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NCS data

TN-2

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Summary

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1 Introduction

This technical note describes the recorded leaks occurring on installations located on the Norwegian Continental Shelf (NCS) in the period 01.01.2001 – 31.12.2017 (17 years) and corresponding population data. The population data consist of equipment counts gathered from QRA's from 84 installations, of which 79 have been in operation in the period.

Abbreviations and expressions used in this technical note are described in TN-1: Abbreviations and expressions.

2 General description of dataset

2.1 Leaks at NCS

The data bases of recorded leaks at the NCS have been established based on the following data sources:

1. RNNP dataset collated by Petroleumstilsynet (Ptil) and Safetec
2. Review of accident investigation reports. Accident investigation reports have been available for the majority of the incidents

According to RNNP, the total number of process leaks that has occurred in the period is 260.

All recorded leaks at NCS have an initial hydrocarbon leak rate of 0.1 kg/s or larger.

2.2 Hole size

It has been attempted to assess the hole size for the incidents based on review of the accident investigation reports. Adequate information to determine the hole size is only available in a fraction of the cases, and further analysis of the hole sizes has been disregarded. It is judged that a detailed review of the incident reports would enable assessment of the hole size for about 50 % of the leaks. The main reason for hole sizes not being available is that it is not a requirement to report that parameter. It is recommended that the future practice for reporting of incidents includes reporting of the hole size (preferably both calculation of the hydraulic hole size (based on pressure and density) as well as measurements of the physical properties of the observed hole (if possible).

2.3 Population data NCS

In total population data for 109 installations has been established containing information about the number and type of equipment with associated inventory properties for each installation. The database is denoted "NCS population dataset". For 85 of the installations the population data has been established by collecting equipment counts performed in QRAs, while the population data for the remaining installations has been established by defining an equivalent installation in the NCS population dataset. In total 90 of the 109 installations have been in operation in the period 2001 – 2017.

3 Relevant historical incidents for the modelled leak scenarios

The total number of leaks reported in RNNP in the period 01.01.2001 – 31.12.2017 is 260. After review of the incidents, it has been concluded that 43 of those incidents are not relevant for the leak scenarios to be modelled by PLOFAM, i.e. they are not process leaks or topside well leaks during normal operation (see TN-4). Typical properties of disregarded incidents are as follows:

- The leak is a release through a vent or a dump line where the rate is not considered to exceed the design specification for the vent or dump line
- The leak is originating from a piece of equipment not being covered by the model, such as a pipeline or a riser
- The leak is occurring in the well system during a drilling operation or intervention

Out of the remaining 217 leaks (260 - 43), 210 leaks have occurred on the 85 installations in the "NCS population dataset" where equipment counts have been performed. The remaining 7 leaks have occurred on the 11 installations in Table 4.1. Detailed information about all 217 relevant leaks is given in Appendix A.

3.1 Distribution of leaks per system

The distribution per system is shown in Table 3.1, i.e. the table gives the number of leaks registered from the different systems. The categorisation of system in this context may not coincide with general industry practice in terms of categorisation of systems. The naming is assumed to be self-explanatory. The table is given to indicate where the leak location has been for the historical leaks. In some cases there may be several leak points, the investigation report is not detailed enough to determine the exact leak location. In these situations the two systems are specified. This indicates the uncertainty in leak location. Note however that all leaks are process leaks as defined in TN-4, i.e. fluid from the process system is released.

The classification of leaks per system is somewhat uncertain and should be interpreted with care, which is due to limited information available in terms of the system the incident is associated with. However, the results can be used to conclude that leaks are in many cases associated with several systems. The typical scenario in cases where several systems are involved is that the leak is fed from the process system, but the leak point itself is associated to the other system.

Table 3.1 - Distribution of all NCS leaks (217) per system. The question mark indicates that the leak location is associated with uncertainty

System where leak is released from	b(0.1-1 kg/s)	c(1-10 kg/s)	d(10-100 kg/s)	e(>100 kg/s)	Grand Total
Closed drain	1		1		2
Closed drain / Open drain system			1		1
Closed drain / Process system	1				1
Flare system	2	3	4	1	10
Fuel gas system	4	2			6
Fuel gas system / Diesel system	1				1
Open drain system		1			1
Process system	114	32	5	2	153
Process system / Closed drain	1				1
Process system / Flare system	4				4
Process system / Fuel gas system		1			1
Process system / Gas lift system		1			1
Process system / Open drain	1				1
Process system / Produced water?	2				2
Process system / Seal oil system	1				1
Process system / Storage	1		1		2
Process system / Utility system		1			1
Process system / Well system	13	4			17
Produced water / Sea water / Open drain		1			1
Produced water system		1			1
Unknown	2	2			4
Well system	1	2			3
Process system (Gas lift)	1				1
Process system / Sea water		1			1
Grand Total	150	52	12	3	217

3.2 Distribution of leaks per leak scenario defined in PLOFAM

The distribution of the leaks per leak scenario defined in PLOFAM (Significant and Marginal, see TN-4), distributed over initial leak rate, is presented in Figure 3.1 through Figure 3.5 and Table 3.2. Figure 3.1 shows the number of Significant and Marginal leaks distributed over four initial leak rate categories. Figure 3.2 and Table 3.2 display the relative distribution between Significant and Marginal leaks for four different initial leak rate categories, while Figure 3.3 shows the distribution over different initial leak rate categories for both Significant and Marginal leaks.

A Marginal leak is a leak where the total mass released to the environment is 10 kg or less. In a Significant leak scenario, the released amount is beyond 10 kg (see TN-4).

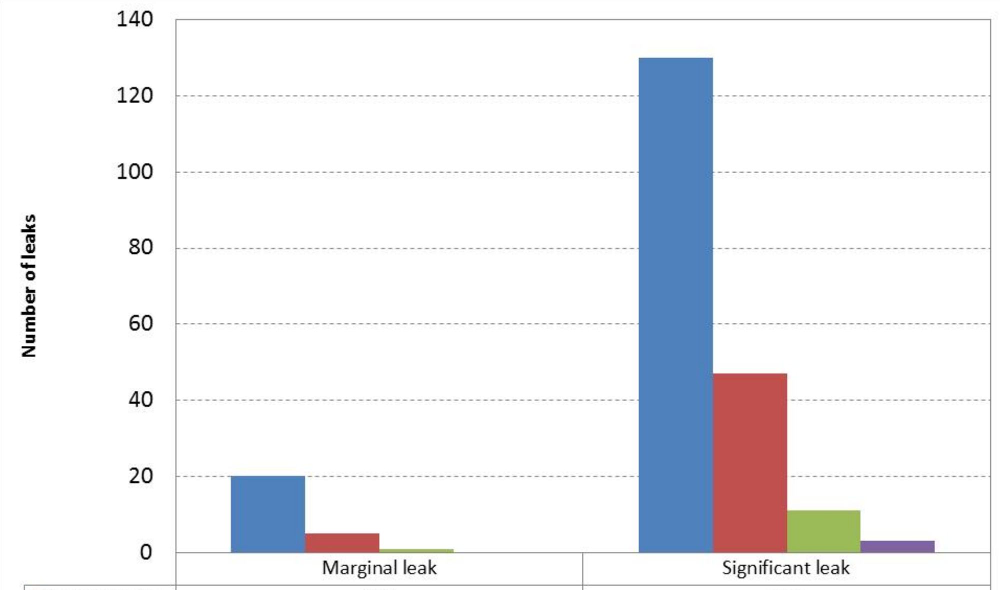
Table 3.2 shows that the fraction of Marginal leaks are about 12 %. The fraction is quite constant for all leak categories, i.e. around 10 %. Note that no Marginal leaks having an initial leak rate larger than 100 kg/s is observed. However, the total number of both Marginal leaks and leaks >100 kg/s is few in the dataset, and the results are therefore sensitive to randomness.

It is likely that several of the scenarios classified as Significant are Marginal, i.e. the actual amount released to the environment was less than 10 kg. The total amount released is not stated in some of the accident investigation reports, and investigation reports for some of the incidents are not available. In all cases where the amount released is unknown, the scenario type is classified as Significant.

The average fraction of Marginal leaks is about 12 % for all leak rates and all fluid types, and should be used to estimate the fraction of Marginal leaks from the total number of leaks. It is expected that future data will provide basis for increasing this figure somewhat. However, the distribution with respect to equipment type, shown in Figure 3.4 and Figure 3.5, point towards the fraction of Marginal leaks being different for the various types of equipment. The results show that a high fraction Marginal leaks is associated with leaks from hoses, producing wells, valves and flanges. Note that only two incidents have been recorded for producing wells (i.e. the result is sensitive to randomness).

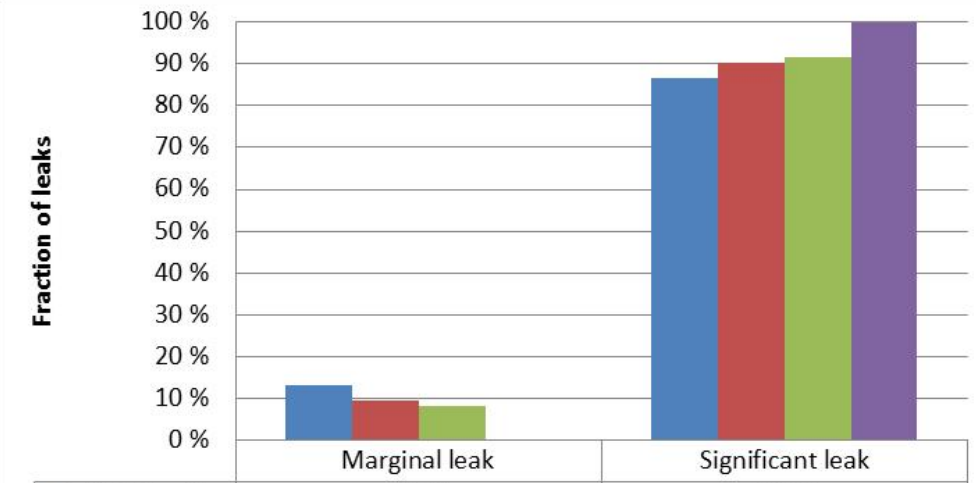
Table 3.2 - Relative distribution of all NCS leaks (217) per leak scenario

Distribution per leak scenario	b(0.1-1 kg/s)	c(1-10 kg/s)	d(10-100 kg/s)	e(>100 kg/s)	Grand Total
Marginal leak	13 %	10 %	8 %	0 %	12 %
Significant leak	87 %	90 %	92 %	100 %	88 %
Grand Total	**100 %**	**100 %**	**100 %**	**100 %**	**100 %**



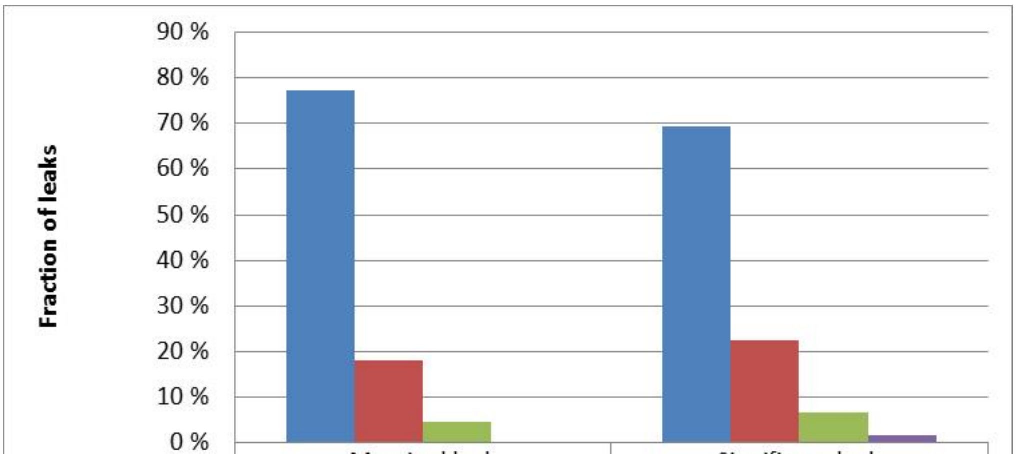
	Marginal leak	Significant leak
b(0.1-1 kg/s)	20	130
c(1-10 kg/s)	5	47
d(10-100 kg/s)	1	11
e(>100 kg/s)		3

