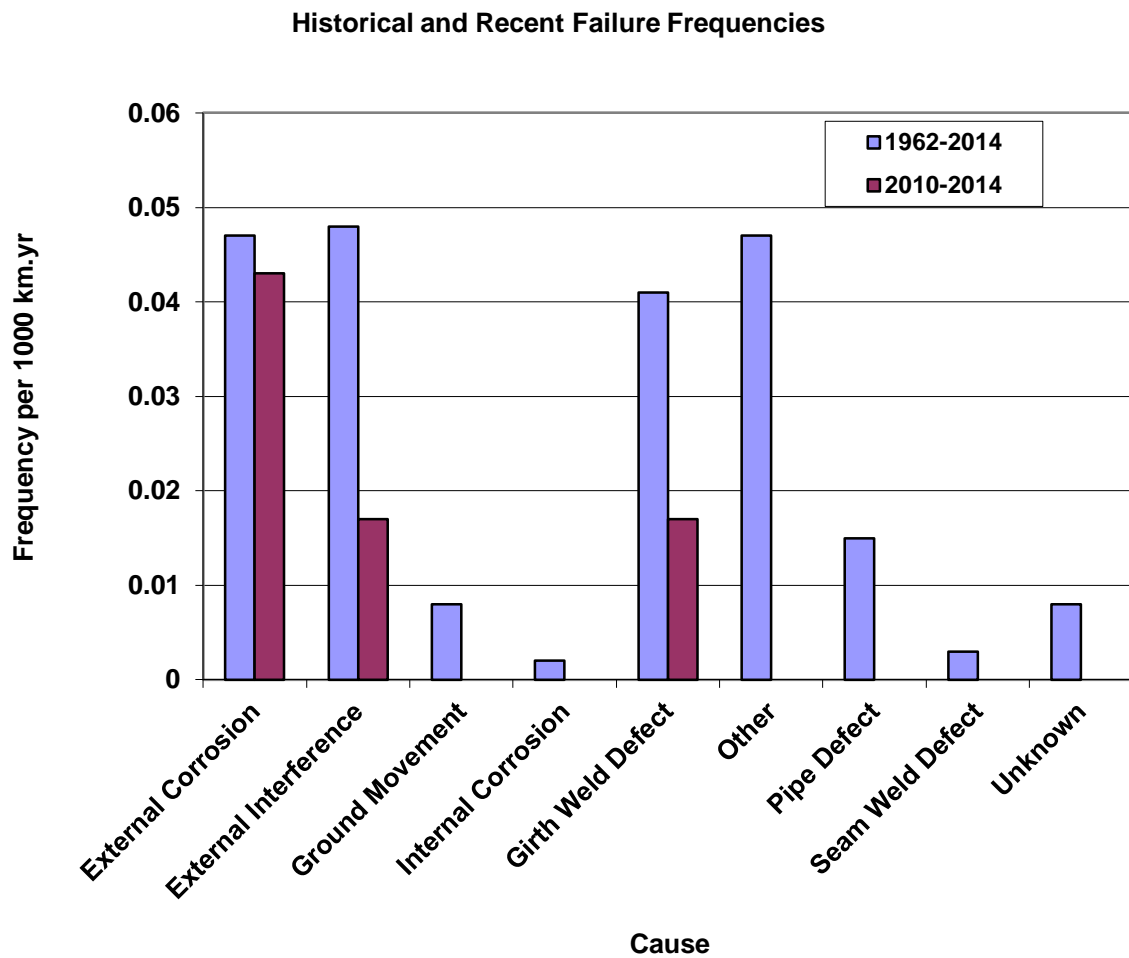
An overview of the product loss incident frequency by cause and size of leak in the period 1962 to 2014 is shown in Figure 9.

Figure 9

Product Loss Incidents by Cause and Equivalent Hole Diameter
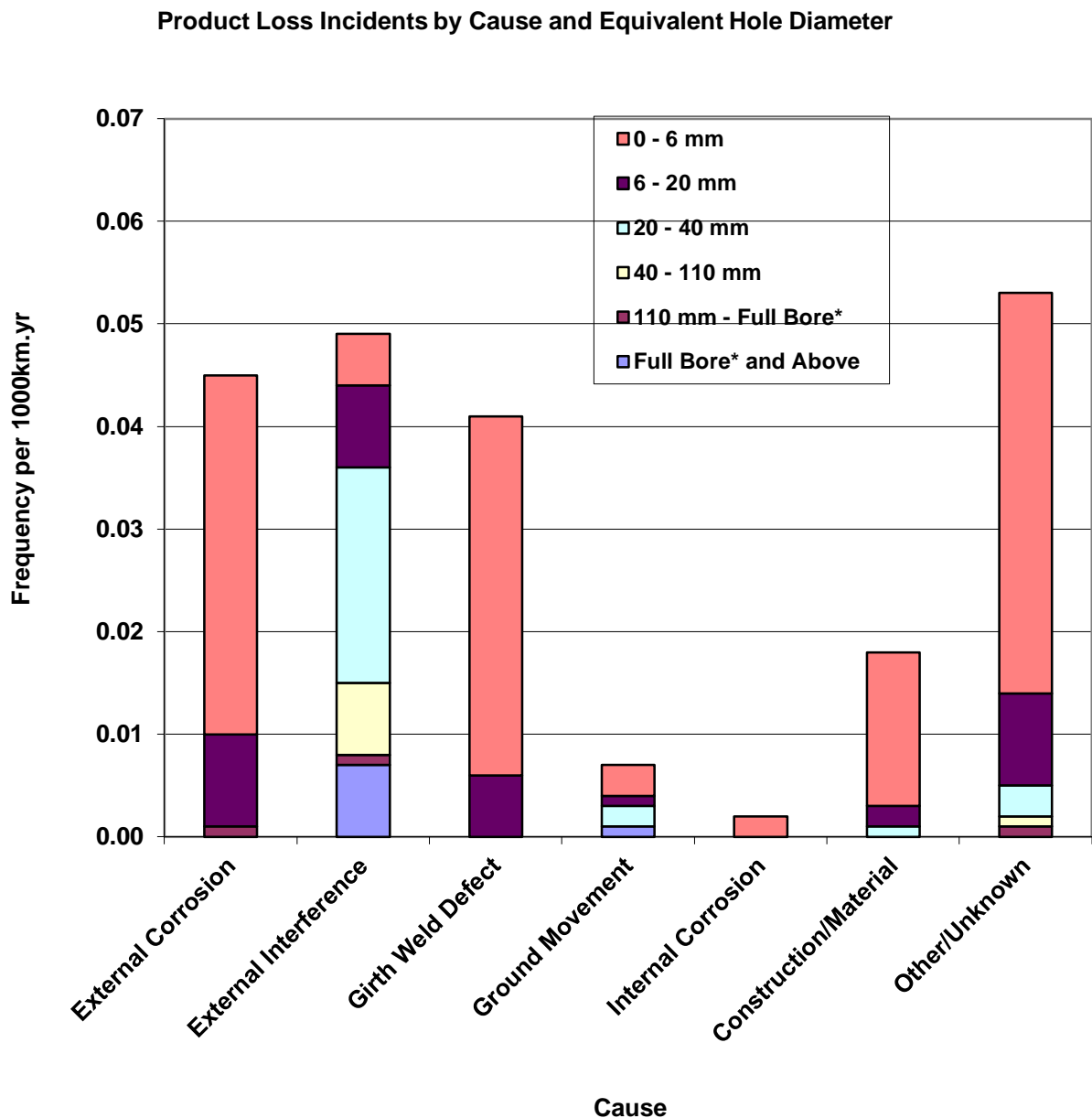
Construction/Material = Seam Weld Defect + Pipe Defect + Pipe Mill Defect + Damage during Original Construction

