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United Kingdom Onshore Pipeline Operators' Association

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UKOPA Pipeline Product Loss Incidents and Faults Report (1962-2013)

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R A McConnell & Dr J V Haswell

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UKOPA PIPELINE FAULT DATABASE

Pipeline Product Loss Incidents and Faults Report

(1962 - 2013)

Report of the UKOPA **F**ault **D**atabase **M**anagement **G**roup

Comprising:

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 R A McConnell & Dr J V Haswell for FDMG

Report Reference: UKOPA/14/0031
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UKOPA

Comments, questions and enquiries about this publication should be directed to the UKOPA Pipeline Fault Database Working Group Chairman:

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

e-mail: enquiries@ukopa.co.uk

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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 2013.

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 2013 is 0.223 incidents per 1000 km.year, whilst in the previous report this figure was 0.227 incidents per 1000 km.year (covering the period from 1962 to 2012). The overall trend continues to show a reduction in failure frequency.

The failure frequency over the last 20 years is 0.077 incidents per 1000 km.year.

For the last 5 years the failure frequency is 0.105 incidents per 1000 km.year, whilst in the previous report this figure was 0.122 incidents per 1000 km.year (covering the 5 year period up to the end of 2012). The most recent 5 year failure frequency shows a slight 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.

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.

Using Structural Reliability Analysis or 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.

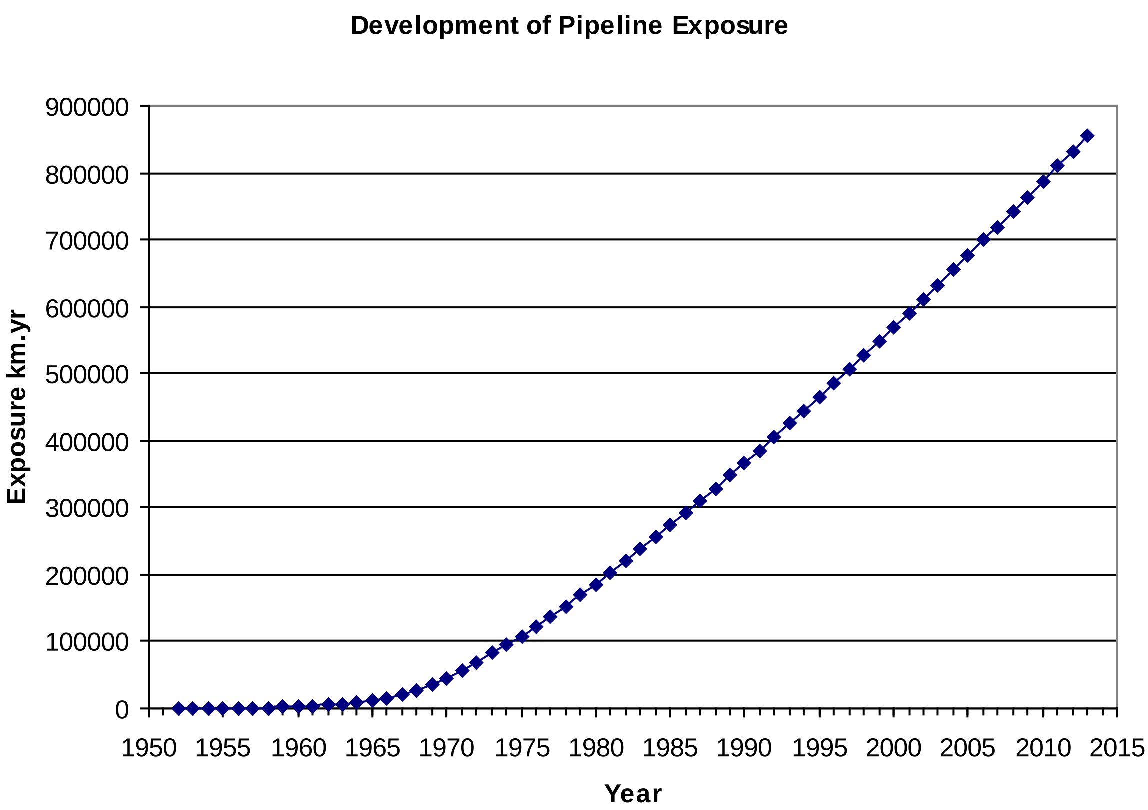
2 Product System Data

2.1 Exposure

The total length of Major Accident Hazard Pipelines* in operation at the end of 2013 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 2013 was 855,458 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



*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.

2.2 Transported Products

The lengths (in km) of pipeline in operation at the end of 2013, 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).

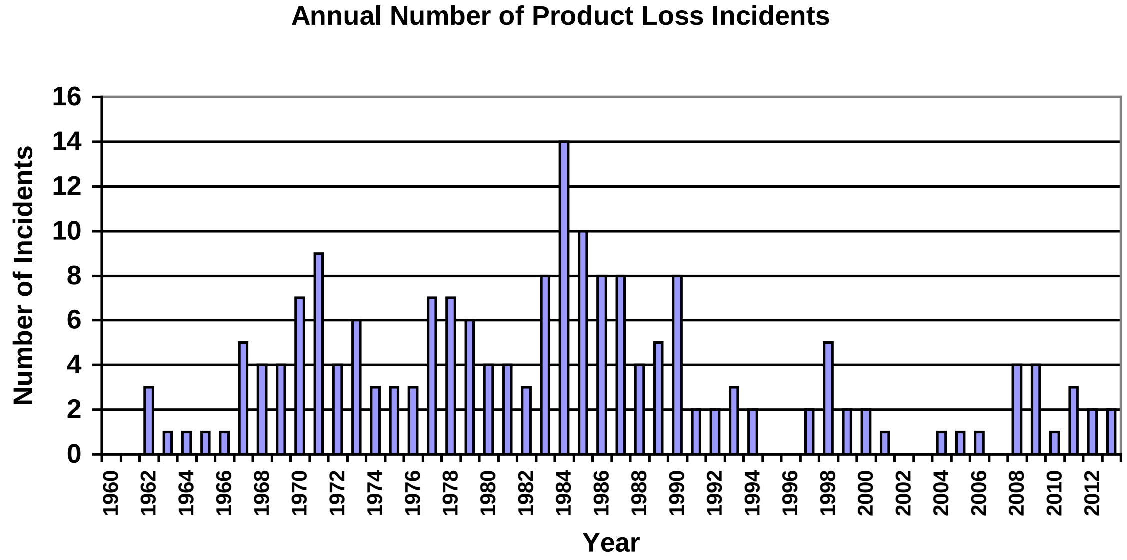
3 Product Loss Incident Data

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 191 product loss incidents were recorded over the period between 1962 and 2013 compared with 189 product loss incidents documented in the report covering the period to 2012. No product loss incidents were recorded prior to 1962. An annual breakdown of incidents is illustrated in Figure 2.

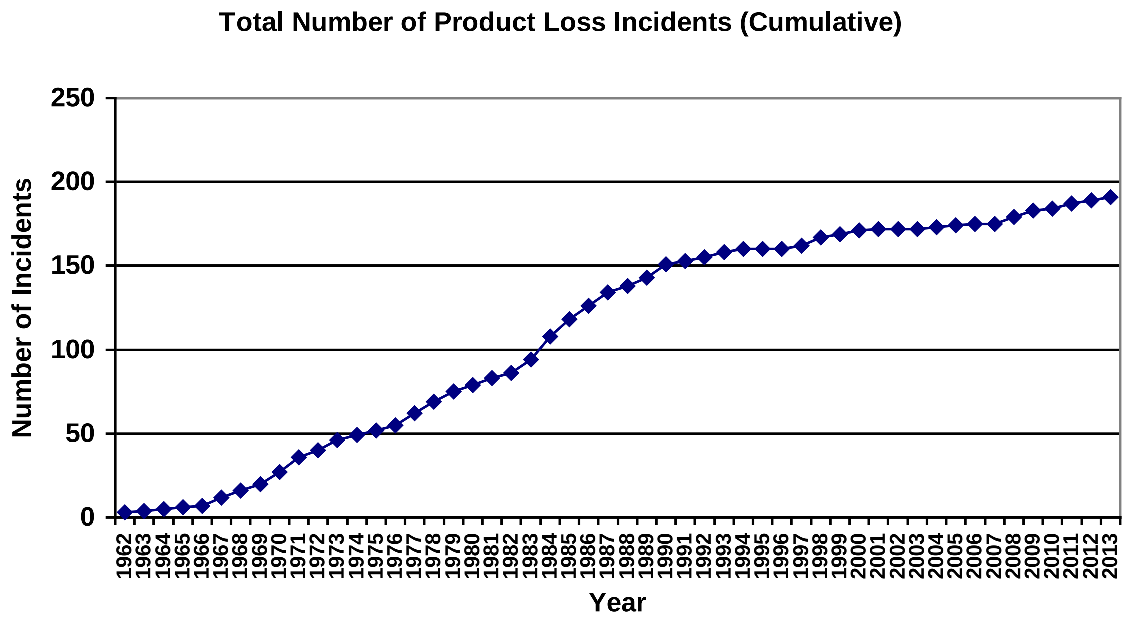
Figure 2



Differences between 2012 and 2013 product loss statistics

Two product loss incidents were recorded in 2013. These incidents were both due to pinholes at girth weld defects. The product loss in each case was minor. The cumulative number of incidents over the period 1962 to 2013 is shown in Figure 3.