Figure 3.1 - Distribution of all NCS leaks (217) per leak scenario



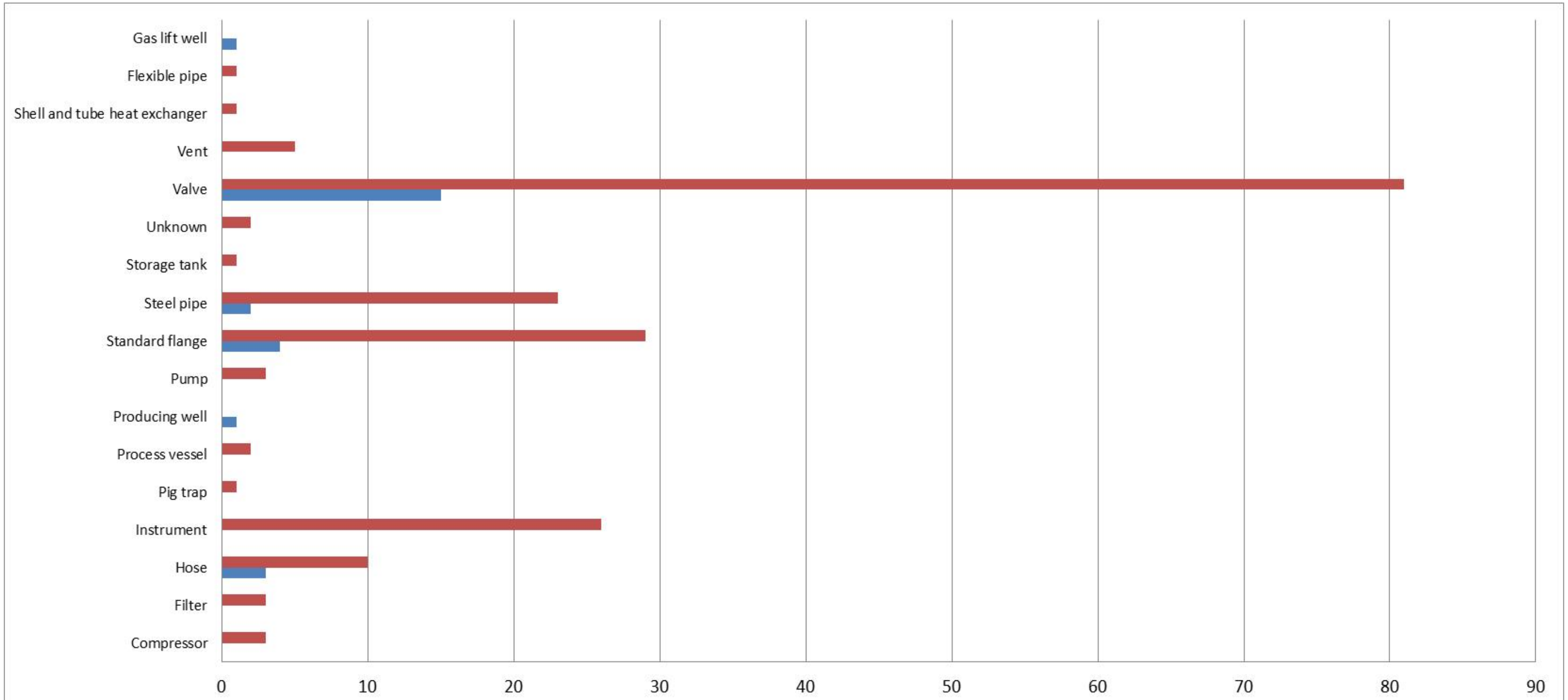
	Marginal leak	Significant leak
b(0.1-1 kg/s)	13 %	87 %
c(1-10 kg/s)	10 %	90 %
d(10-100 kg/s)	8 %	92 %
e(>100 kg/s)	0 %	100 %

Figure 3.2 - Relative distribution of all NCS leaks (217) per leak scenario. The contributions from Marginal and Significant leaks sum up to 100%



	Marginal leak	Significant leak
b(0.1-1 kg/s)	77 %	69 %
c(1-10 kg/s)	18 %	22 %
d(10-100 kg/s)	5 %	7 %
e(>100 kg/s)	0 %	2 %

Figure 3.3 - Relative distribution of all NCS leaks (217) per leak scenario. The contributions from the initial leak rates categories sum up to 100%



	Compressor	Filter	Hose	Instrument	Pig trap	Process vessel	Producing well	Pump	Standard flange	Steel pipe	Storage tank	Unknown	Valve	Vent	Shell and tube heat exchanger	Flexible pipe	Gas lift well
Significant leak	3	3	10	26	1	2		3	29	23	1	2	81	5	1	1	
Marginal leak			3				1		4	2			15				1

Number of leaks

Figure 3.4 - Distribution of all NCS leaks (217) per leak scenario per equipment type

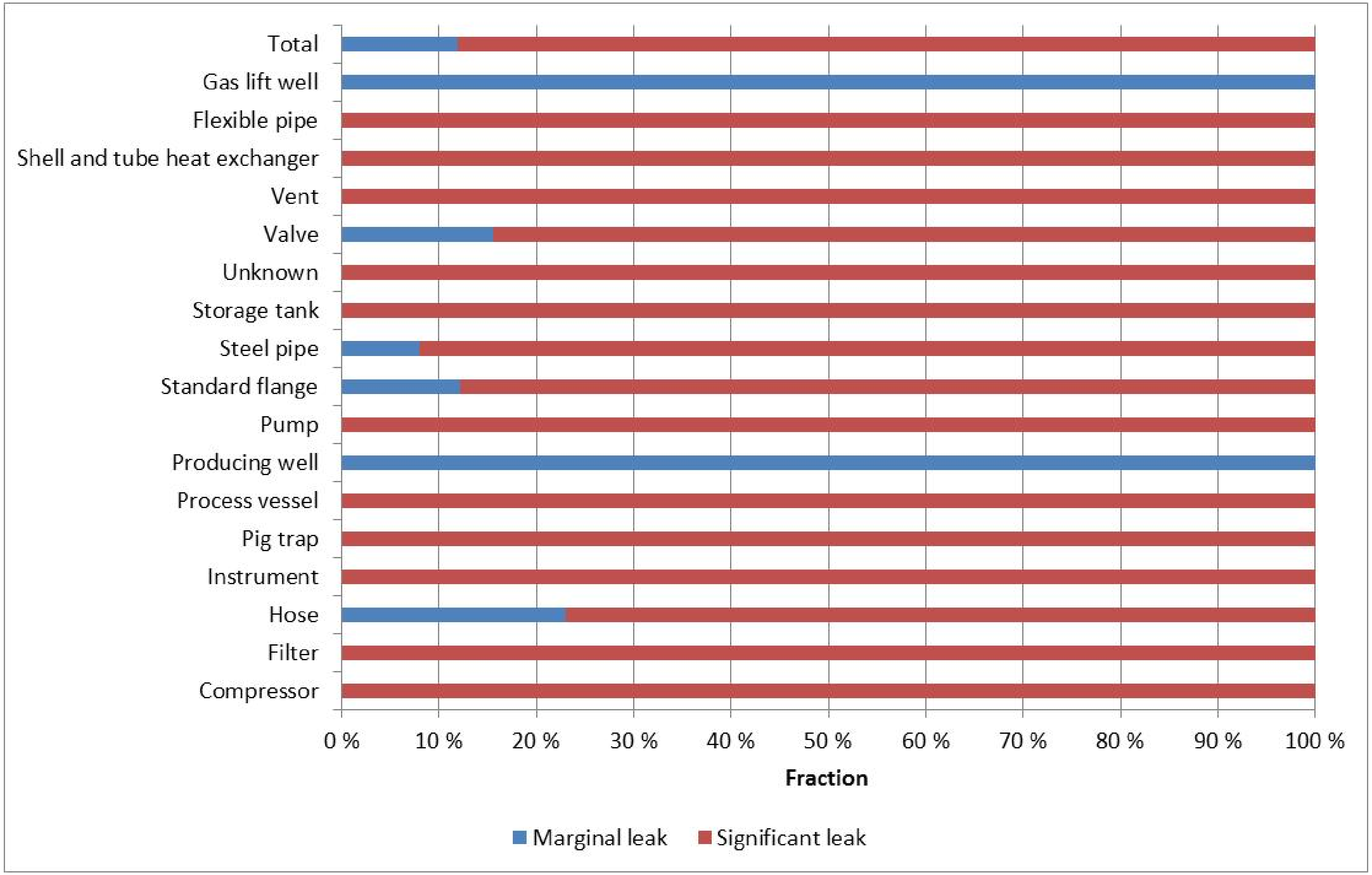


Figure 3.5 - Relative distribution of all NCS leaks (217) per leak scenario per equipment type. NB! Only two events are related to producing wells

3.3 Distribution of leaks per leak rate per equipment type

The distribution of the leaks per equipment type is shown in Table 3.3 and Table 3.4 illustrated in Figure 3.7 through Figure 3.9.

The quality of the assessment of equipment type causing the leak is considered to be high. A thorough review has been performed to relate the leak point to the correct equipment type.

The leaks from vents are releases from vents where the design specification of the vent has been exceeded.

Hoses in this context are hoses used for temporary operations, such as bleed off from well annulus to flare system. 7 % of the leaks are related to use of hoses in temporary operations. No leaks have been found that is related to flexible piping. In terms of technical properties, flexible piping may similar to hoses (however this is not investigated), but a flexible pipe is equipment that in general is intended for permanent use (actual use may of course only be a fraction of time).

The results demonstrate that valves, by far, are the largest contributor. The equipment type valve cover all types of valves both in terms of how it is operated (manual vs. actuated valve), functionality (e.g. safety valve vs. control valve) and design (e.g. gate valve vs. ball valve). Almost 50 % of the leaks are tagged to valves. The second and third largest contributors are standard flange and steel pipe. The three mentioned equipment types plus instruments constitute about 83 % of the leaks at NCS. All of the incidents related to flanges are from standard flanges. However the information related to the sealing type used (i.e. metal ring or gaskets) is scarce. No leaks stemming from compact flanges have been identified

The distribution is quite unaffected when looking at only leaks originating from leak sources in the process system (see Table 3.3 vs Table 3.4).

An important element to note when comparing the data with the HCR data for UKCS installations is a difference with regard to classification of leaks stemming from valves and flanges associated with an instrument connection. For the NCS leaks it is judged that it may be a bias towards logging leaks stemming from a valve, flange or tubing associated with instrument connections to the valve, flange or steel pipe, and not to the instrument connection as a whole. This may be due to scarce information or misinterpretation of information in the investigation report. Therefore a review of small leaks from valves, flanges and steel pipes was conducted and some leaks were re-categorized as instruments. However, there may still be some leaks related to valves, flanges and steel pipes that should have been logged on instruments. For illustration, a couple of examples of instruments including other equipment types such as valves and flanges are shown in Figure 3.6. In PLOFAM an instrument, including its valves, flanges and instrument tubing, is counted as one instrument only. Photos showing examples of instruments are given in TN-6. Hence, these valves and flanges should not be counted separately (see TN-5 Appendix B)

In some of these cases it is not known or unclear (based on the accident investigation report) whether the leak point is related to a valve or flange attached to the instrument connection or a piece of equipment in the vicinity of the instrument connection.

The following statement describes how flanges and valves connected to instruments should be included in the HCRD population database

> *"One Instrument could comprise the instrument itself, plus up to 2 valves, up to 4 flanges, 1 fitting, and associated small bore piping (1"or less). Corrosion coupons should be treated as flanged, valved connections with instrument (probe & cap) attached."*

The statement is ambiguous, which means that there are some uncertainty related to how valves and flanges associated with instruments are put in the HCR population data, which is important to account for when assessing the difference in frequency between flanges, valves and instruments. This is further discussed in Chapter 4.8.

Note that some incidents in HCRD are logged on equipment type "steel pipe" and reported as "left open" and "opened" as causes. These incidents should most likely have been logged on valves. It is assessed that this error is most likely not performed on the NCS data.