* Full Bore ≡ diameter of pipeline
 # Equivalent hole diameter is the circular hole diameter in mm with an area equivalent to the observed (usually non-circular) hole size

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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.

Figure 10

Number of Girth Weld Defects by Year of Construction and Equivalent Hole Diameter
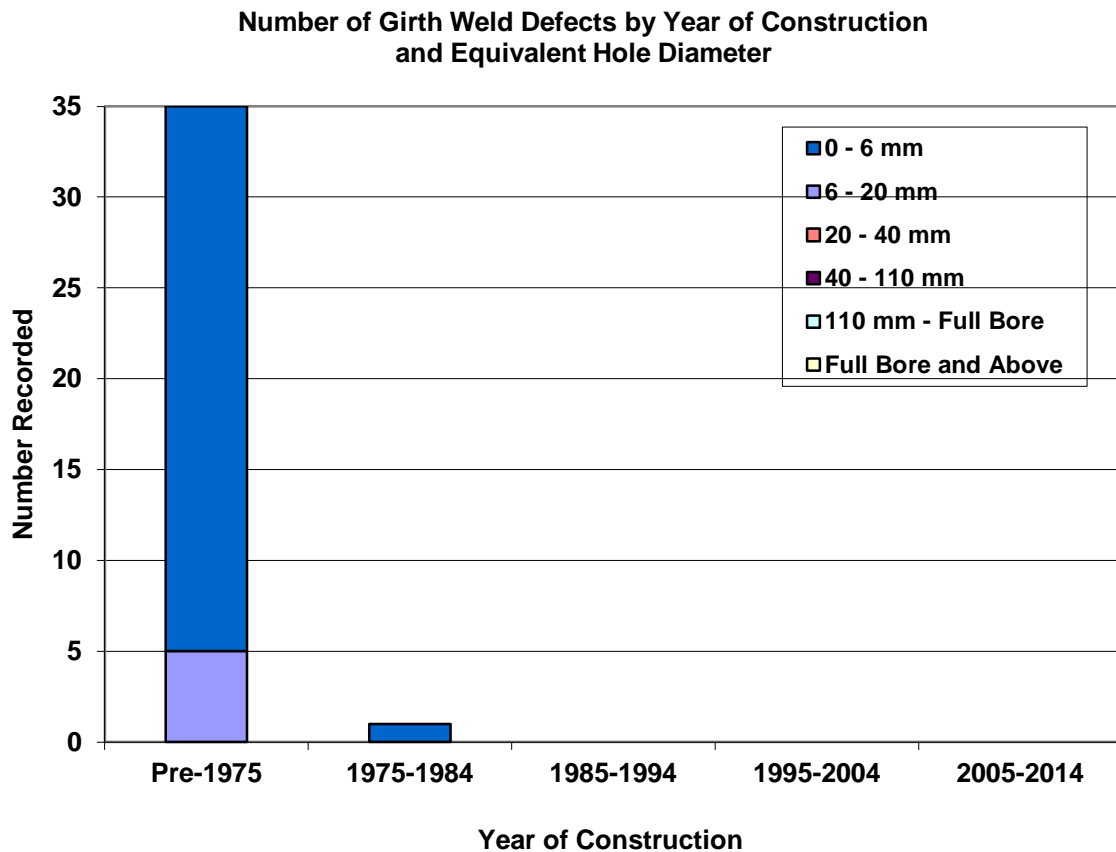
The reduction in the number of girth weld defects in pipelines constructed after 1972 is associated with the improvements in field weld inspection and quality control procedures, and the increasing capability of in line inspection tools to detect girth weld anomalies.

3.4 External Interference

External interference is one of the main causes of product loss incidents with 41 recorded failures attributable to this cause.

3.4.1 External Interference by Diameter Class

Figure 11 shows the product loss incident frequencies associated with external interference by diameter class and by hole size.