Figure 3



3.1 Incident Ignition

There were 9 out of 191 (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 48 Years

The incident frequency over eight consecutive 5-year periods up to the end of 2013 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]
1964 – 1968	12	20,741.72	0.579
1969 – 1973	30	54,654.24	0.549
1974 – 1978	23	71,385.11	0.322
1979 – 1983	25	84,055.16	0.297
1984 – 1988	44	91,352.98	0.482
1989 – 1993	20	96,423.67	0.207
1994 – 1998	9	101,971.47	0.088
1999 – 2003	5	105,807.61	0.047
2004 – 2008	7	107,995.93	0.065
2009 – 2013	12	114,479.96	0.105

The overall incident frequency by hole size over the period 1962 - 2013 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*	3	0.004
40mm – 110mm	7	0.008
20mm – 40mm	23	0.027
6mm – 20mm	31	0.036
0 – 6mm	118	0.138
Unknown	2	0.002
Total	191	0.223

* 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 1994-2013 is 427,756 km.years and the resulting incident frequency is shown in Table 5.

Table 5

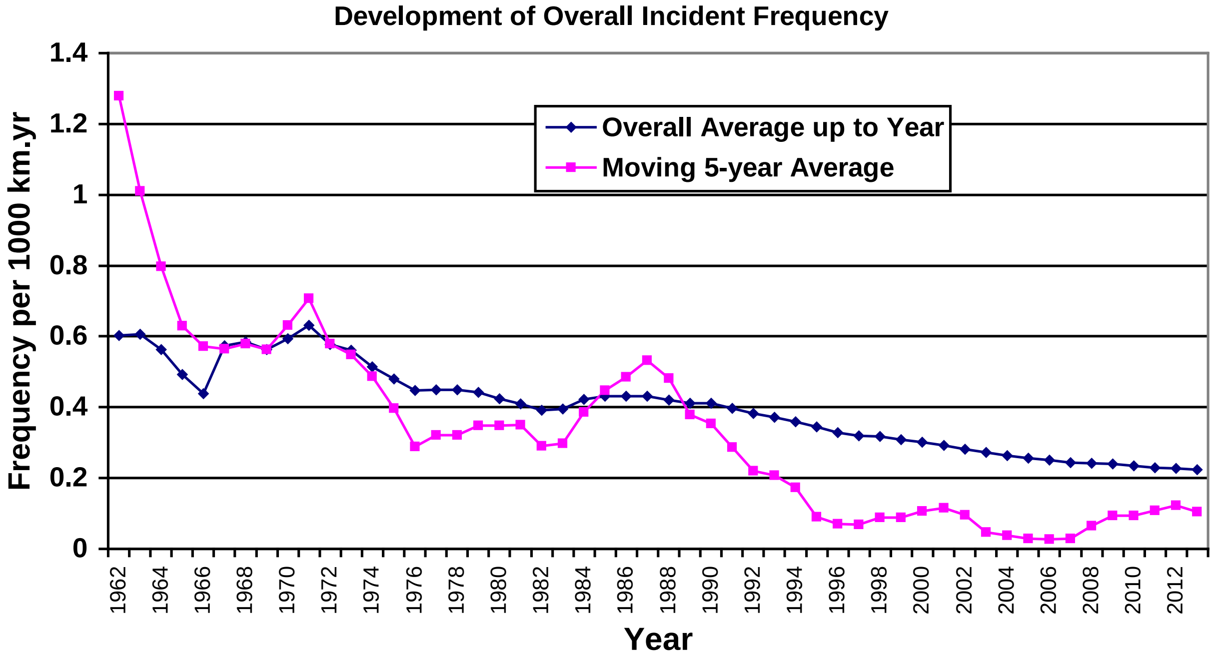
Hole Size Class	Number of Incidents	Frequency [Incidents per 1000 km.yr]
Exposure	**1994-2013**	**427756**
Full Bore* and Above	0	0
110mm – Full Bore*	0	0.000
40mm – 110mm	0	0.000
20mm – 40mm	5	0.012
6mm – 20mm	5	0.012
0 – 6mm	23	0.054
Unknown	0	0.000
Total	33	0.077

The failure frequency over the last 20 years is therefore 0.077 incidents per 1000 km.years and for the last 5 years (2009-2013) is 0.105 incidents per 1000 km.yr.

These compare with the failure frequency during the period 1962-2013 of 0.223incidents per year per 1000 km.yr. An overview of the development of this failure frequency over the period 1962 to 2013 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 (2009-2013, 2008-2012, 2007-2011 etc.).

Figure 4



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

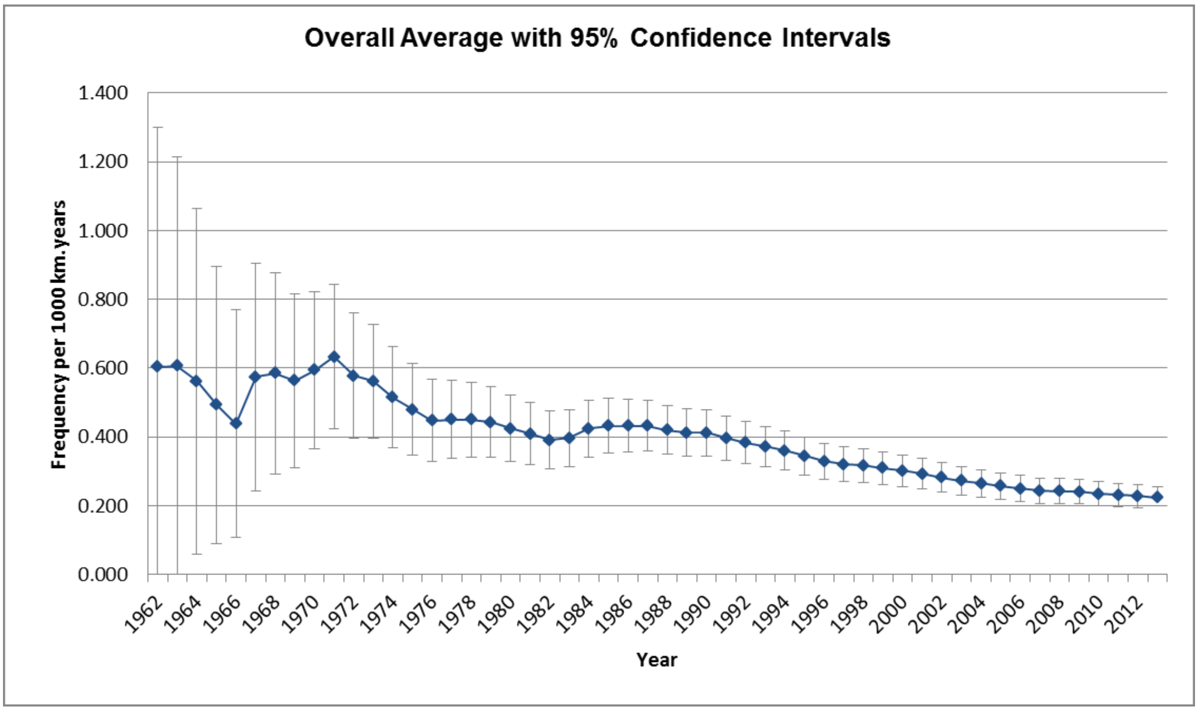


Figure 5 shows that the overall frequency for the whole period is 0.223 per 1000 km.years +/- 0.033.