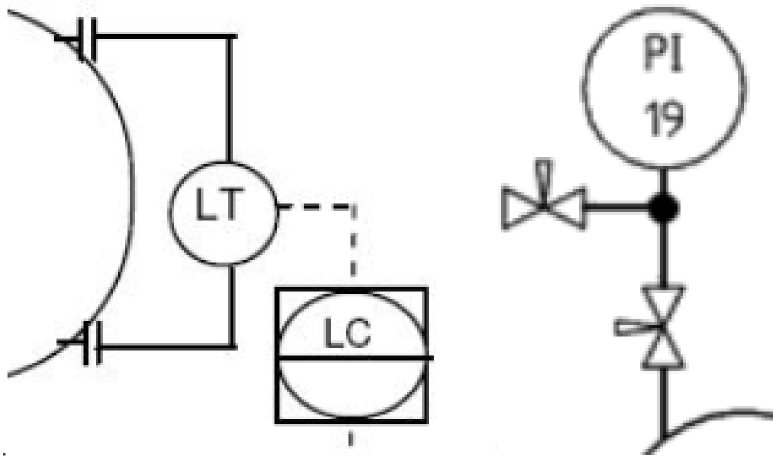


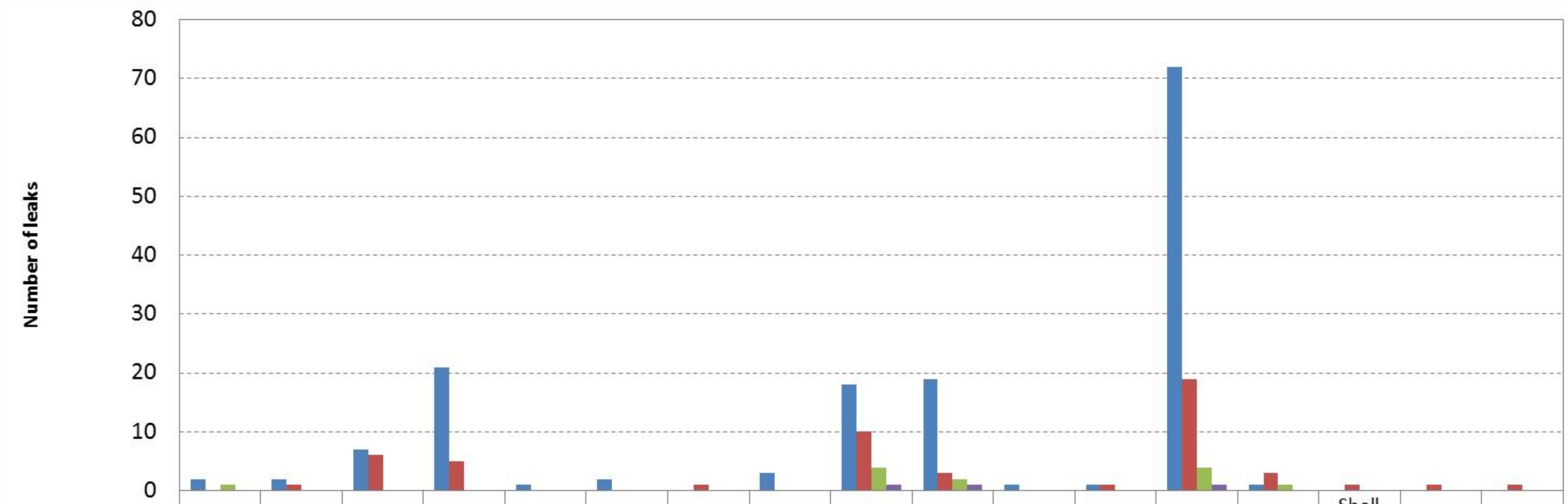
Figure 3.6 - Examples instrument connections

Table 3.3 - Relative distribution of all NCS leaks (217) per equipment type

Distribution per equipment type	b(0.1-1 kg/s)	c(1-10 kg/s)	d(10-100 kg/s)	e(>100 kg/s)	Grand Total
Compressor	0.9 %	0.0 %	0.5 %	0.0 %	1.4 %
Filter	0.9 %	0.5 %	0.0 %	0.0 %	1.4 %
Hose	3.2 %	2.8 %	0.0 %	0.0 %	6.0 %
Instrument	9.7 %	2.3 %	0.0 %	0.0 %	12.0 %
Pig trap	0.5 %	0.0 %	0.0 %	0.0 %	0.5 %
Process vessel	0.9 %	0.0 %	0.0 %	0.0 %	0.9 %
Producing well	0.0 %	0.5 %	0.0 %	0.0 %	0.5 %
Pump	1.4 %	0.0 %	0.0 %	0.0 %	1.4 %
Standard flange	8.3 %	4.6 %	1.8 %	0.5 %	15.2 %
Steel pipe	8.8 %	1.4 %	0.9 %	0.5 %	11.5 %
Storage tank	0.5 %	0.0 %	0.0 %	0.0 %	0.5 %
Unknown	0.5 %	0.5 %	0.0 %	0.0 %	0.9 %
Valve	33.2 %	8.8 %	1.8 %	0.5 %	44.2 %
Vent	0.5 %	1.4 %	0.5 %	0.0 %	2.3 %
Shell and tube heat exchanger	0.0 %	0.5 %	0.0 %	0.0 %	0.5 %
Flexible pipe	0.0 %	0.5 %	0.0 %	0.0 %	0.5 %
Gas lift well	0.0 %	0.5 %	0.0 %	0.0 %	0.5 %
Grand Total	**69.1 %**	**24.0 %**	**5.5 %**	**1.4 %**	**100.0 %**

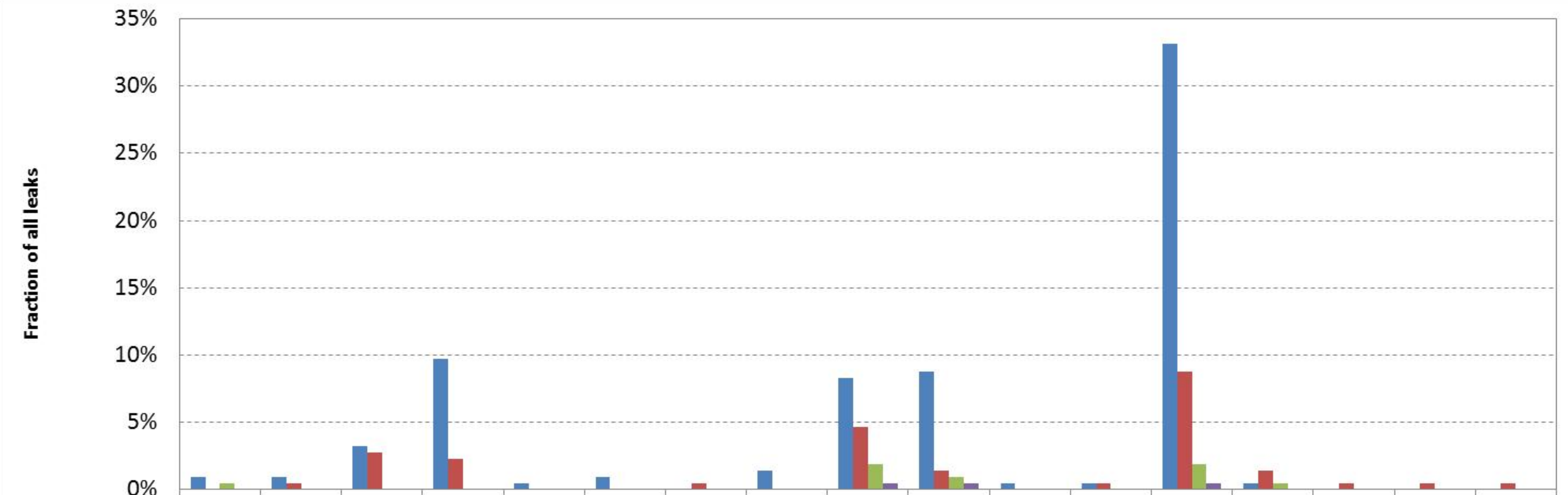
Table 3.4 - Relative distribution of NCS leaks (193) per equipment type where leaks stemming from equipment in open drain, closed drain, flare system, well system, produced water system and unknown systems have been disregarded (see Table 3.1)

Distribution per equipment type	b(0.1-1 kg/s)	c(1-10 kg/s)	d(10-100 kg/s)	e(>100 kg/s)	Grand Total
Compressor	1.0 %	0.0 %	0.5 %	0.0 %	1.6 %
Filter	1.0 %	0.5 %	0.0 %	0.0 %	1.6 %
Hose	2.6 %	2.6 %	0.0 %	0.0 %	5.2 %
Instrument	10.9 %	2.6 %	0.0 %	0.0 %	13.5 %
Pig trap	0.5 %	0.0 %	0.0 %	0.0 %	0.5 %
Process vessel	0.5 %	0.0 %	0.0 %	0.0 %	0.5 %
Pump	1.6 %	0.0 %	0.0 %	0.0 %	1.6 %
Standard flange	8.8 %	4.7 %	0.0 %	0.5 %	14.0 %
Steel pipe	9.3 %	1.6 %	1.0 %	0.0 %	11.9 %
Storage tank	0.5 %	0.0 %	0.0 %	0.0 %	0.5 %
Valve	36.8 %	8.3 %	1.6 %	0.5 %	47.2 %
Vent	0.5 %	0.5 %	0.0 %	0.0 %	1.0 %
Shell and tube heat exchanger	0.0 %	0.5 %	0.0 %	0.0 %	0.5 %
Flexible pipe	0.0 %	0.5 %	0.0 %	0.0 %	0.5 %
Gas lift well					
Grand Total	**74.1 %**	**21.8 %**	**3.1 %**	**1.0 %**	**100.0 %**



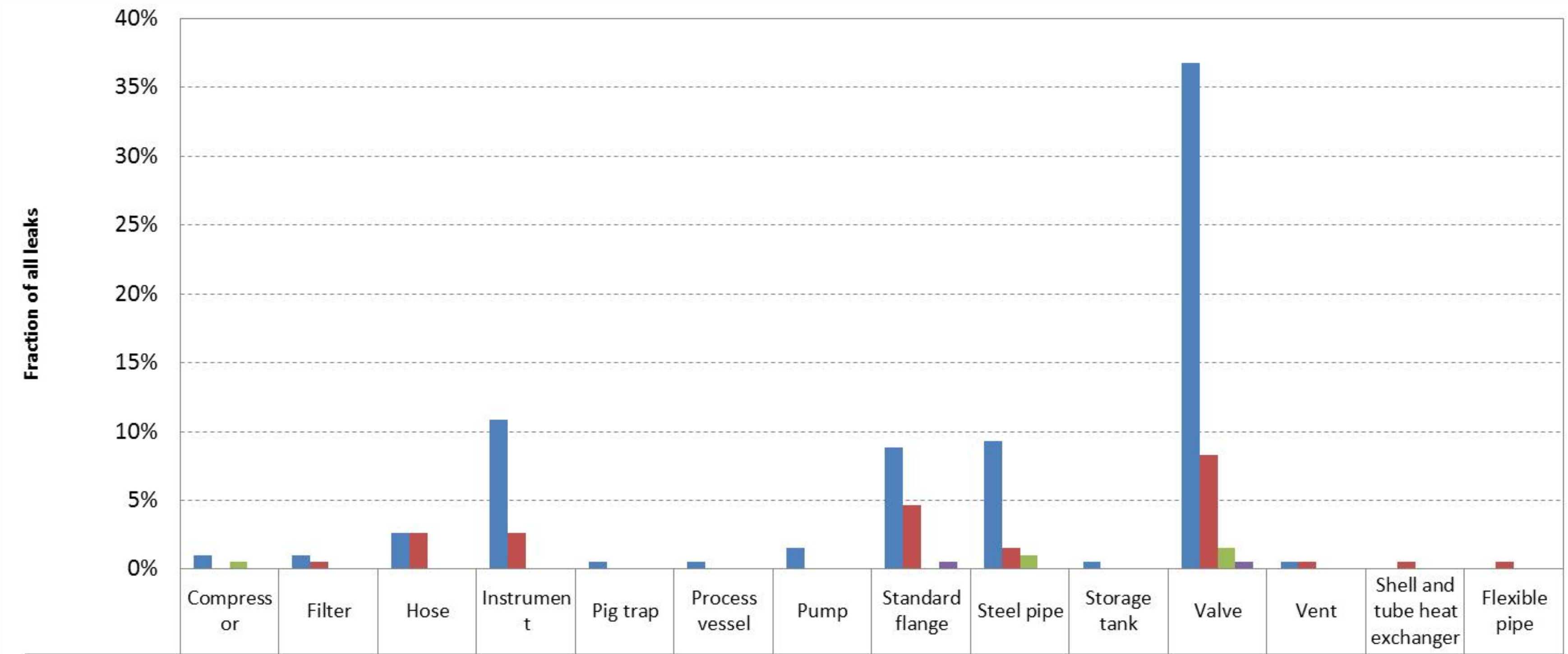
	Compre ssor	Filter	Hose	Instrum ent	Pig trap	Process vessel	Produci ng well	Pump	Standar d flange	Steel pipe	Storage tank	Unknow n	Valve	Vent	Shell and tube heat exchang er	Flexible pipe	Gas lift well
b(0.1-1 kg/s)	2	2	7	21	1	2		3	18	19	1	1	72	1			
c(1-10 kg/s)		1	6	5			1		10	3		1	19	3	1	1	1
d(10-100 kg/s)	1								4	2			4	1			
e(>100 kg/s)									1	1			1				