Figure 11
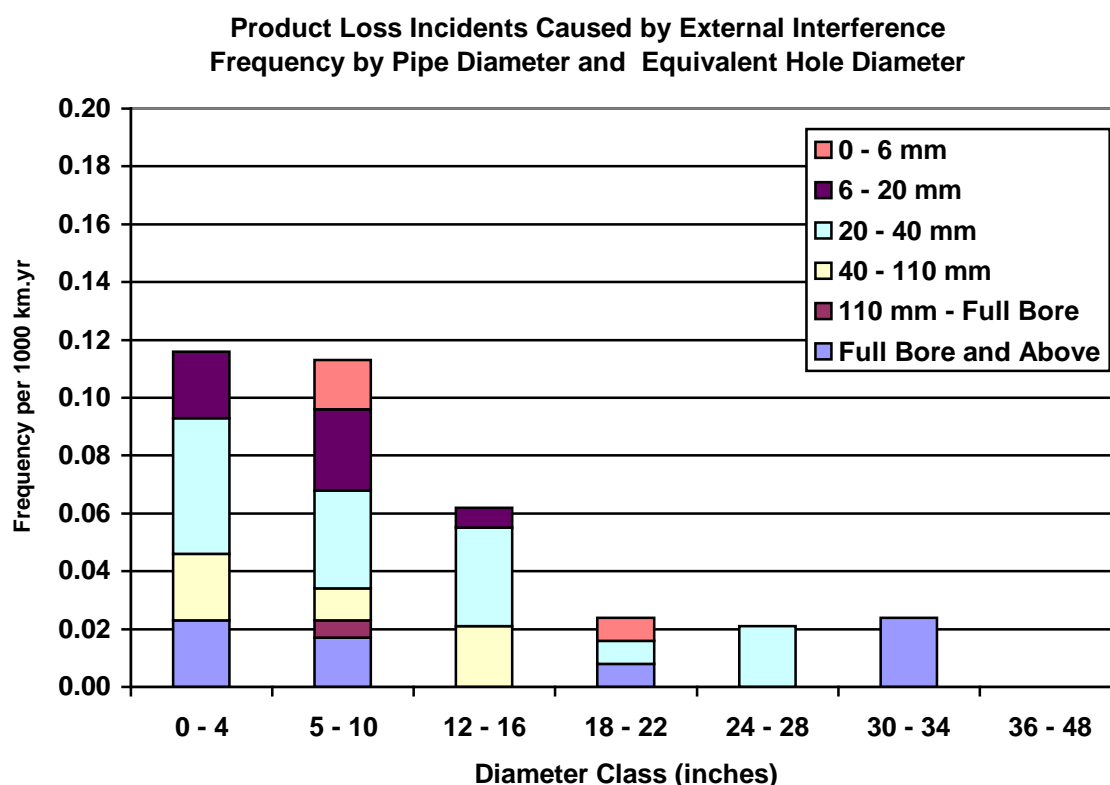
Table 7 – Exposure by Diameter Class

Diameter [inches]	Exposure [km.yr]	External Interference Incidents	Frequency [per 1000km.yr]
0-4	42902	5	0.117
5-10	178483	21	0.118
12-16	145896	9	0.062
18-22	126824	3	0.024
24-28	141312	3	0.021
30-34	41930	1	0.024
36-48	200251	0	0.000
Total	877598	41	0.047

3.4.2 External Interference by Measured Wall Thickness Class

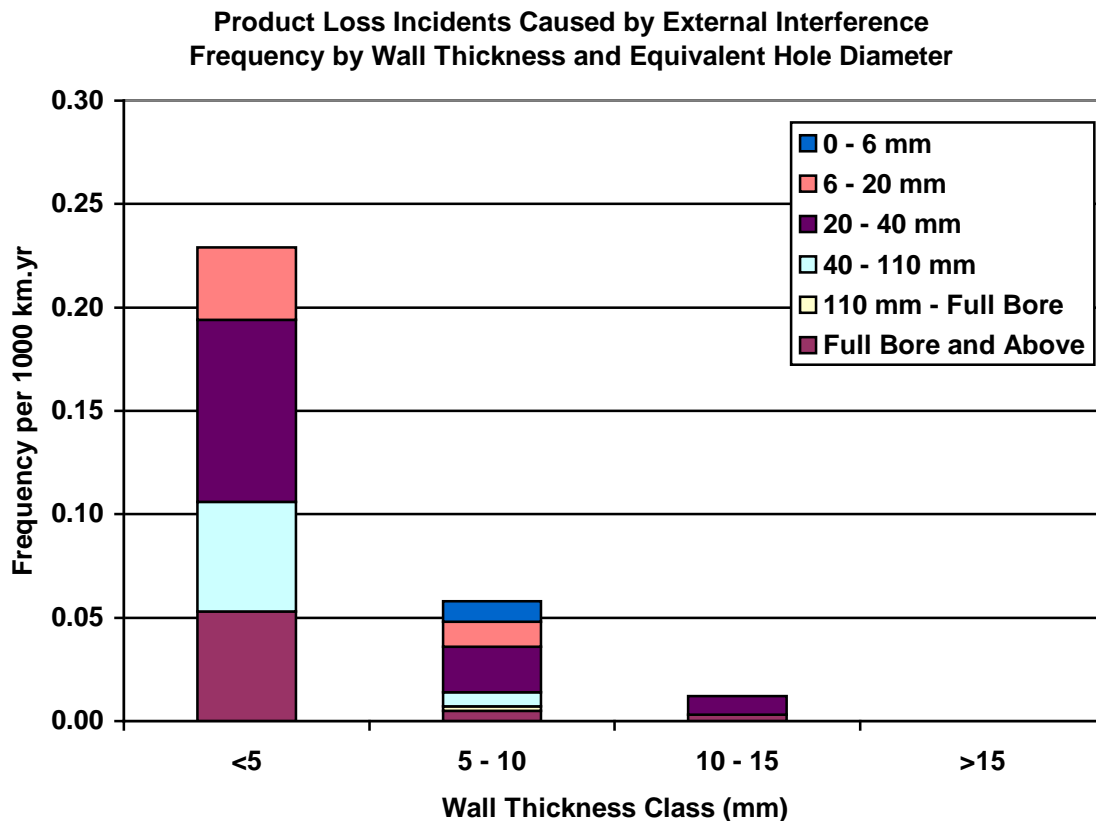The relationship between product loss incidents caused by third party interference and wall thickness is shown in Figure 12.

Figure 12

Note: Largest wall thickness for loss of product incident caused by external interference to date is 12.7mm.

Table 8 – Exposure by Wall Thickness Class

Wall Thickness [mm]	Exposure [km.yr]	External Interference Incidents	Frequency [per 1000 km.yr]
<5	56585	13	0.230
5-10	412050	25	0.061
10-15	336816	4	0.012
>15	72145	0	0.000
Total	877597	42	0.048

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3.4.3 External Interference by Area Classification