Figure 6

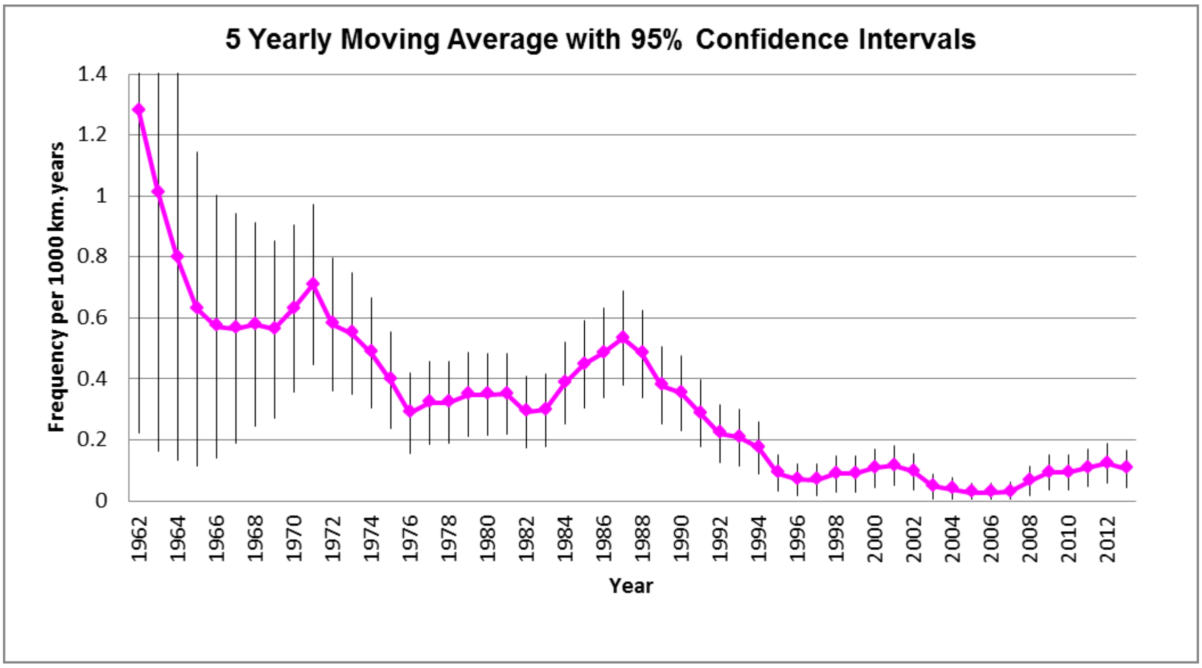


Figure 6 shows that the 5-year average failure frequency for 2009-2013 is 0.105 per 1000 km.years +/- 0.061.

3.3 Incident Frequency by Cause

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

Figure 7

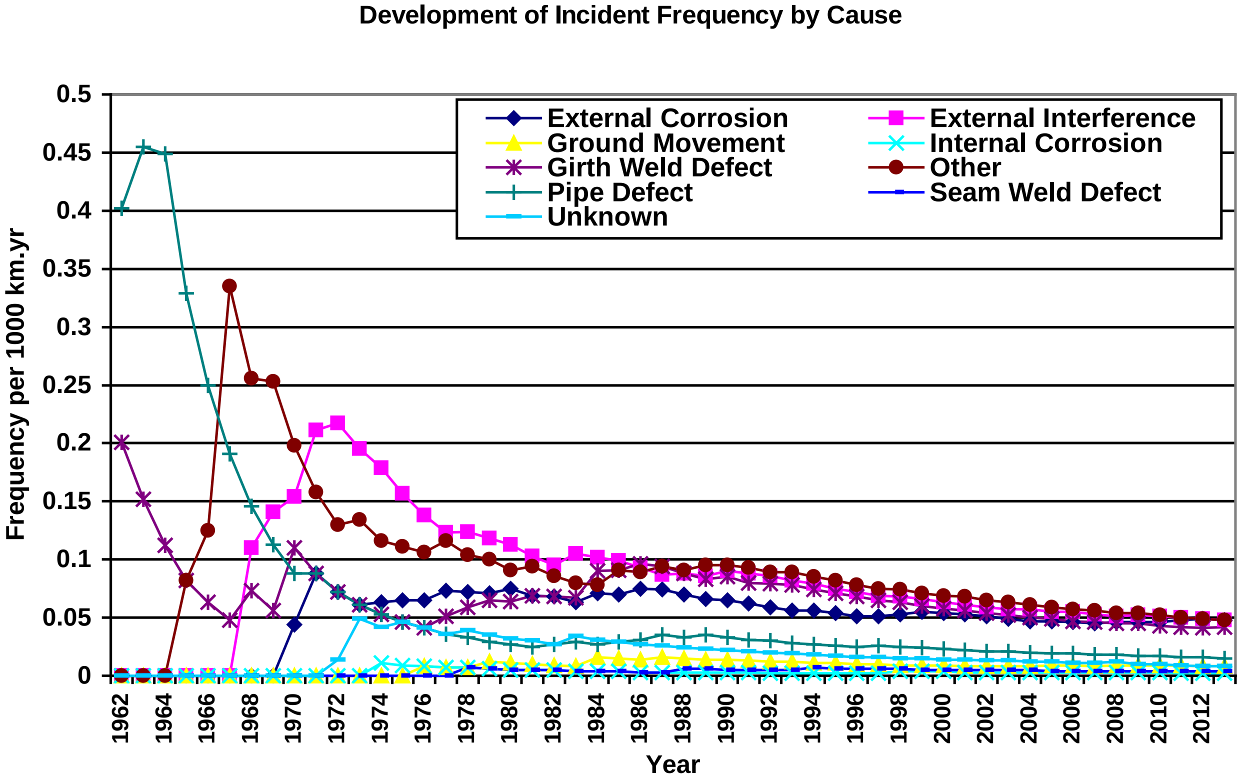


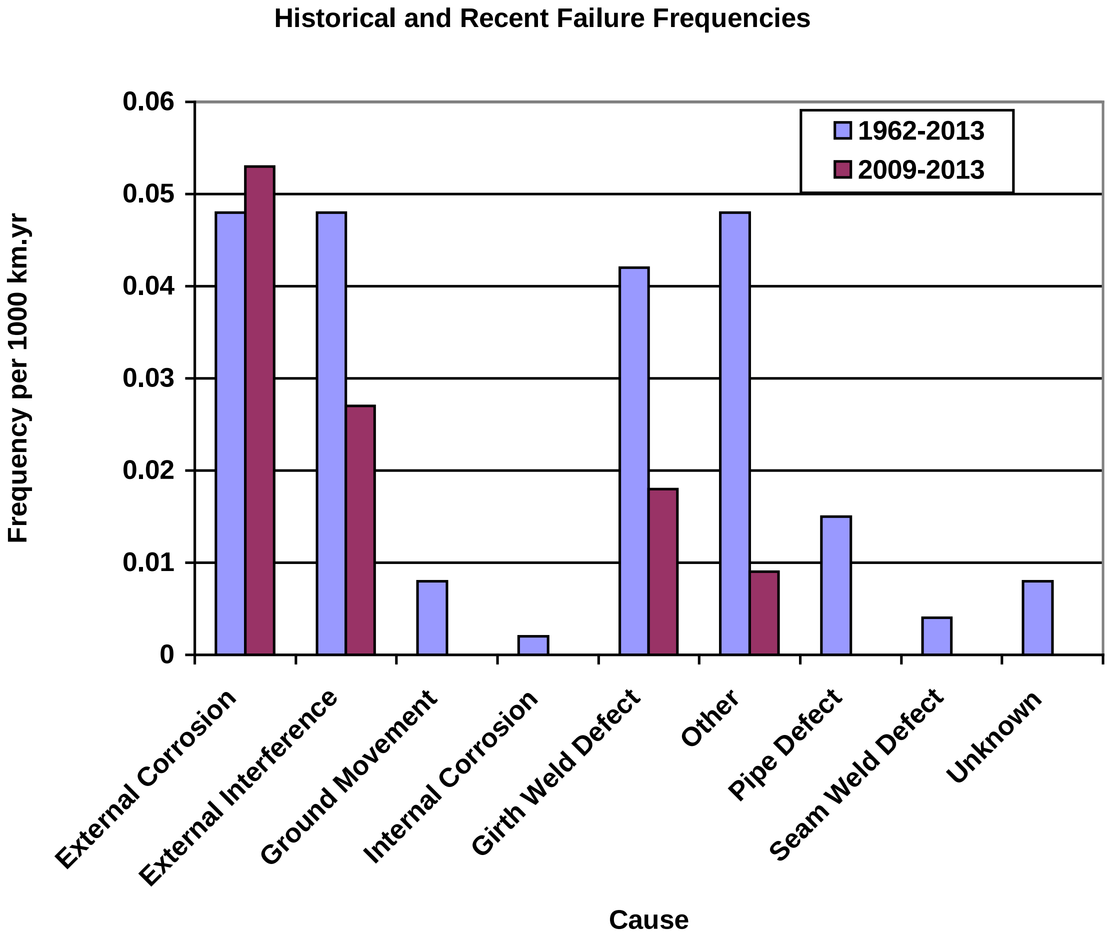
Table 6 – Product Loss Incidents by Cause