Figure 3.7 - Distribution of all NCS leaks (217) per equipment type



	Compressor	Filter	Hose	Instrument	Pig trap	Process vessel	Producing well	Pump	Standard flange	Steel pipe	Storage tank	Unknown	Valve	Vent	Shell and tube heat exchanger	Flexible pipe	Gas lift well
b(0.1-1 kg/s)	0.9 %	0.9 %	3.2 %	9.7 %	0.5 %	0.9 %	0.0 %	1.4 %	8.3 %	8.8 %	0.5 %	0.5 %	33.2 %	0.5 %	0.0 %	0.0 %	0.0 %
c(1-10 kg/s)	0.0 %	0.5 %	2.8 %	2.3 %	0.0 %	0.0 %	0.5 %	0.0 %	4.6 %	1.4 %	0.0 %	0.5 %	8.8 %	1.4 %	0.5 %	0.5 %	0.5 %
d(10-100 kg/s)	0.5 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	1.8 %	0.9 %	0.0 %	0.0 %	1.8 %	0.5 %	0.0 %	0.0 %	0.0 %
e(>100 kg/s)	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.5 %	0.5 %	0.0 %	0.0 %	0.5 %	0.0 %	0.0 %	0.0 %	0.0 %

Figure 3.8 - Relative distribution of all NCS leaks (217) per equipment type



	Compressor	Filter	Hose	Instrument	Pig trap	Process vessel	Pump	Standard flange	Steel pipe	Storage tank	Valve	Vent	Shell and tube heat exchanger	Flexible pipe
b(0.1-1 kg/s)	1.0 %	1.0 %	2.6 %	10.9 %	0.5 %	0.5 %	1.6 %	8.8 %	9.3 %	0.5 %	36.8 %	0.5 %	0.0 %	0.0 %
c(1-10 kg/s)	0.0 %	0.5 %	2.6 %	2.6 %	0.0 %	0.0 %	0.0 %	4.7 %	1.6 %	0.0 %	8.3 %	0.5 %	0.5 %	0.5 %
d(10-100 kg/s)	0.5 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	1.0 %	0.0 %	1.6 %	0.0 %	0.0 %	0.0 %
e(>100 kg/s)	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.5 %	0.0 %	0.0 %	0.5 %	0.0 %	0.0 %	0.0 %

Figure 3.9 - Relative distribution of all NCS leaks (193) per equipment type where leaks stemming from equipment in open drain, closed drain, flare system, well system, produced water system and unknown systems have been disregarded (see Table 3.1)

3.4 Distribution of leaks per leak rate

The distribution of leaks with respect to initial leak rate is shown in Figure 3.10 through Figure 3.21.

The following conclusions can be extracted from the data displayed in the various figures:

- Liquid leaks tend to result in slightly larger leaks than gas leaks. The difference between gas and liquid leaks is becoming more and more prominent with increasing leak rate, and is significant for leaks with an initial leak rate greater than 100 kg/s. The fraction of liquid leaks beyond 100 kg/s is five times bigger than for gas leaks. This may be explained by the higher density of liquids. The overall fraction of leaks above 100 kg/s is about 2 %. The fraction of gas leaks for such leaks is between 0.5 and 1 %, and slightly less than 5 % for liquid leaks. Given a gas leak and a liquid leak having an initial leak rate above 0.1 kg/s, it is about 7 times more likely that the initial leak rate of the liquid leak is larger than 100 kg/s than the gas leak
- The fraction of leaks having an initial leak rate larger than 10 kg/s is about 7 % (gas and liquid leaks combined)
- The fraction of leaks having an initial leak rate larger than 1 kg/s is about 32 % (gas and liquid leaks combined)
- The relative leak rate distribution is largely the same for Significant and Marginal leaks. No leaks having an initial leak rate greater than 100 kg/s has been observed for Marginal leaks. That is however judged to be rare event, and it is concluded that randomness can explain why such a leak has not been observed. The duration of such an event would be very small (~0.1 second)
- The relative distribution for the dominant equipment types (valves, flanges, instrument and steel pipe) are different, see Figure 3.15. Valves and instruments tend to produce considerable smaller leak rates than flanges. Figure 3.16 demonstrates that the relative distribution for leaks originating from steel pipes is very different for gas and liquid leaks. For the other equipment types, the relative distribution is quite similar for gas and liquid leaks. However, the assessment of the difference between equipment types for the various fluid types is due to the low number of incidents sensitive to randomness (i.e. the observed result may be due to randomness and do not represent actual underlying causes)
- There are not registered leaks from hoses with an initial leak rate above 10 kg/s. The fraction of leaks (11 in total for all leaks at NCS) is split approximately evenly between leaks in the intervals 0.1 – 1 kg/s and 1 – 10 kg/s. The distribution is clearly different from other equipment types (see Figure 3.21). This is caused by the large rupture fraction of hoses, and that the temporary hoses very seldom are larger than 0.75”
- No leaks having a leak rate larger than 10 kg/s have originated from a different equipment type than valve, standard flange or steel pipe.
- Figure 3.17 - Figure 3.20 illustrates three important points:
  - The number of large leaks, and hence the fraction of large leaks, i.e. leaks >10 kg/s and in particular leaks > 100 kg/s is low and therefore highly influenced by stochastic effects. To illustrate this Figure 3.17 shows the complementary cumulative leak rate distribution based on data from 2006 – 2017 and 2007 – 2017. Due to one leak >100 kg/s occurring in 2006 the fraction of leaks above 100 kg/s is predicted twice as high using the data period 2006 -2017 (purple curve) instead of 2007 – 2017 (green curve). Using the full data period 2001 – 2017 (blue curve) results in predicted fractions between the values predicted based on the data period 2006 -2017 and 2007 – 2017.
  - The blue and the black curve are based on the same data, but while the black curve uses the best estimated leak rate for each historical leak, the blue curve is based on the same data categorized into number of leaks with leak rate larger than 0.1, 1, 5, 10, 30, 100 and 300 kg/s. For leaks larger than about 50kg/s this gives different results. Note however that there is uncertainties related to the predicted initial leak rate that could shift the large leaks along the x-axis. Note also that the correct way of plotting the curves would not be to interpolate between data points, but from one data point drop immediately along the y-axis to the next y-value, before drawing a horizontal line to the next data point. This way the full black curve would cross x=100 kg/s and x=300 kg/s at

the same y-value as the blue curve. This is illustrated in Figure 3.18 where the dotted black line shows the actual fraction of leaks being larger than the value on the x-axis, and represents the most correct way of visualizing the data. The reader should have this in mind when evaluating the curves, which in the other figures are interpolated between the data points.

- Data for historical leaks occurring at installations located in the NCS before 2001 is available for leak rate categories 0.1 – 1 kg/s, 1-10 kg/s and >10 kg/s for Statoil and Hydro installations. Based on this the number of leaks occurring in the period 01.01.1992 - 31.12.2000 has been estimated in the MISOF report, Ref. /1/, and are given in Table 3.5. Table 3.6 gives the number of leaks on NCS larger than 0.1, 1 and 10 kg/s. Combined with data for 2001 – 2017 (given in this TN) gives also data for the full period 1992 – 2017. The table also includes a data set with adjusted number of large leaks (added 10 leaks >10 kg/s where 2 of them are >100 kg/s) of the latter data period that would give similar complementary cumulative probability distribution as observed for the period 2001 – 2017. The corresponding complementary cumulative probability distribution are given in Figure 3.19 (red curves), and illustrates that the fraction of large leaks in the period after 2001 is considerable higher than the fraction found in the data before 2001. Even though one reason could be that the industry has succeeded in reducing the number of small leaks more than the number of large leaks, the project has not been able to find a clear explanation based on failure modes, shift in technology or other causes that could justify the difference. However, as the number of large leaks is small and the causes for large leaks often are unique, stochastic effects will be prominent and it cannot be concluded that the difference in the number of large leaks is not solely due to stochastic variations (see also Chapter 6).

Figure 3.20 combines Figure 3.17 - Figure 3.19 to show the total variation among the curves described above.

It should be noticed that as basis for the historical leak rate distributions does not only include leaks stemming from the process system, but also leaks from the utility system and flare system. It turns out that leaks from flare system are associated with a significantly higher fraction of large leaks (see TN-2), hence increasing the targeted fraction of large leaks from the process system. This approach ensures that the risk factors associated with the flare system are embedded in the model. This particular aspect should be explored further for potential implementation of a model feature reflecting flare system leaks specifically.

Table 3.5 – Estimated number of leaks on NCS in period 01.01.1992-31.12.2000. Data given in leak rate categories

Table Heading	0.1-1 kg/s	1-10 kg/s	>10 kg/s	Total
Estimated number of leaks 01.01.1992-31.12.2000	158.2	66.1	4.5	228.8

Table 3.6 – Estimated number of leaks on NCS larger than 0.1, 1 and 10 kg/s for the data periods 1992 -2000, and 1992 – 2017. A data set with adjusted number of large leaks of the latter data period that would give the same complementary cumulative probability distribution as observed for the period 2001 – 2017 is also given

Table Heading	>0.1 kg/s	>1 kg/s	>10 kg/s	>100 kg/s
NCS Total (1992 - 2000)	228.8	70.7	4.5	0
NCS Total (1992 - 2017)	419.8	131.7	18.5	3
NCS Total (1992 - 2017), adjusted	429.8	141.7	28.5	5.0