Figure 13

**Product Loss Incidents Caused by External Interference
Frequency by Area Classification and Equivalent Hole Diameter**
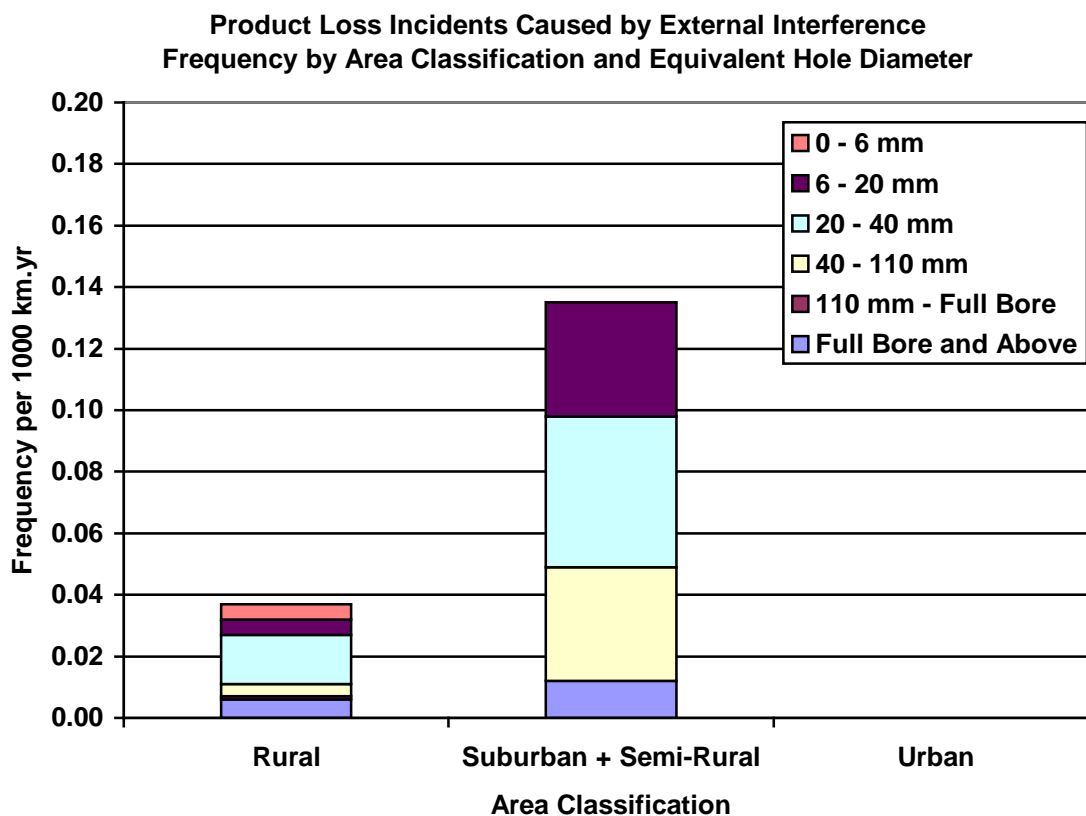
Table 9 – Exposure by Area Classification in km.yr

Area Classification	Exposure [km.yr]	External Interference Incidents	Frequency [per 1000 km.yr]
Rural	795069	31	0.039
Suburban	81352	11	0.135
Urban	1175	0	0.000
Total	877597	42	0.048

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

3.5 External Corrosion

3.5.1 External Corrosion by Wall Thickness Class
Figure 14

**Product Loss Incidents Caused by External Corrosion
Frequency by Wall Thickness and Equivalent Hole Diameter**

Legend:
- 0 - 6 mm
- 6 - 20 mm
- 20 - 40 mm
- 40 - 110 mm
- 110 mm - Full Bore
- Full Bore and Above

X-axis: Wall Thickness Class (mm) — <5, 5 - 10, 10 - 15, >15
Y-axis: Frequency per 1000 km.yr

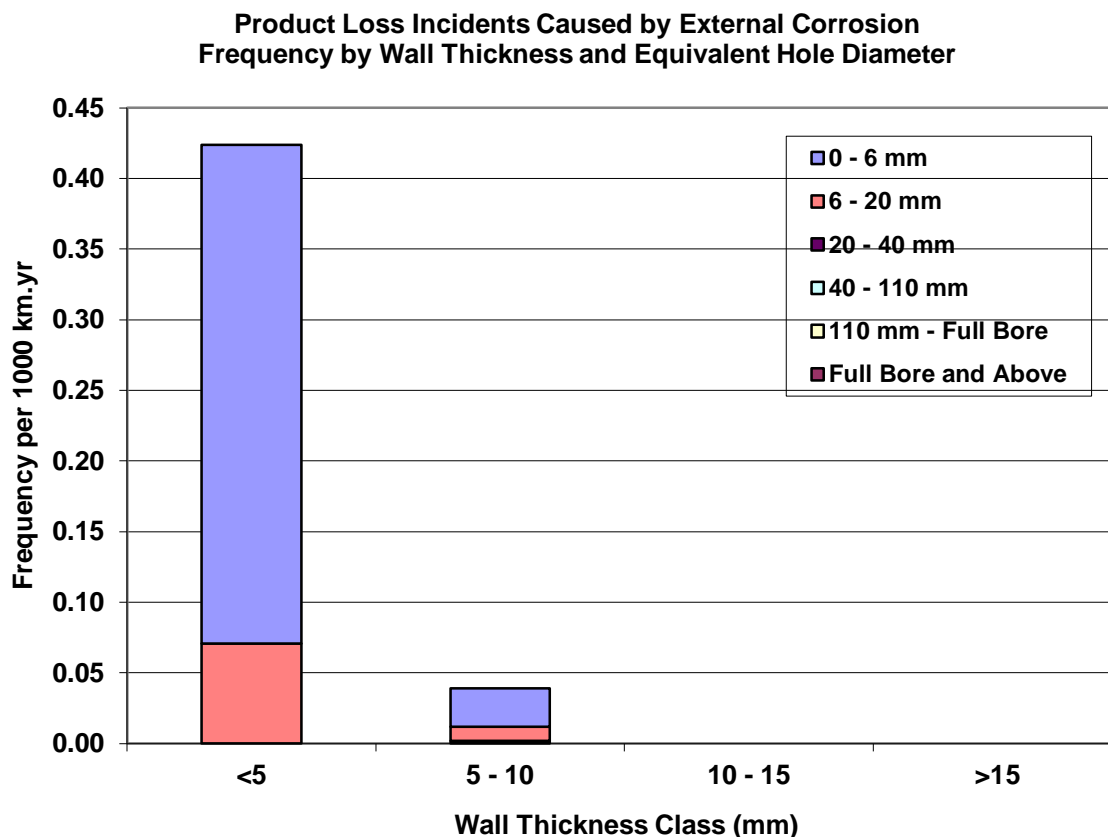**Table 10 – Exposure by Wall Thickness Class**

Wall Thickness [mm]	Exposure [km.yr]	External Corrosion Incidents	Frequency [per 1000 km.yr]
<5	56585	24	0.424
5-10	412050	16	0.039
10-15	336816	0	0.000
>15	72145	0	0.000
Total	877597	40	0.046

Note – one corrosion leak wall thickness size is unknown.