Product Loss Cause	No. of Incidents
Girth Weld Defect	36
External Interference	41
Internal Corrosion	2
External Corrosion	41
Unknown	7
Other	41
Pipe Defect	13
Ground Movement	7
Seam Weld Defect	3
Total	**191**

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**

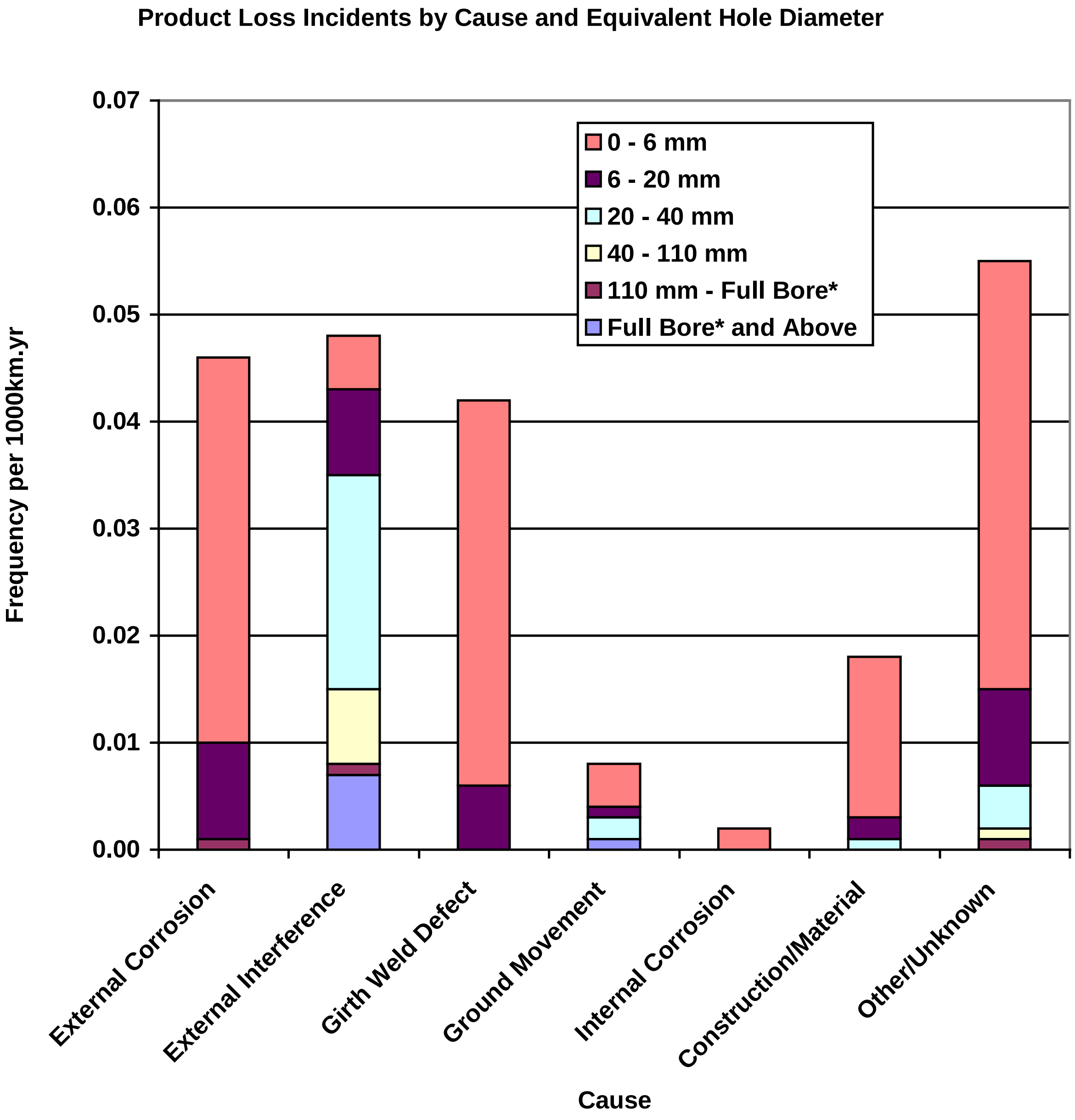
Figure 8 shows the product loss incident frequency by cause over the period 1962-2013 compared with the frequency over the last 5 years (2009-2013).

Figure 8



An overview of the product loss incident frequency by cause and size of leak in the period 1962 to 2013 is shown in Figure 9.

Figure 9



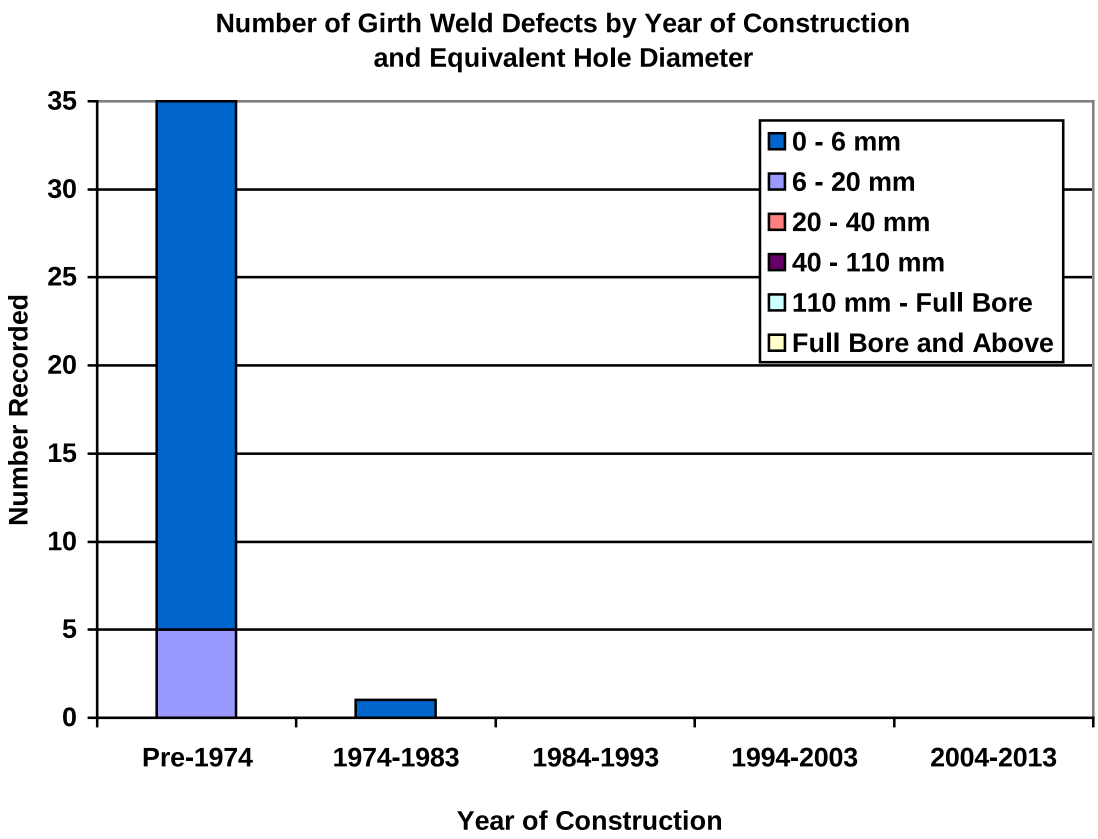
Construction/Material = Seam Weld Defect + Pipe Defect + Pipe Mill Defect + Damage during Original Construction

** 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

Girth Weld Defects

Figure 10 shows that 36 leaks due to girth weld defects were recorded in pipelines constructed before 1984, 35 of which were in pipelines constructed before 1972.