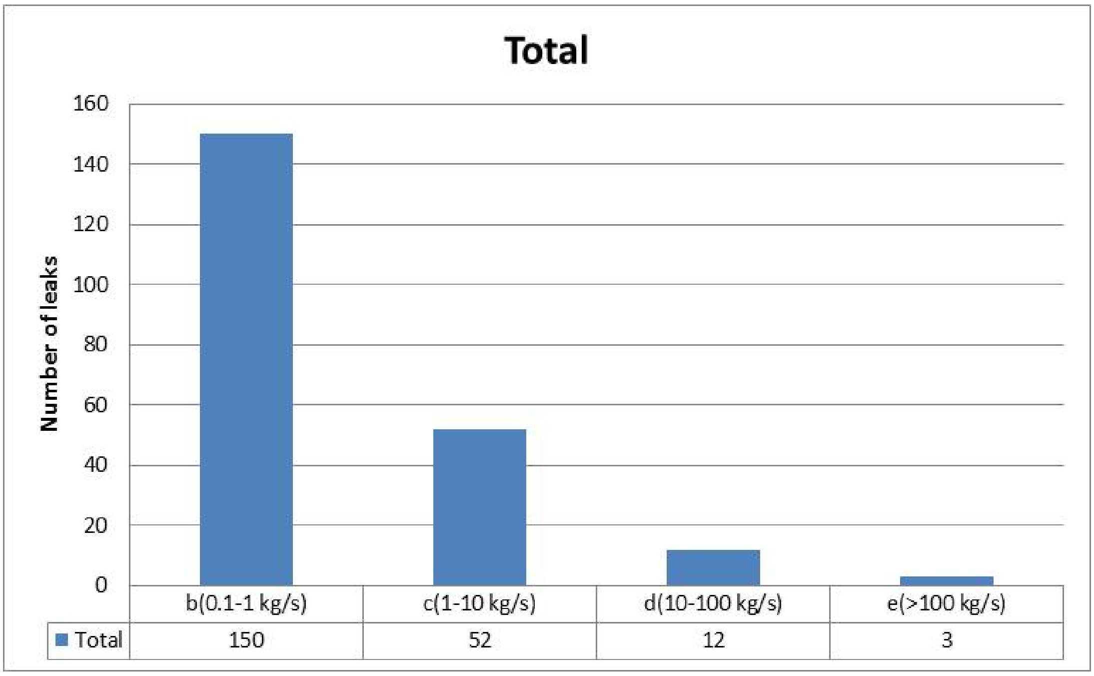


Figure 3.10 - Distribution of all NCS leaks (217) per leak category

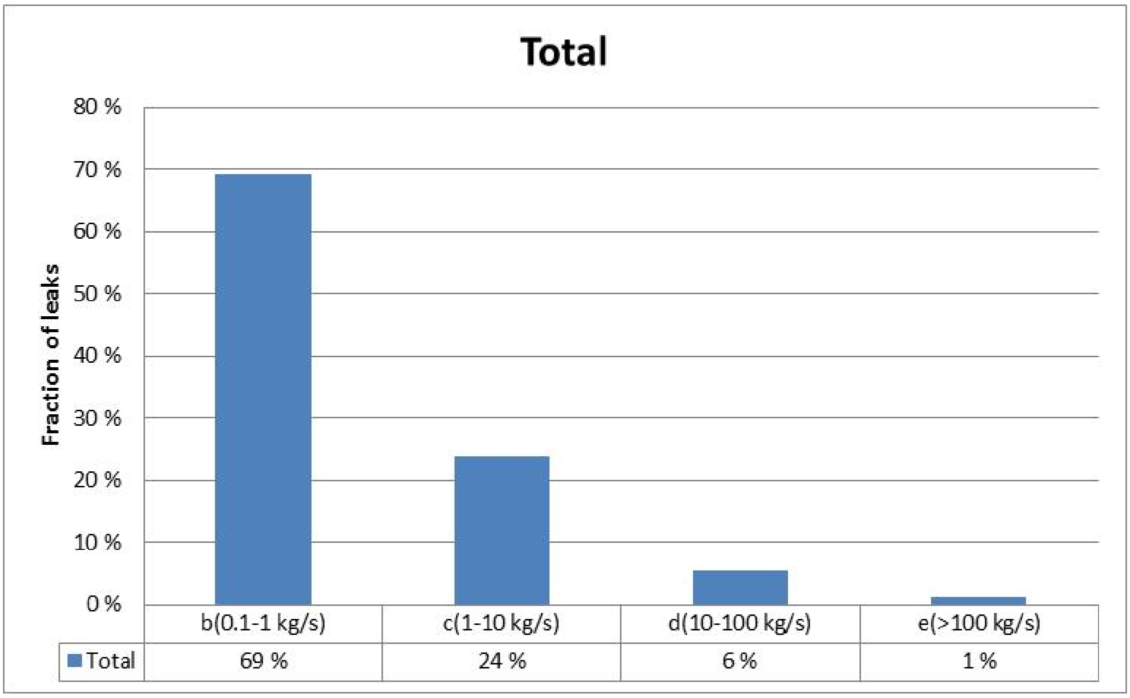


Figure 3.11 - Relative distribution of all NCS leaks (217) per leak category

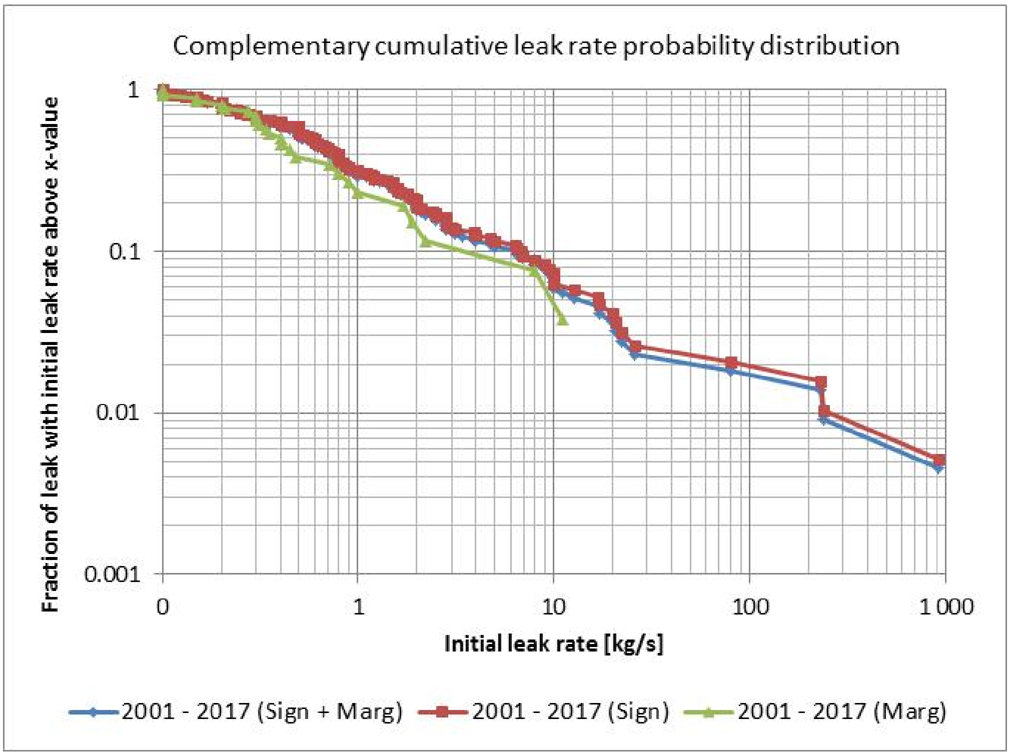


Figure 3.12 - Complementary cumulative probability distribution of NCS leaks with respect to initial leak rate both for Significant leak (total leaked quantity >10 kg, see TN-4), Marginal leak and both

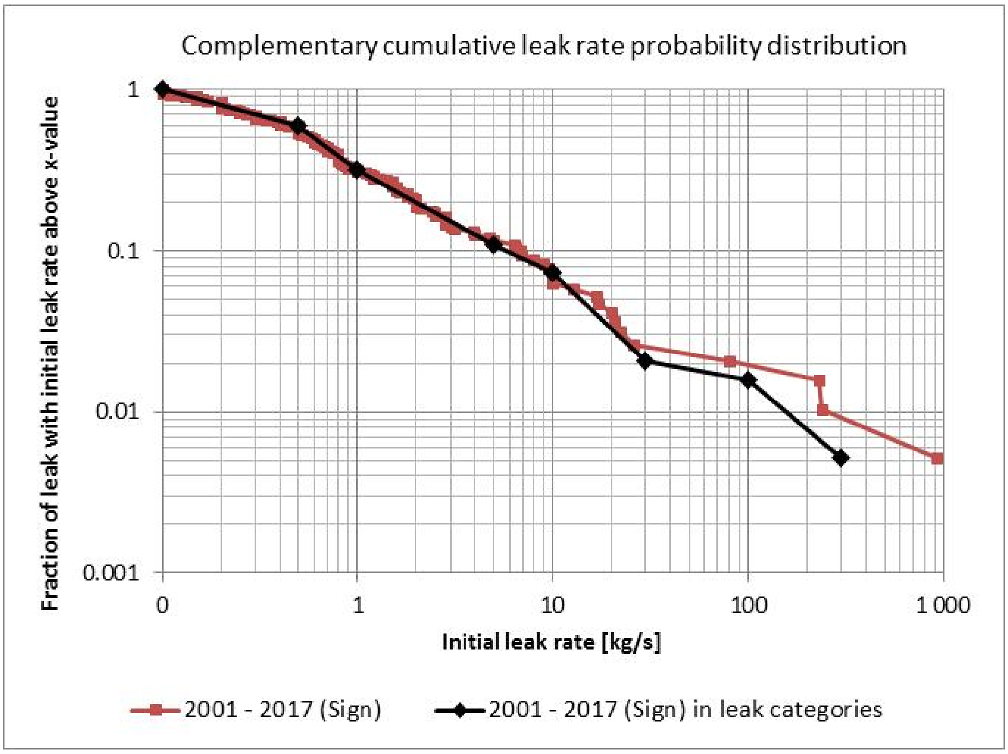


Figure 3.13 - Complementary cumulative probability distribution with respect to initial leak rate for Significant leaks (total leaked quantity >10 kg, see TN-4), based on logged leak rate and grouped in categories

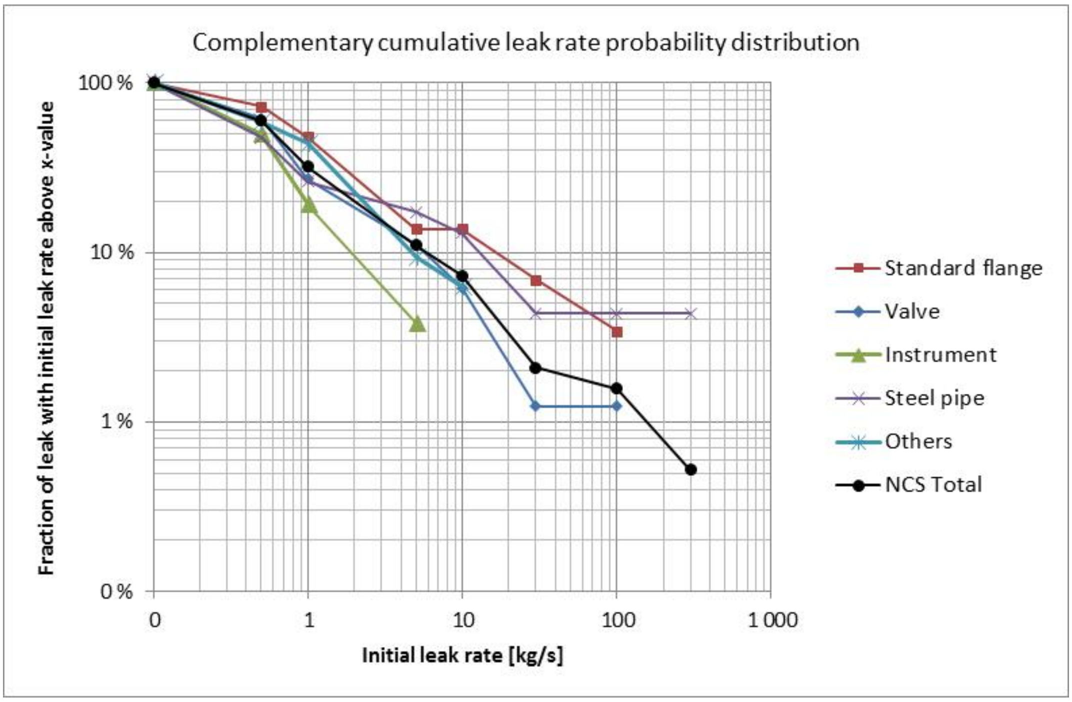


Figure 3.14 - Complementary cumulative probability distribution with respect to initial leak rate for Significant leaks on installations in the NCS population dataset. Note that the leaks are categorized into leak rate categories. See also text above

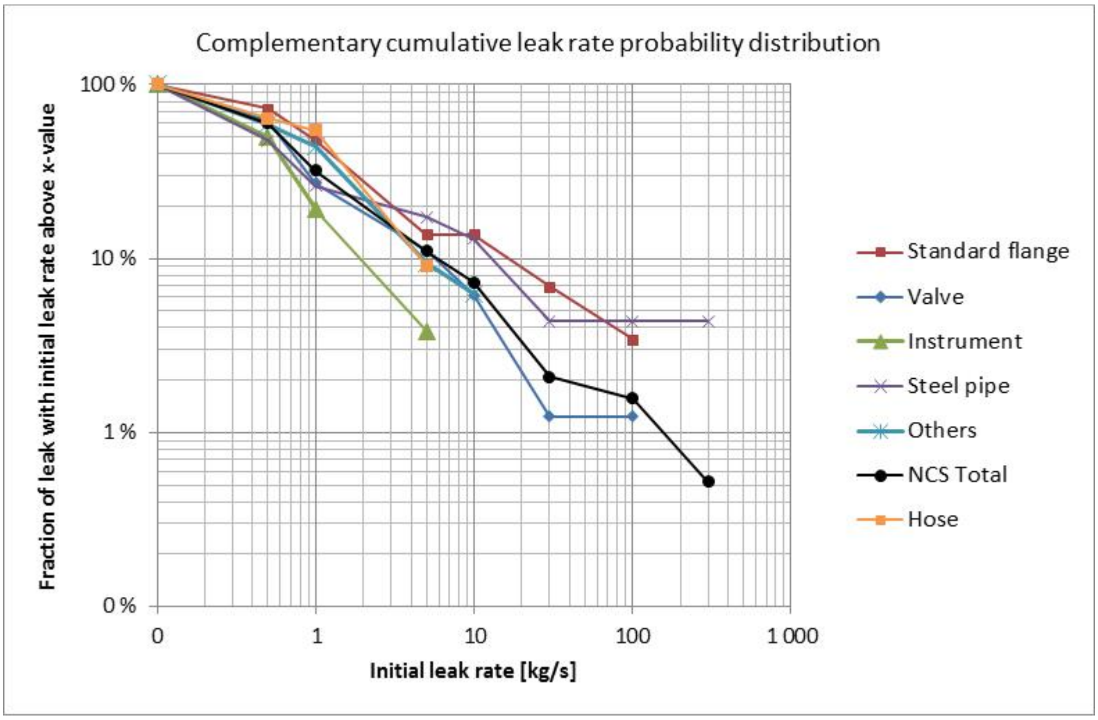


Figure 3.15 - Complementary cumulative probability distribution with respect to initial leak rate for Significant NCS leaks, including Hose leaks. Note that the leaks are categorized into leak rate categories. See also text above