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3.5.2 External Corrosion by Year of Construction

Figure 15

Product Loss Incidents Caused by External Corrosion
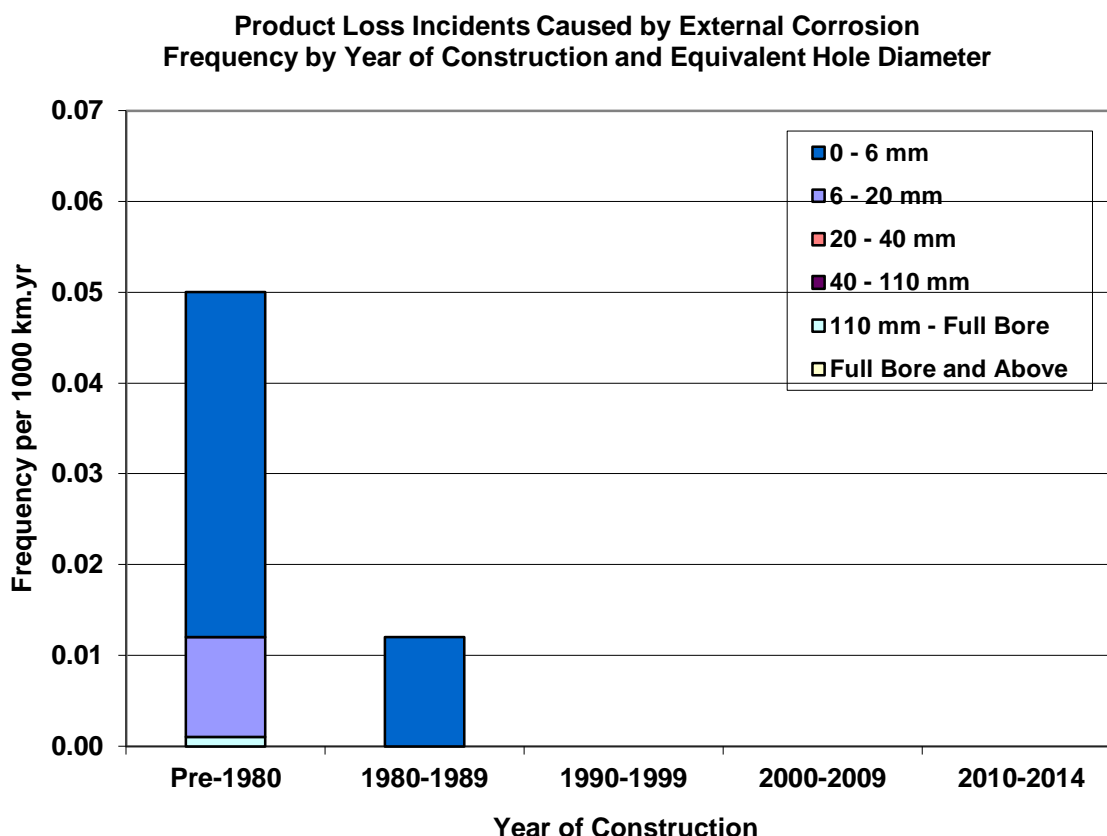Frequency by Year of Construction and Equivalent Hole Diameter

Table 11 – Exposure by Year of Construction

Construction Year	Exposure [km.yr]	External Corrosione Incidents	Frequency /[per 000 km.yr]
Pre-1980	728518	37	0.051
1980-1989	85860	1	0.012
1990-1999	42285	0	0.000
2000-2009	20592	0	0.000
2010-2014	341	0	0.000
	877597	38	0.043

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 defect are detected and repaired before developing to through-wall product loss incidents.

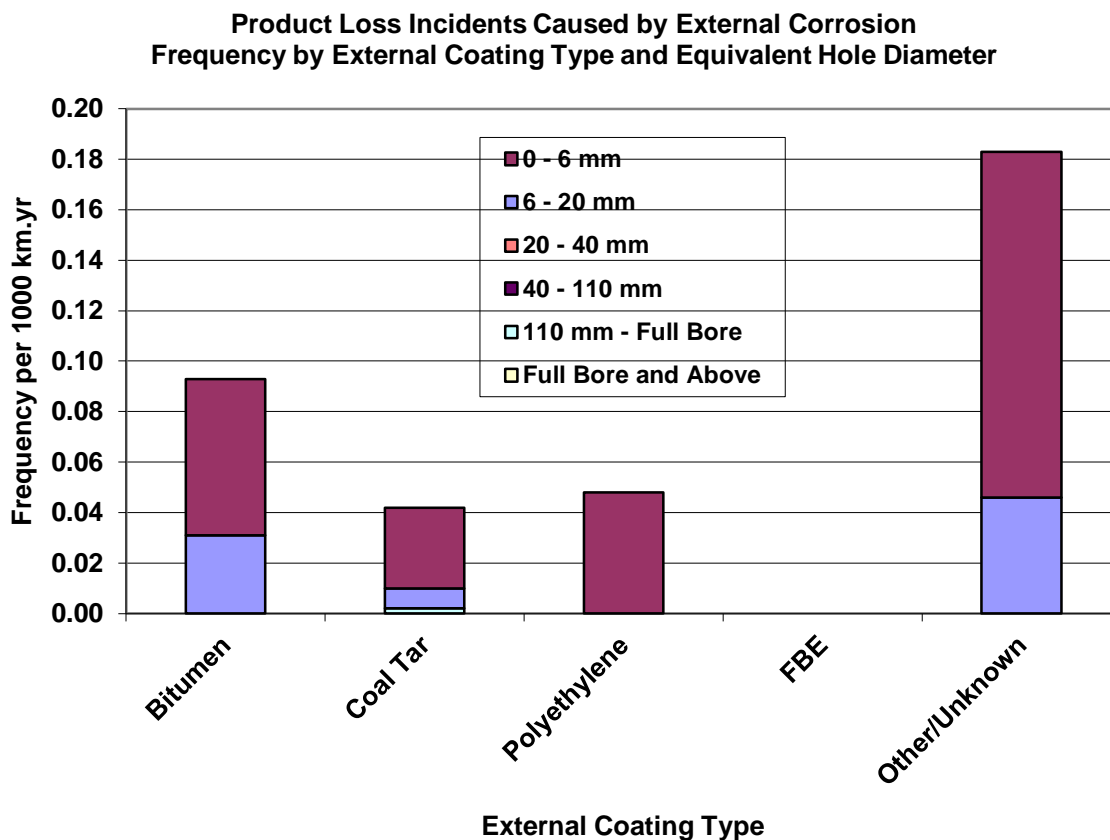### 3.5.3 External Corrosion by External Coating Type