Figure 10



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

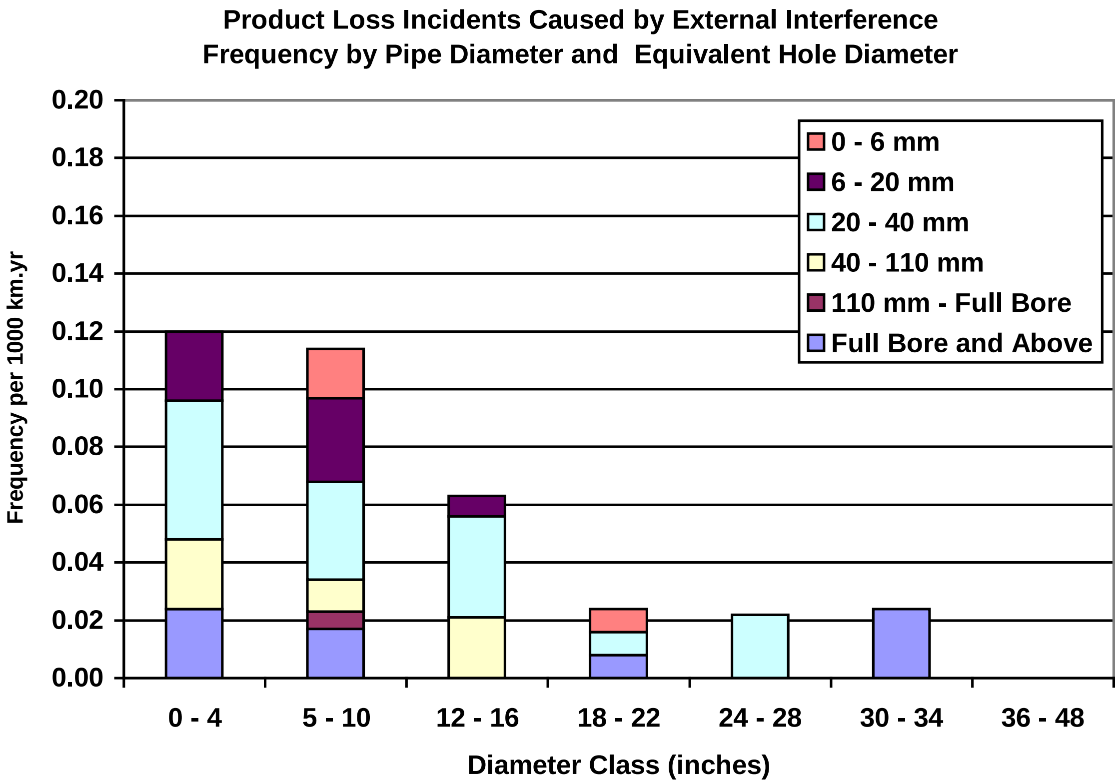


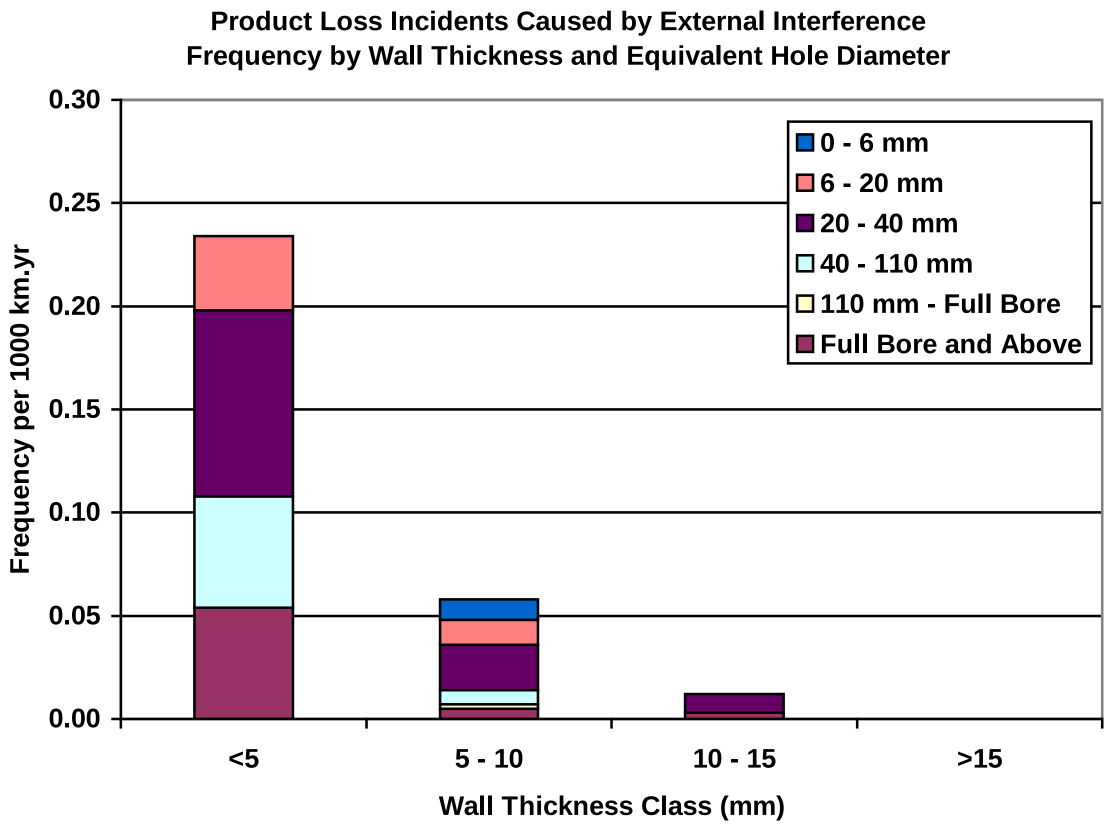
Table 7 – Exposure by Diameter Class

Diameter [inches]	Exposure [km.yr]	Incidents	Frequency [per 1000km.yr]
0-4	42001	5	0.119
5-10	174375	20	0.115
12-16	142745	9	0.063
18-22	123923	3	0.024
24-28	137959	3	0.022
30-34	40937	1	0.024
36-48	193517	0	0.000
Total	855458	41	0.048

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]	Incidents	Frequency [per 1000 km.yr]
<5	55684	13	0.233
5-10	402388	24	0.060
10-15	328081	4	0.012
>15	69306	0	0.000
Total	855458	41	0.048

3.4.3 External Interference by Area Classification

Figure 13

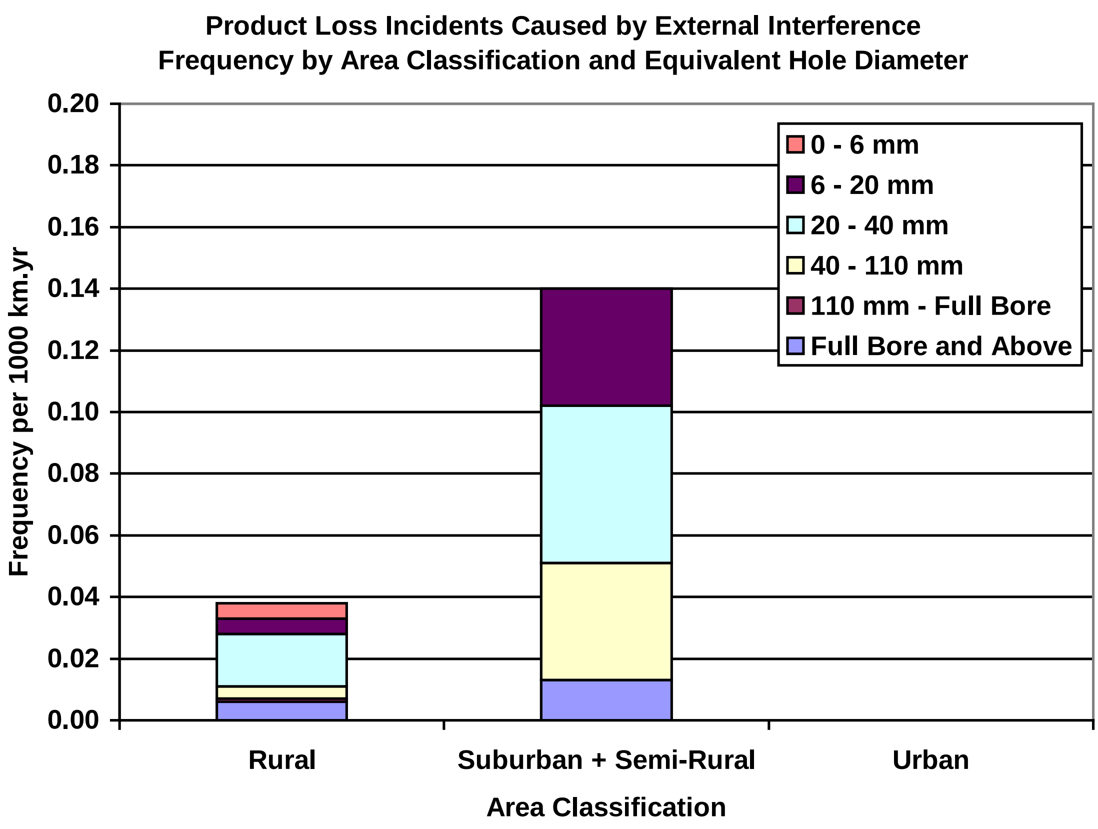


Table 9 – Exposure by Area Classification in km.yr

Area Classification	Exposure [km.yr]	Incidents	Frequency [per 1000 km.yr]
Rural	775198	30	0.039
Suburban	79119	11	0.139
Urban	1141	0	0.000
Total	855458	41	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