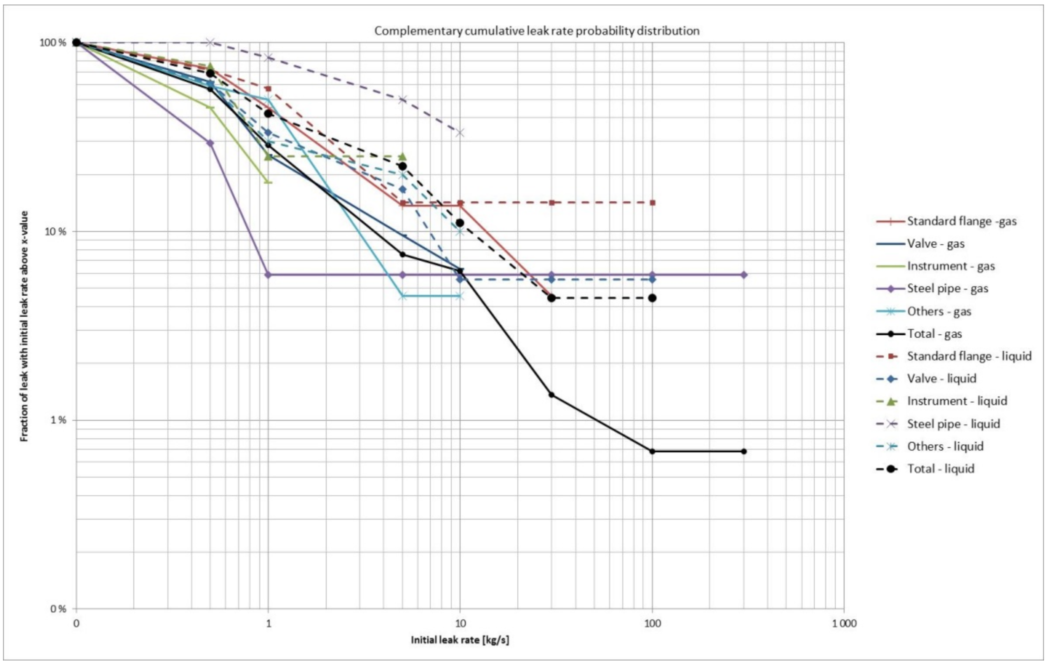


Figure 3.16 - Complementary cumulative probability distribution with respect to initial leak rate for Significant NCS leaks (total leaked quantity >10 kg, see TN-4) per fluid phase. Note that the leaks are categorized into leak rate categories. See also text above

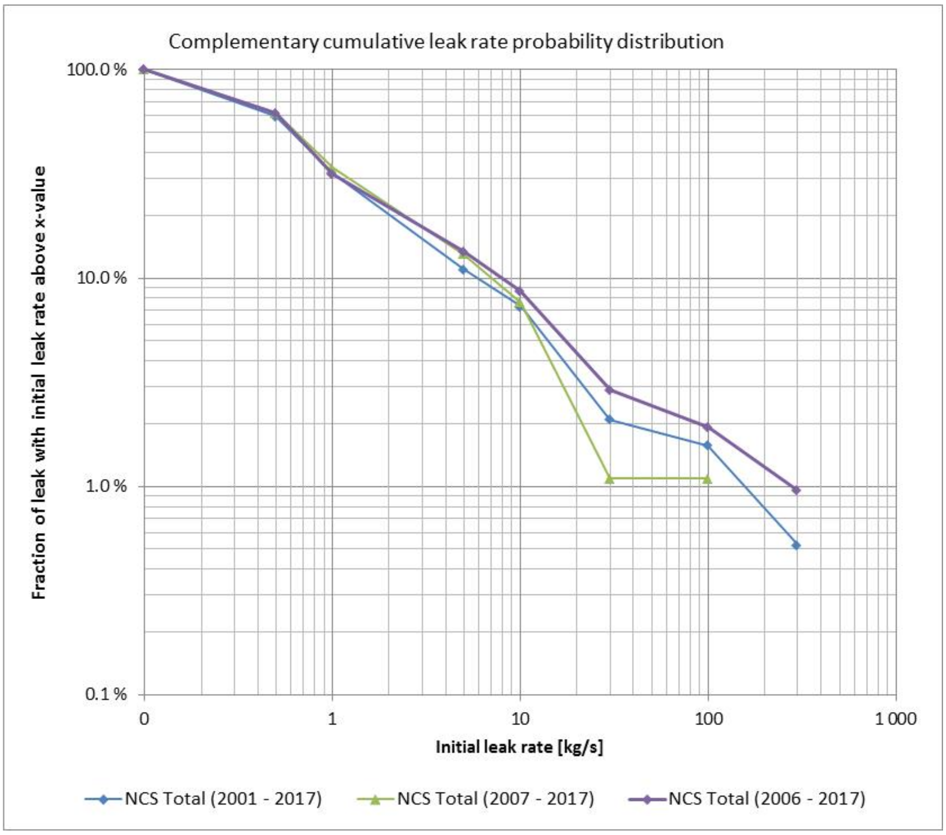


Figure 3.17 - Complementary cumulative probability distribution with respect to initial leak rate for Significant NCS leaks (total leaked quantity >10 kg, see TN-4) for different data periods. Note that the leaks are categorized into leak rate categories. See also text above

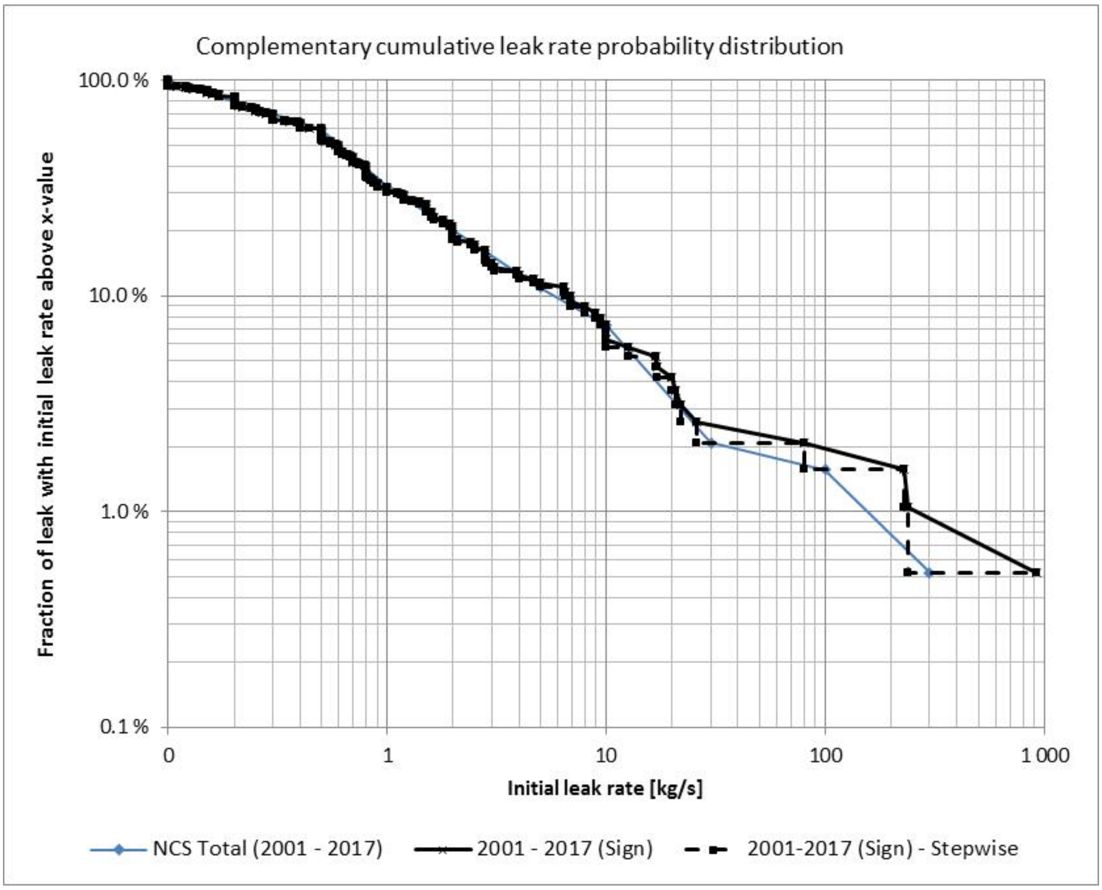


Figure 3.18 - Complementary cumulative probability distribution with respect to initial leak rate for Significant NCS leaks (total leaked quantity >10 kg, see TN-4) in period 2001 - 2017. The blue and the black curves are based on the same data, but while the black curves use the best estimated leak rate for each historical leak, the blue curve is based on the same data categorized into number of leaks with leak rate larger than 0.1, 1, 5, 10, 30, 100 and 300 kg/s. The full black line is interpolated between the data points, while the dotted black line shows the actual fraction of leaks being larger than the value on the x-axis, and represents the most correct way of visualizing the data

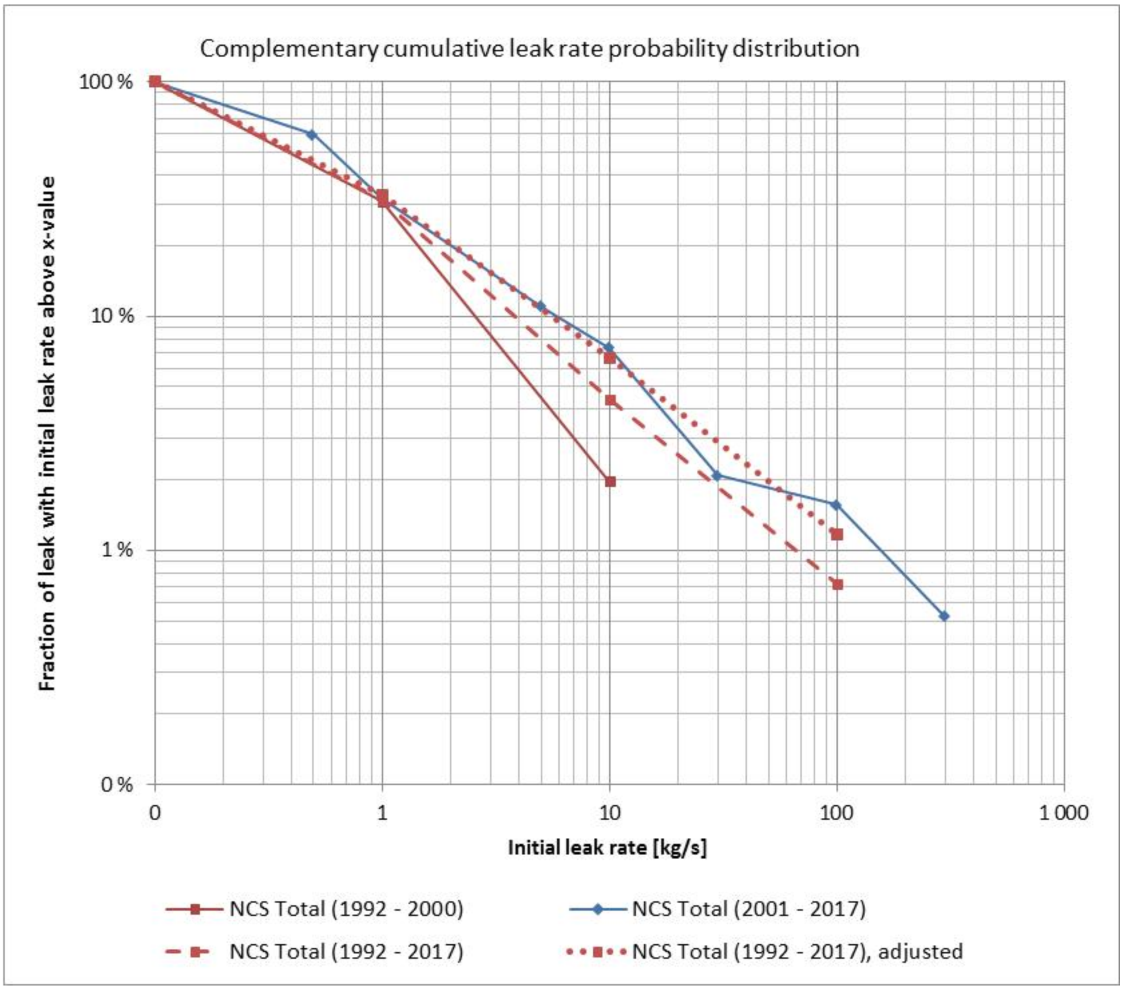


Figure 3.19 - Complementary cumulative probability distribution with respect to initial leak rate for Significant NCS leaks (total leaked quantity >10 kg, see TN-4) in period 2001 – 2017, together with corresponding curves including data from the period 1992-2000