Figure 16

**Product Loss Incidents Caused by External Corrosion
Frequency by External Coating Type and Equivalent Hole Diameter**

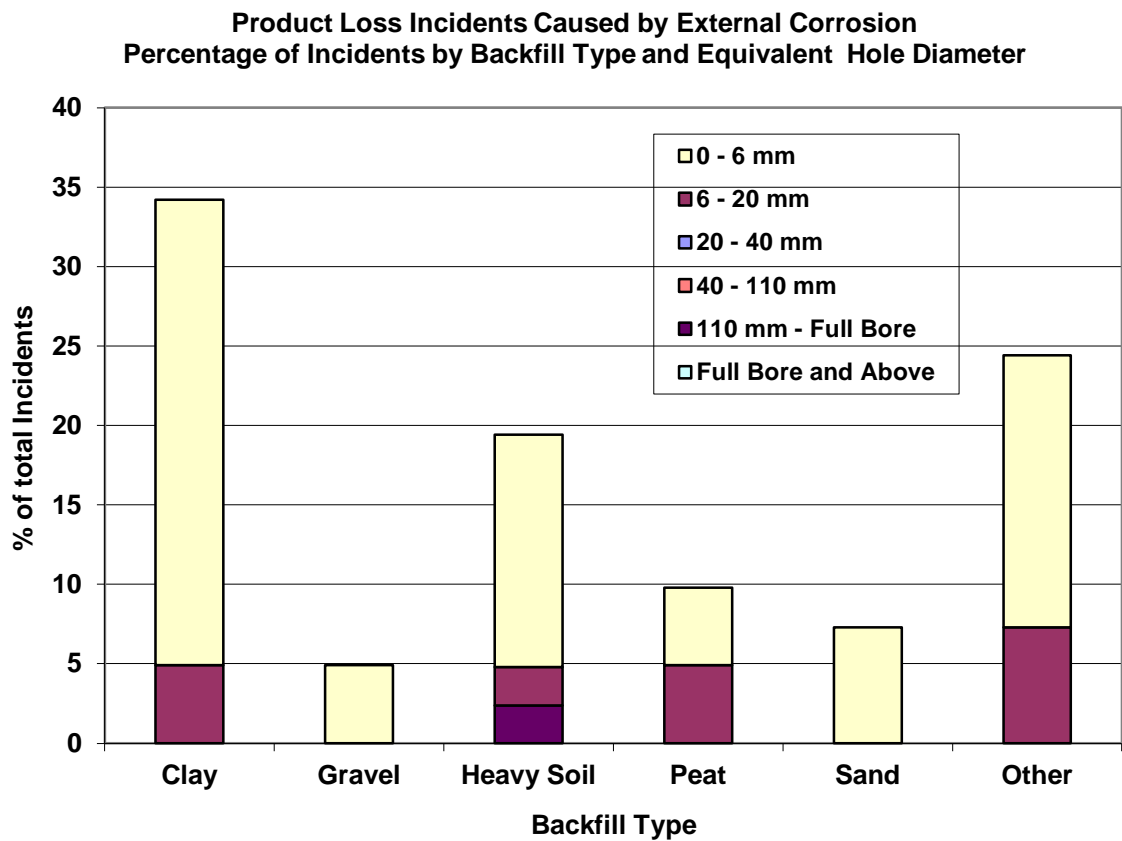**Table 12 – Exposure by External Coating Type**

External Coating	Exposure [km.yr]	External Corrosion Incidents	Frequency [per 1000 km.yr]
Bitumen	32373	3	0.093
Coal Tar	623828	26	0.042
Polyethylene	84112	4	0.048
FBE	93345	0	0.000
Other/Unknown	43939	8	0.182
Total	877597	41	0.047

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3.5.4 External Corrosion by Type of Backfill

Figure 17

Product Loss Incidents Caused by External Corrosion
Percentage of Incidents by Backfill Type and Equivalent Hole Diameter

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3.6 Pipeline Failure Classified as "Other"

Pipeline failure rates 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:-

Table 13 – Pipeline Failures Classified as "Other"

| 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
Total	**41**

The UKOPA product loss data indicates that "Other" causes account for approximately 21% of the total failure rate.

88% (36 out of 41) 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.

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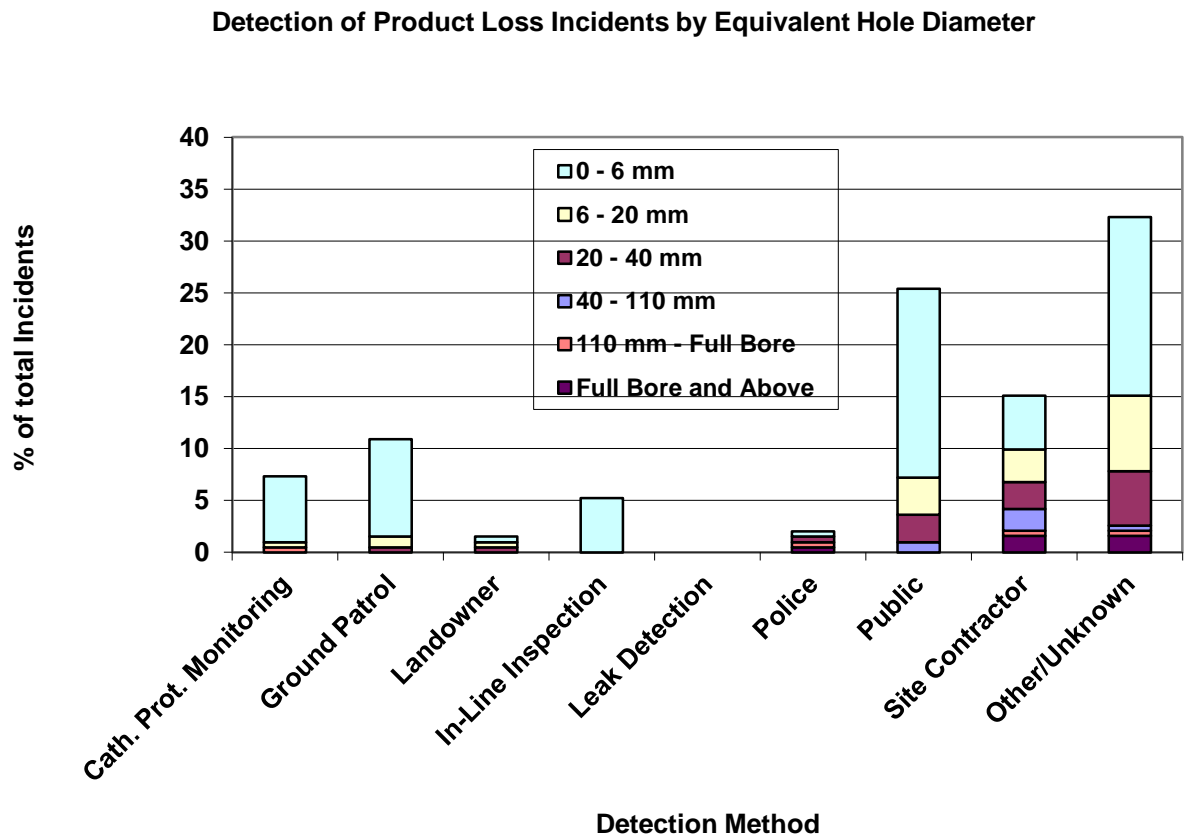## 3.7 Pipeline Failures Caused by Internal Cracking