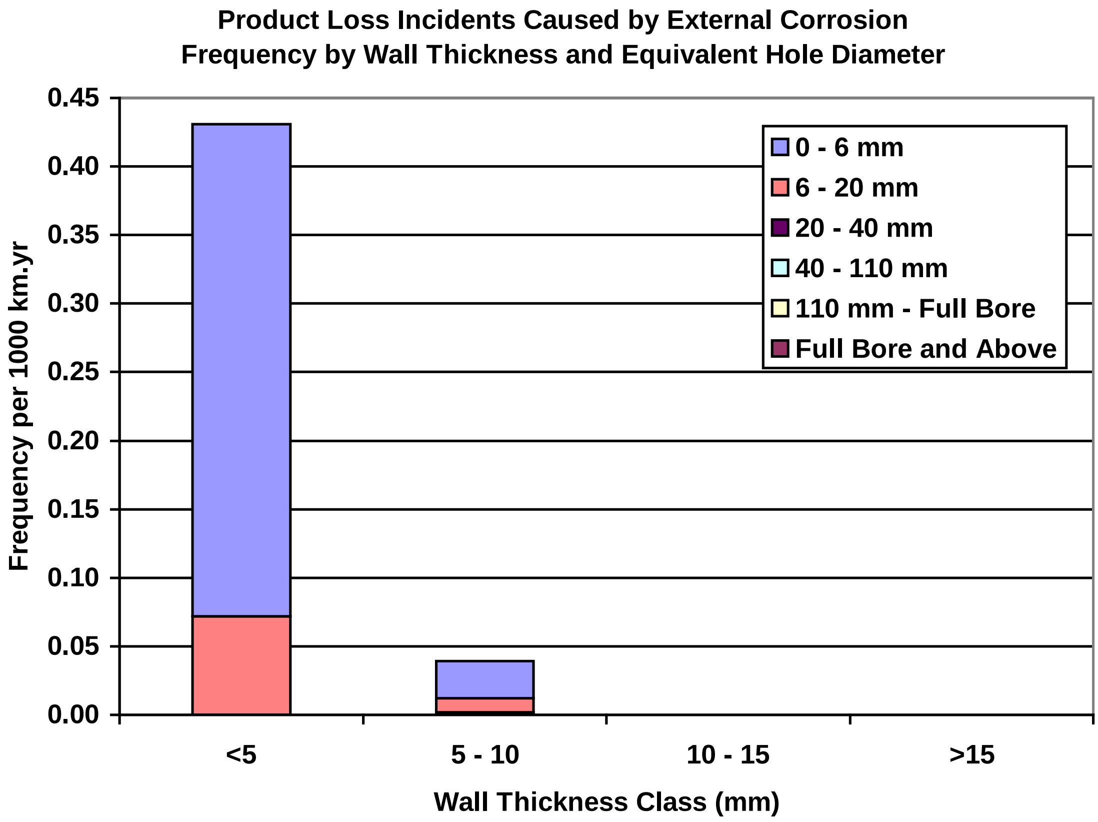


Table 10 – Exposure by Wall Thickness Class

Wall Thickness [mm]	Exposure [km.yr]	Incidents	Frequency [per 1000 km.yr]
<5	55684	24	0.431
5-10	402388	16	0.040
10-15	328081	0	0.000
>15	69306	0	0.000
Total	855458	40	0.047

Note – one corrosion leak wall thickness size is unknown.

3.5.2 External Corrosion by Year of Construction

Figure 15

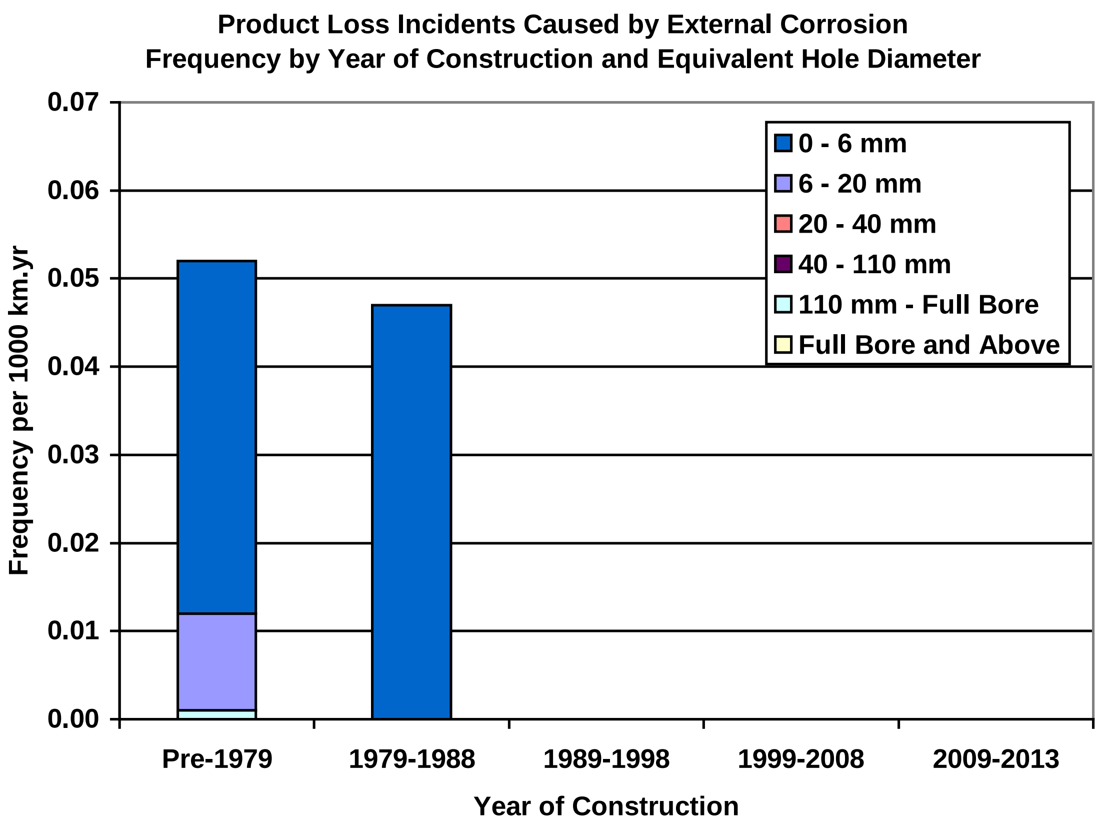


Table 11 – Exposure by Year of Construction

Construction Year	Exposure [km.yr]	Incidents	Frequency /[per 000 km.yr]
Pre-1979	707108	37	0.052
1979-1988	85787	4	0.047
1989-1998	41841	0	0.000
1999-2008	20237	0	0.000
2009-2013	485	0	0.000
	855458	41	0.048

The reduction in the number of incidents due to external corrosion for pipelines constructed after 1979 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