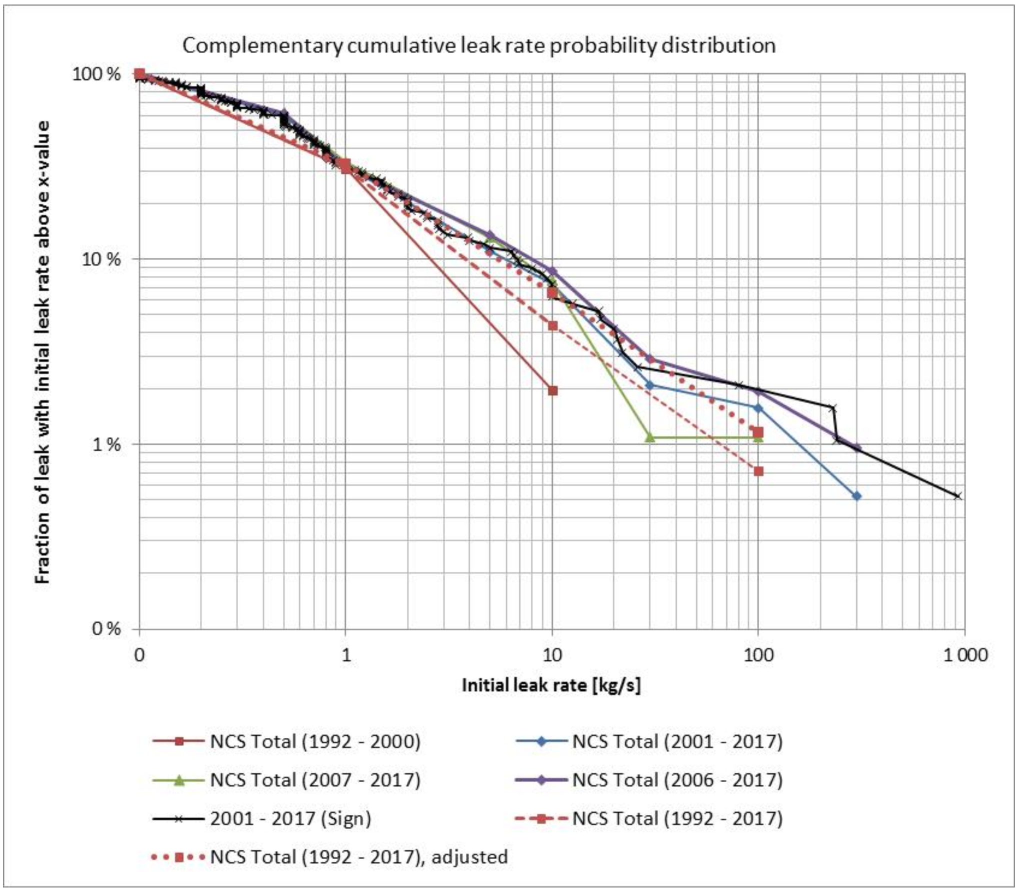
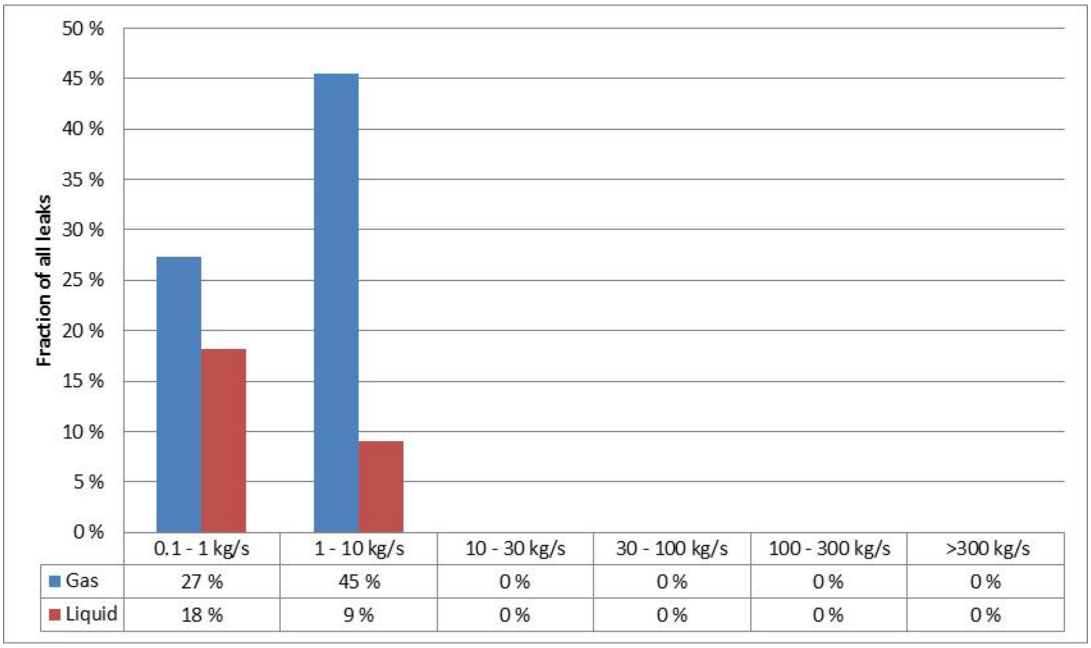


Figure 3.20 - Complementary cumulative probability distribution with respect to initial leak rate for Significant NCS leaks (total leaked quantity >10 kg, see TN-4) for different data periods



	0.1 - 1 kg/s	1 - 10 kg/s	10 - 30 kg/s	30 - 100 kg/s	100 - 300 kg/s	>300 kg/s
Gas	27 %	45 %	0 %	0 %	0 %	0 %
Liquid	18 %	9 %	0 %	0 %	0 %	0 %

Figure 3.21 - Relative distribution of leaks from hoses with respect to initial leak rate for all Significant NCS leaks (total leaked quantity >10 kg, see TN-4) per fluid phase

3.5 Distribution of leaks per leak rate per fluid type

The distribution of leaks with respect to initial leak rate is shown in Table 3.7 and Figure 3.22 through Figure 3.24.

Leaks categorized as condensate, oil or well fluid is considered to be liquid leaks when applying the data for validation of the model in TN-6. Furthermore, leaks with unknown fluid is distributed according to the overall relative distribution for the known incidents (see Chapter 6). The resulting distribution per fluid phase (gas or liquid) is shown in Figure 3.23 and Figure 3.24.

The main conclusion extracted from the data is that about 3 out 4 leaks are gas leaks. This fraction is quite independent of initial leak rate except for the very large leaks (having an initial leak rate beyond 100 kg/s). For leaks with rate above 100 kg/s, the fraction of liquid leaks is different. For such leaks, 2 out of 3 are liquid leaks. This may be explained by the higher density of liquid leaks (i.e. the leak rate is considerable higher for the same hole size for liquid leaks than for gas leaks) and/or unique causes for leaks related to steel pipe (see Figure 3.16 and statement evaluation in previous section). But the number of leaks in this category is only 3, and the relative distribution as well as the assessment of the causes is sensitive to randomness.

Table 3.7 - Distribution of all NCS leaks (217) per fluid type

Distribution fluid type	Condensate	Gas	Oil	Unknown	Well fluid	Grand Total
b(0.1-1 kg/s)	5	115	24	5	1	150
c(1-10 kg/s)	1	35	10	3	3	52
d(10-100 kg/s)		9	3			12
e(>100 kg/s)	1	1	1			3
Grand Total	**7**	**160**	**38**	**8**	**4**	**217**

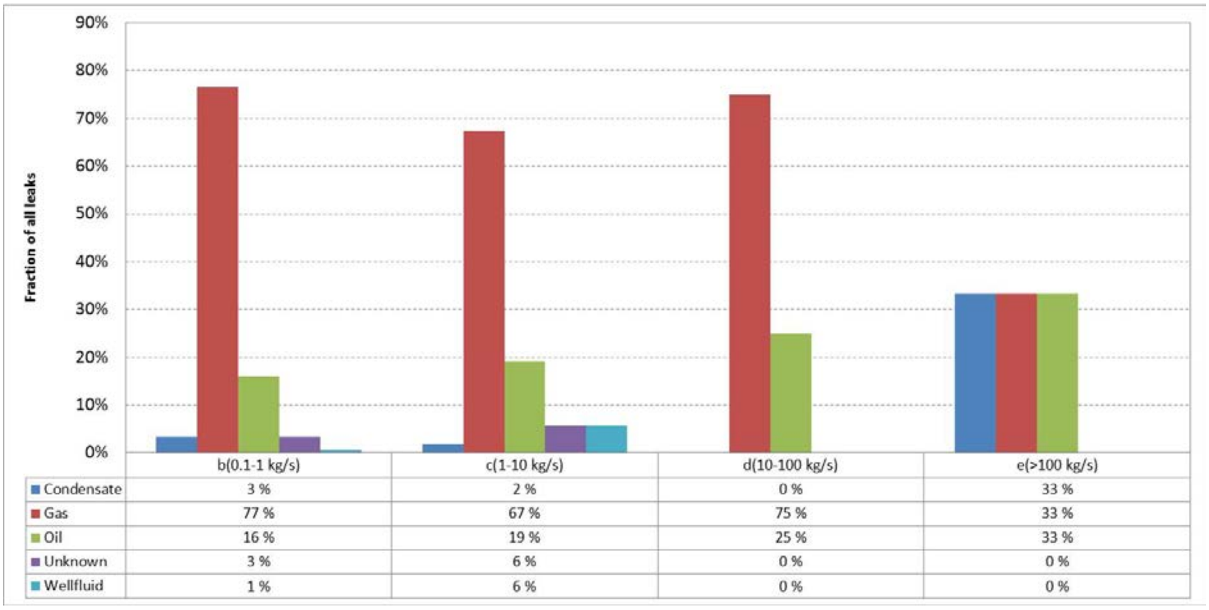
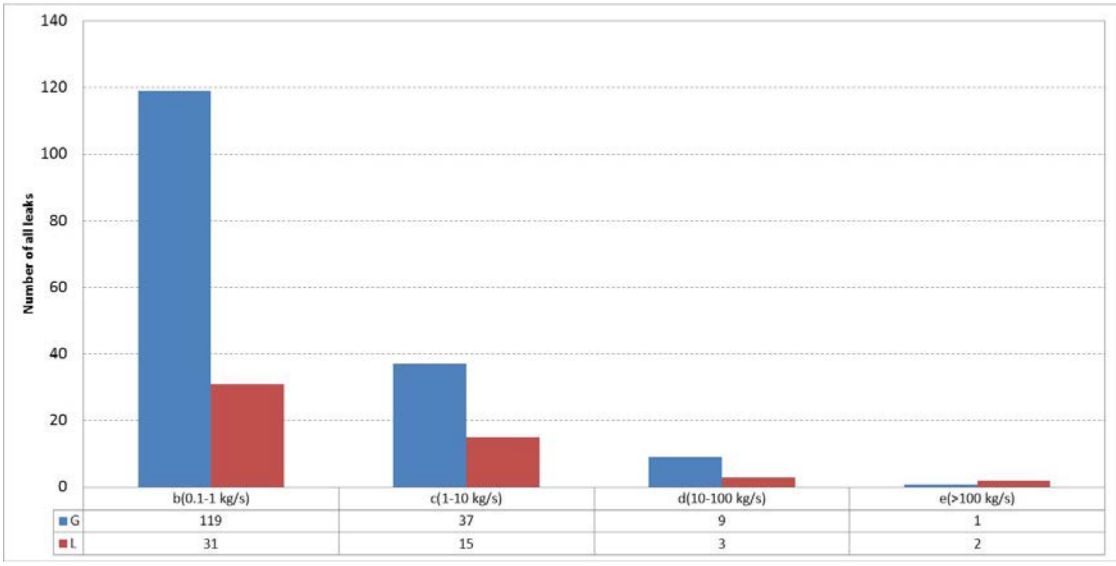
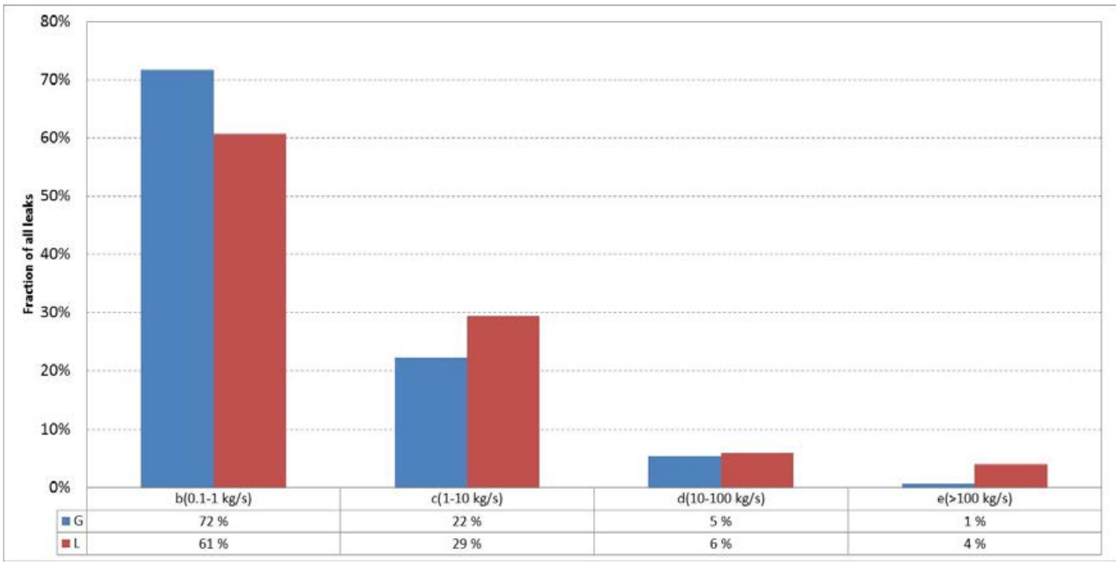