A significant proportion of the failures classified as "Other" (30 out of 41 = 73%) were caused by internal cracking (stress corrosion cracking [SCC]) in pipelines which had seen wet towns gas (pre-natural gas) service. 93% of these failures (28 out of 30) were in pipelines constructed before 1972.

Figure 18

Number of Failures caused by Internal SCC by Year of Construction and Equivalent Hole Diameter
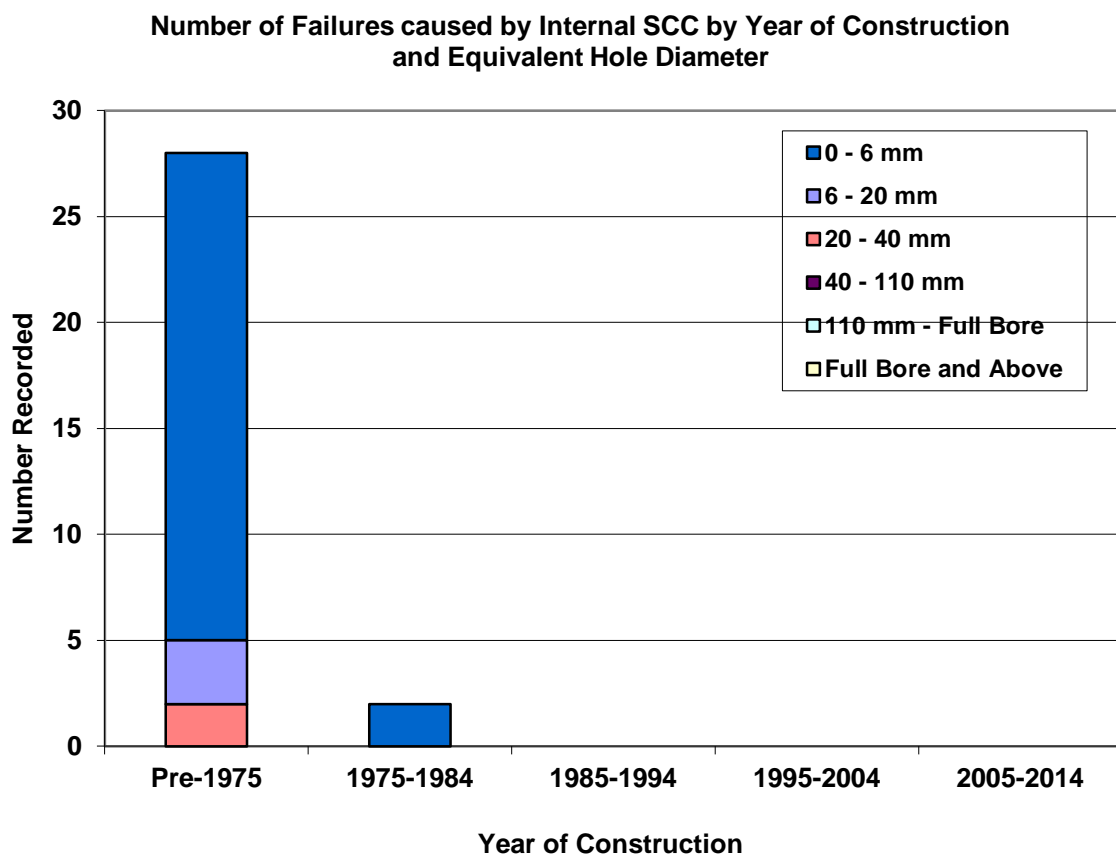
3.8 Detection of Pipeline Failures

Figure 19

Detection of Product Loss Incidents by Equivalent Hole Diameter

*Note: Leak detection and In-Line Inspection (ILI) are not applicable to all pipelines.*

4 Fault Data

4.1 Pipeline Damage Data

A Fault is a feature that has been confirmed by field investigation, excavation and measurement. 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 Faults recorded for the period 1962 - 2014 was 3545. The main causes of the Faults are shown in Figure 20.