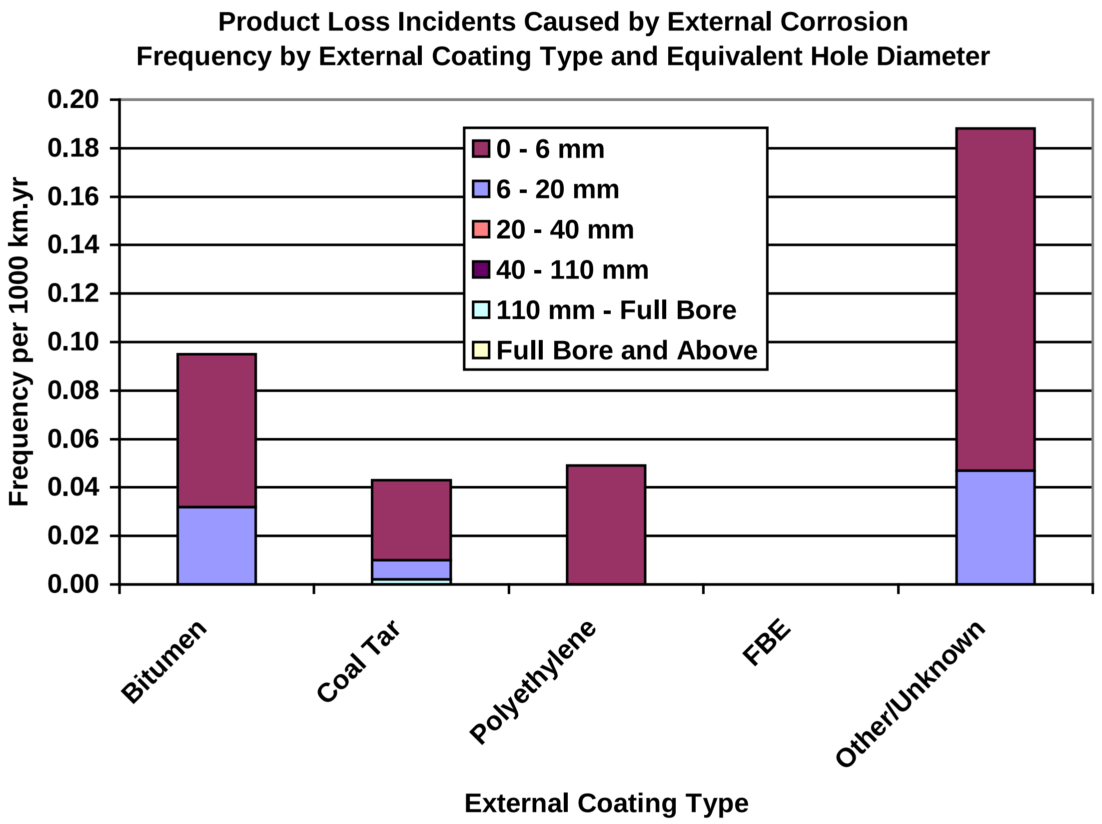
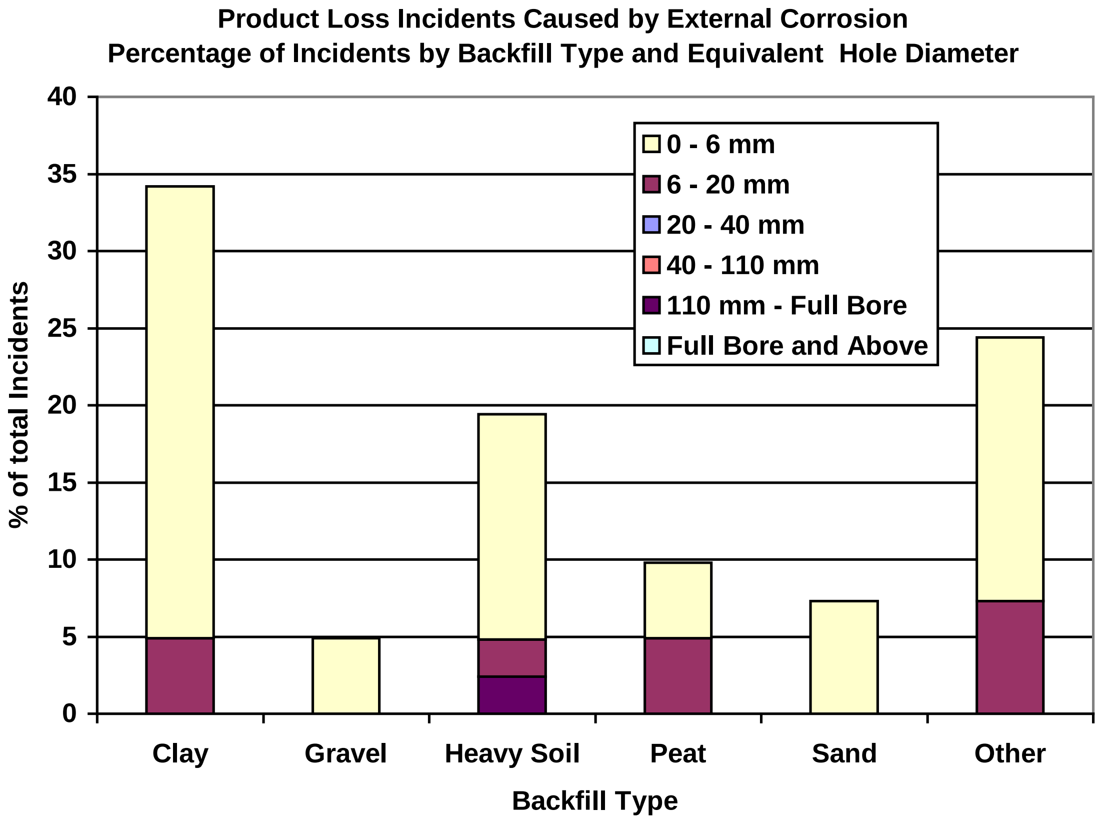


Table 12 – Exposure by External Coating Type

External Coating	Exposure [km.yr]	Incidents	Frequency [per 1000 km.yr]
Bitumen	31586	3	0.095
Coal Tar	610422	26	0.043
Polyethylene	81908	4	0.049
FBE	88997	0	0.000
Other/Unknown	42545	8	0.188
Total	855458	41	0.048

3.5.4 External Corrosion by Type of Backfill

Figure 17



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**

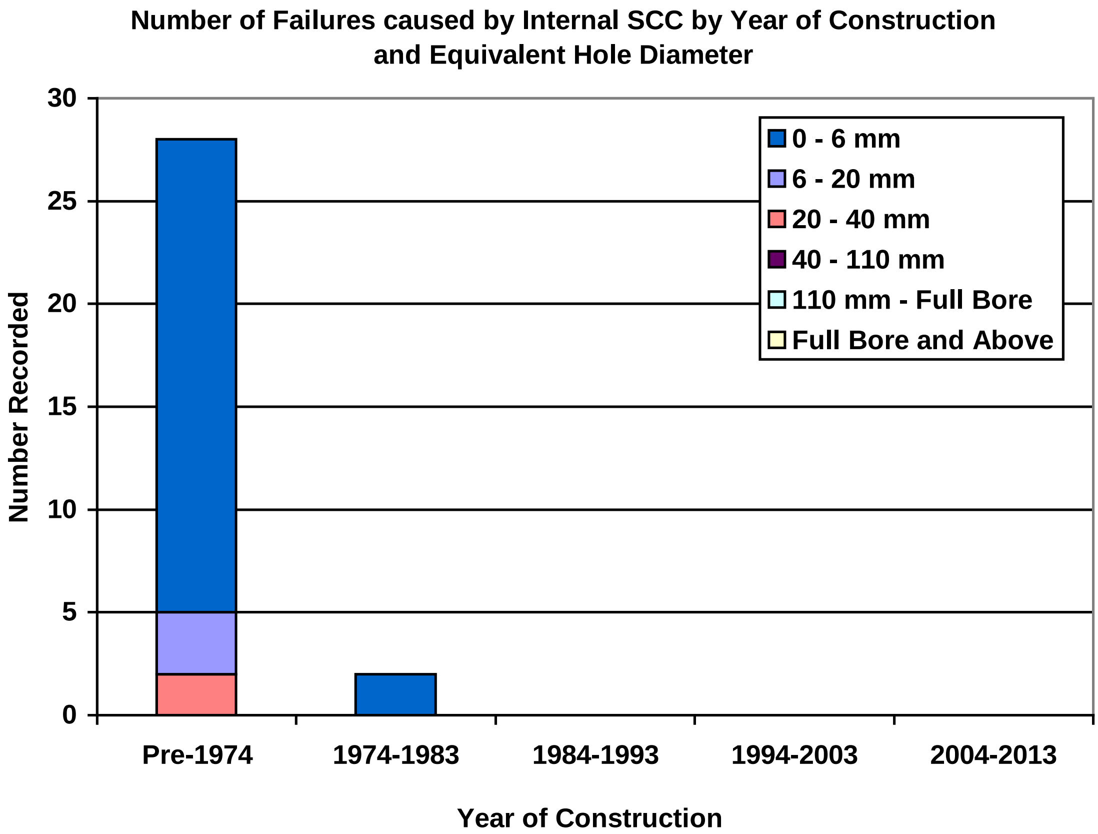
The UKOPA product loss data indicates that “Other” causes account for approximately 21% of the total failure rate.

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.

3.7 Pipeline Failures Caused by Internal Cracking

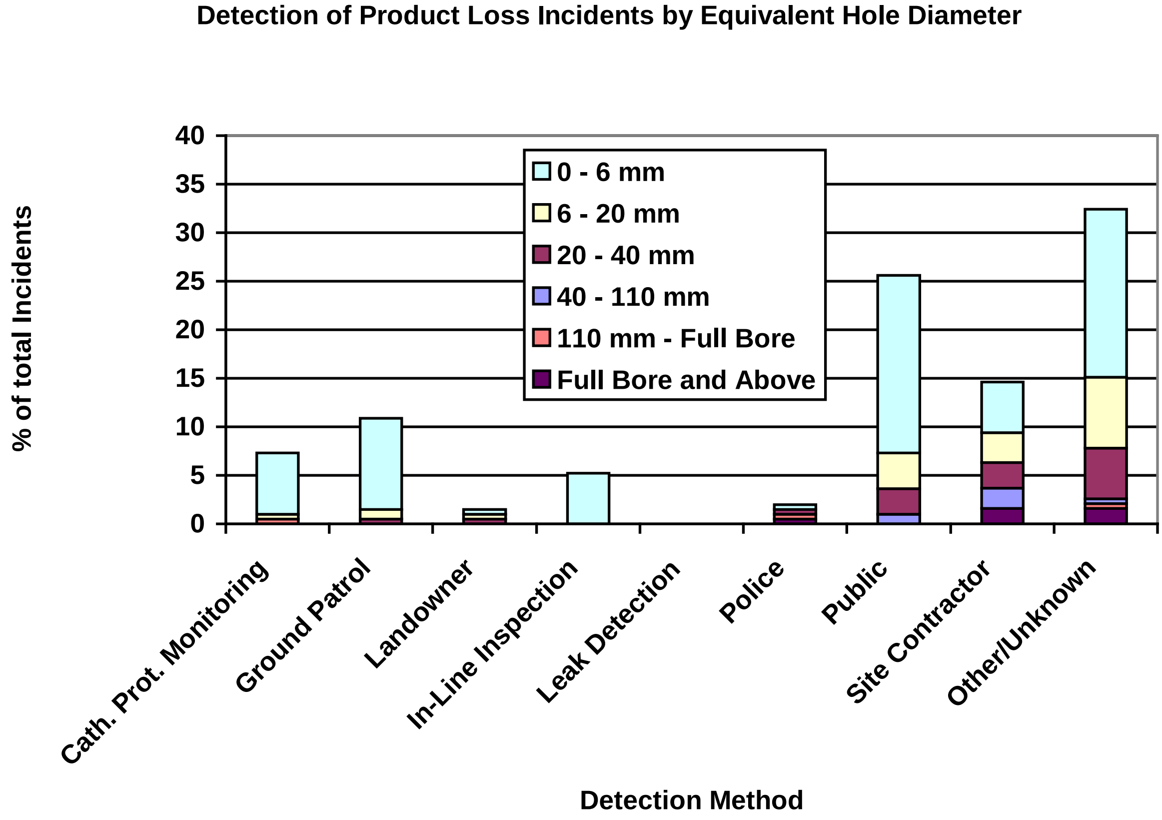
A significant proportion of the failures classified as "Other" (30 out of 41 = 73%) were caused by internal cracking (stress corrosion cracking [SCC]) in pipelines which had seen wet towns gas (pre-natural gas) service. 93% of these failures (28 out of 30) were in pipelines constructed before 1972.

Figure 18



3.8 Detection of Pipeline Failures

Figure 19



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

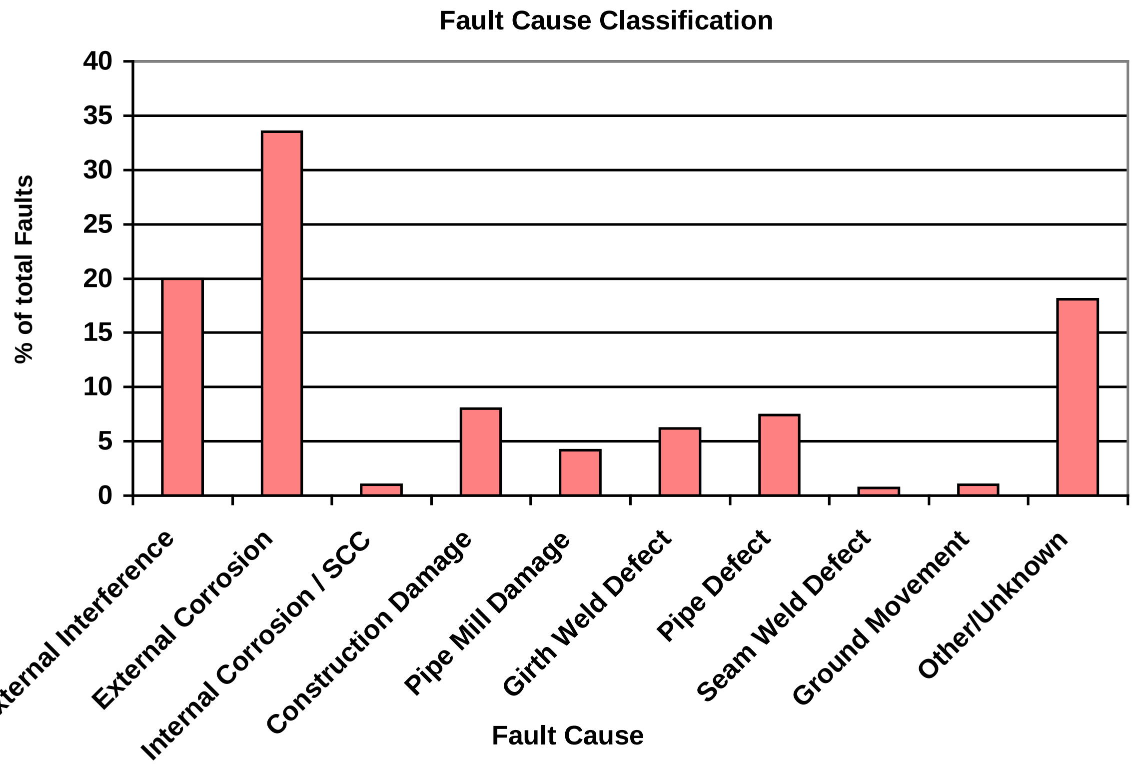
4 Fault Data

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 - 2013 was 3461. The main causes of the Faults are shown in Figure 20.

Figure 20

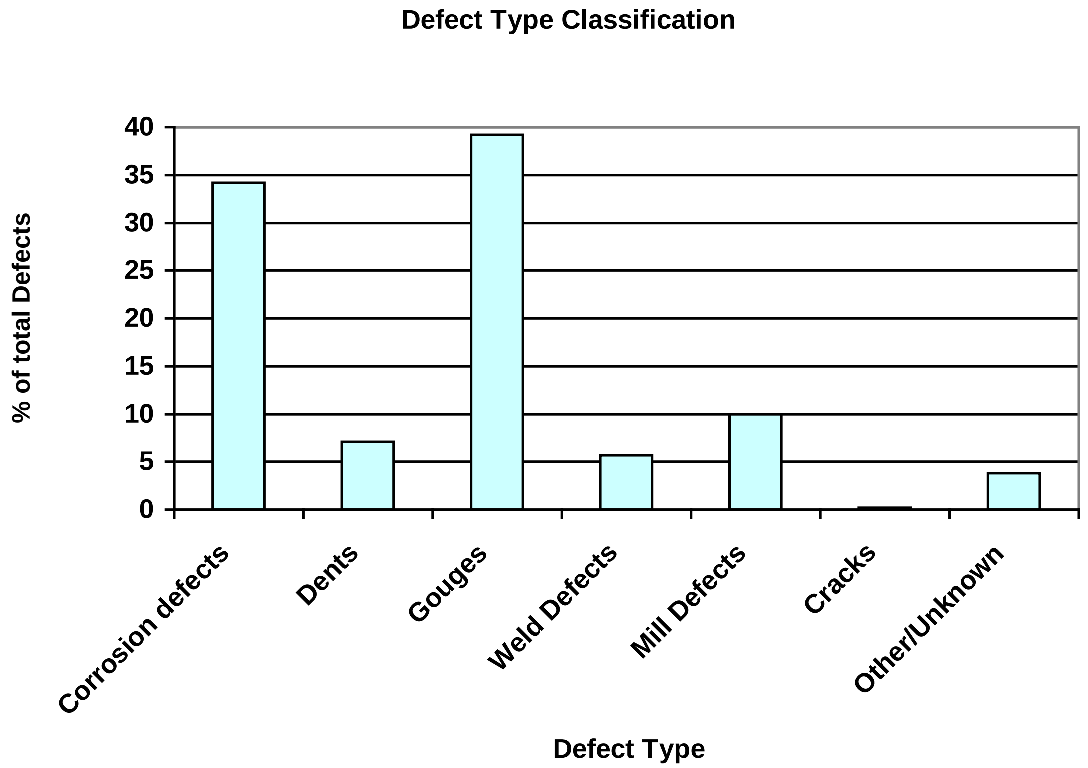


4.2 Part-Wall Defect Data

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 5581 defects recorded in the period 1962 - 2013.

Classification of defect data is shown in Figure 21.

Figure 21



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 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 – 2013, which includes an additional 27 faults and 60 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.

Note: Weibull distributions were identified as appropriate distributions in 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.