**Figure 20**

Fault Cause Classification

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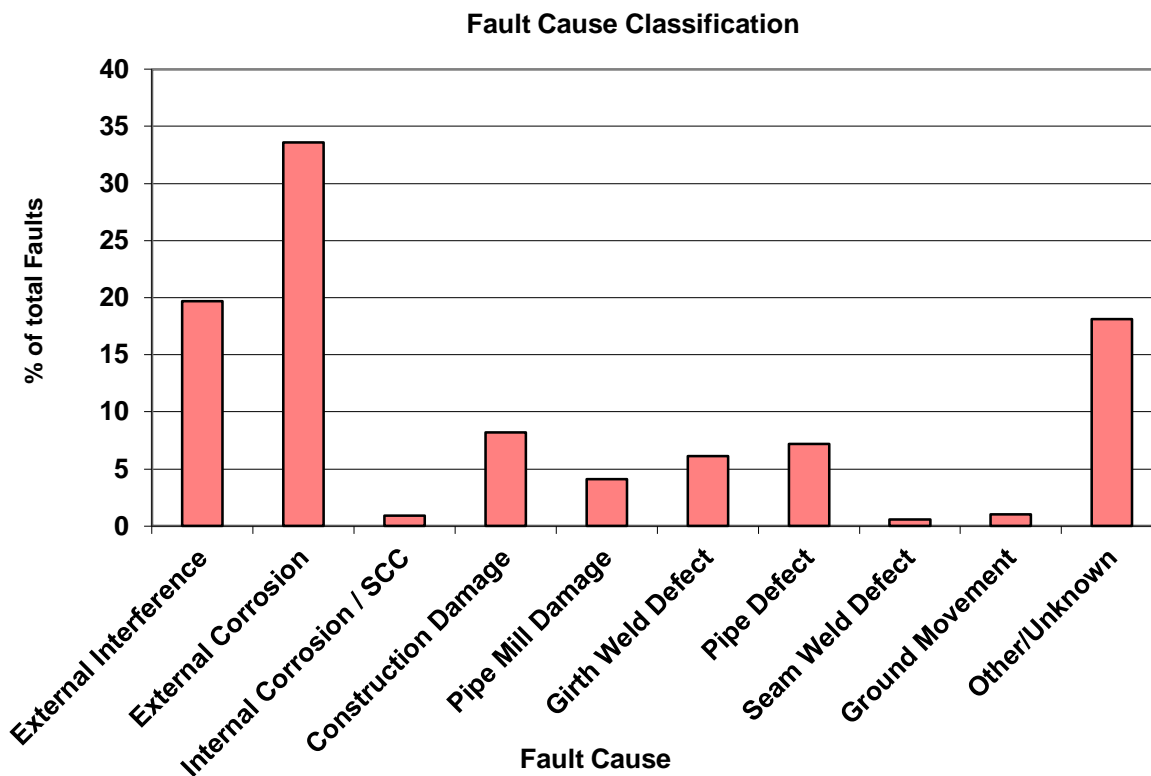
4.2 Part-Wall Defect Data

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 5700 defects recorded in the period 1962 - 2014.

Classification of defect data is shown in Figure 21.

Figure 21

Defect Type Classification
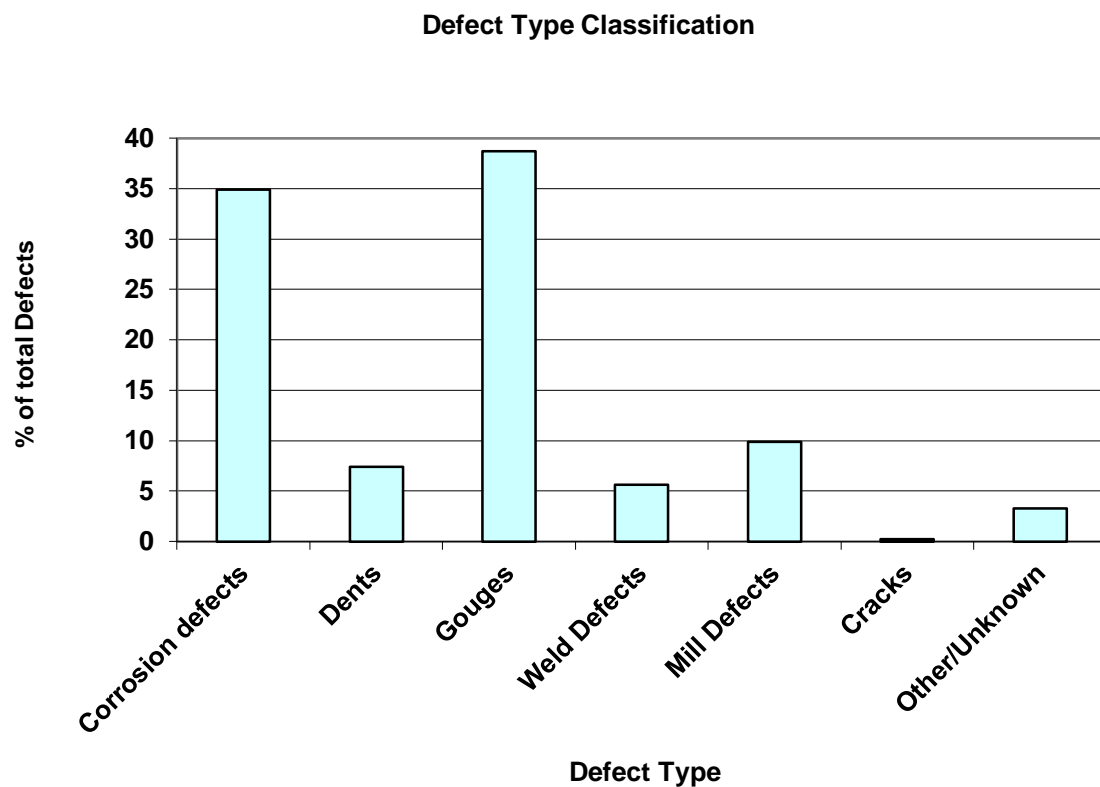
4.3 Statistical Distributions of Defect Dimensions

Pipeline damage due to external interference occurs in the form of gouges, dents or combinations of these. 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 (1,2,3,4) 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 combinations of these), 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. The parameters have not yet been updated to include the 2011 – 2014 data, which includes an additional 35 faults and 72 associated defects due to external interference. UKOPA will update these parameters at periodic intervals.

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

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

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 frequencies to be calculated. "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 kmyrs.

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

1   A Methodology for the prediction of Pipeline Failure Frequency Due to External Interference. C Lyons, J V Haswell, P Hopkins, R Ellis, N Jackson. IPC 2008-64375, 7th International Pipeline Conference, Calgary 2008.

2   Reduction Factors for Estimating the Probability of failure of Mechanical Damage Due to External Interference. A Cosham, J V Haswell, N Jackson. IPC 2008-64345, 7th International Pipeline Conference, Calgary 2008.

3   Modelling of Dent and Gouges, and the Effect on the Failure Probability of Pipelines. P Seevam, C Lyons, P Hopkins, M Toft. IPC 2008-64061, 7th International Pipeline Conference, Calgary 2008.

4   The Application of Risk Techniques to the Design and Operation of Pipelines. I Corder. C502/016/95, Proceedings of International Conference on Pressure Systems: Operation and Risk Management, Institution of Mechanical Engineers, London, UK, p. 113-125. 1995.

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