Figure 3.22 - Distribution of all NCS leaks (217) per fluid type



	b(0.1-1 kg/s)	c(1-10 kg/s)	d(10-100 kg/s)	e(>100 kg/s)
G	119	37	9	1
L	31	15	3	2

Figure 3.23 - Distribution of all NCS leaks (217) per fluid phase



	b(0.1-1 kg/s)	c(1-10 kg/s)	d(10-100 kg/s)	e(>100 kg/s)
G	72 %	22 %	5 %	1 %
L	61 %	29 %	6 %	4 %

Figure 3.24 - Distribution of all NCS leaks (217) per fluid

3.6 Hose leaks

In total 13 leaks from hoses have occurred on NCS in 2001 – 2017. Detailed information regarding, initial leak rate, released quantity, hole size and pressure for the 13 scenarios are given in Figure 3.25 - Figure 3.28. Black colour indicates that the scenario was an oil leak, while blue colour indicates that the released medium was gas phase.

The following should be noted regarding the recorded leaks from hose:

- The maximum initial leak rate recorded in 8 kg/s. The releases are associated with small hole sizes and small - medium initial release rate
- The hole size is normally small (less than 1" for all recorded leaks) but still large compared to the hose dimension (most hoses are ¾"). Full rupture is recorded in about 1/3 of the incidents. This is explained by the large fraction of hose leaks related to over pressurization, resulting in full rupture
- Historical leaks are associated with pressure up to 140 barg for gas leaks, but significantly lower for oil leaks

- The released quantity is normally relatively small. Except one of the 13 leaks, all leaks resulted in less than 200 kg being released. The fraction of Marginal leaks is more than twice as high as for other equipment types. The reason why the full inventory from an ESD segment is released is because hose operations are often special operation where the hose is not connected to a fully pressurized ESD segment. Also, manual intervention is common under hose leaks because personnel are frequently at the scene of the incident detecting the problem and terminates the unfolding scenario

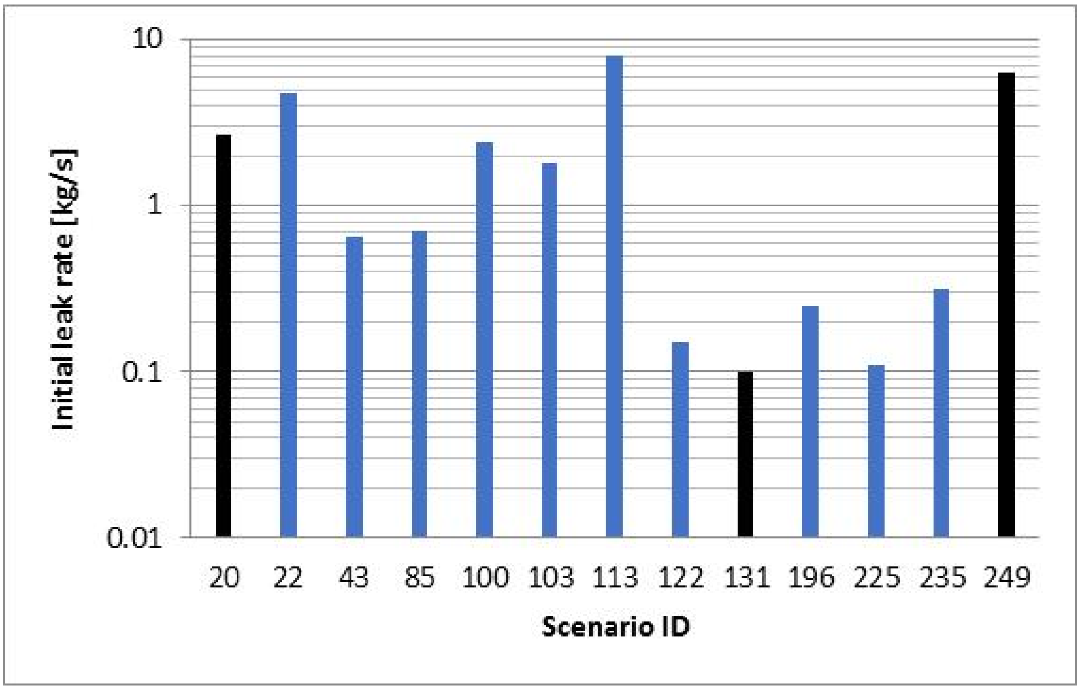


Figure 3.25 – Initial leak rate for hose leaks on NCS 2001 – 2017. The y-axis is in logarithmic scale

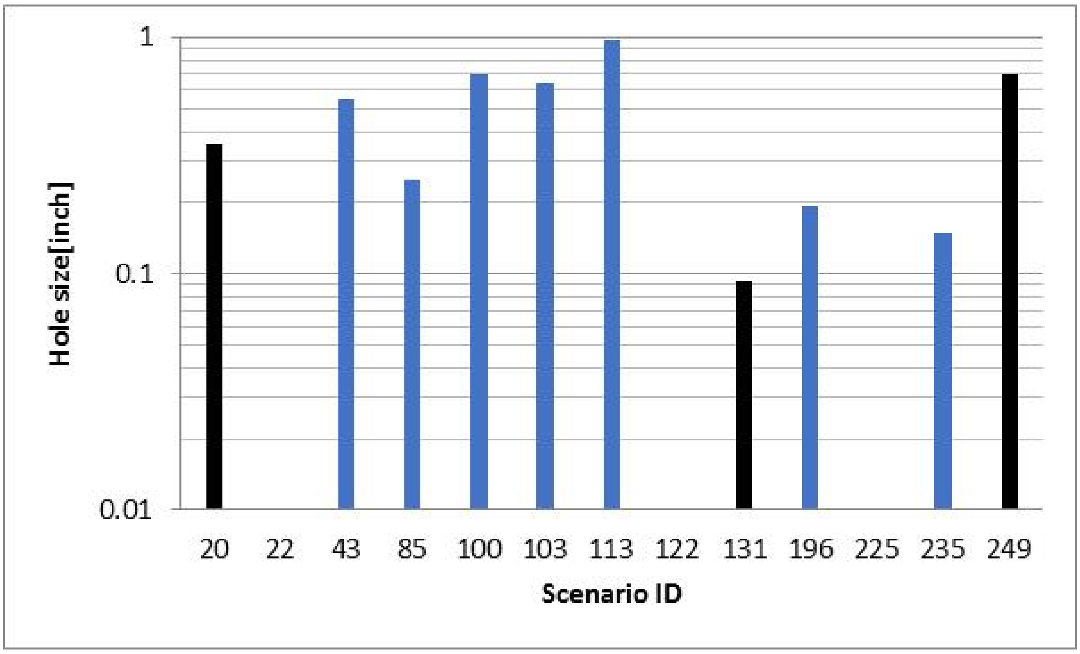


Figure 3.26 – Hole size for hose leaks recorded on NCS 2001 – 2017. The y-axis is in logarithmic scale

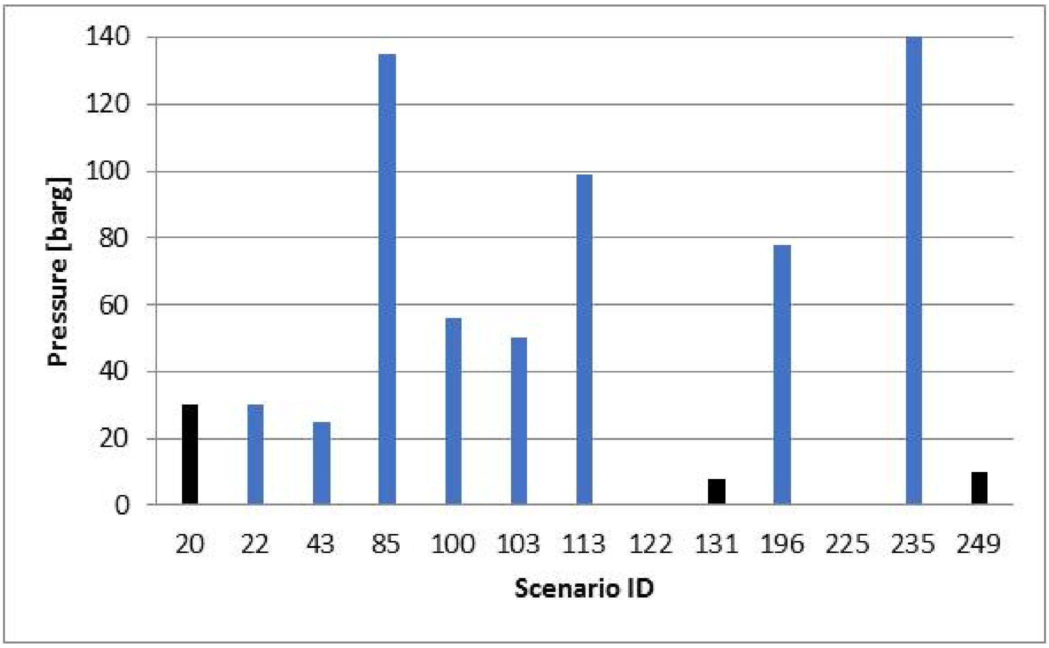


Figure 3.27 – Inventory pressure for hose leaks recorded on NCS 2001 – 2017

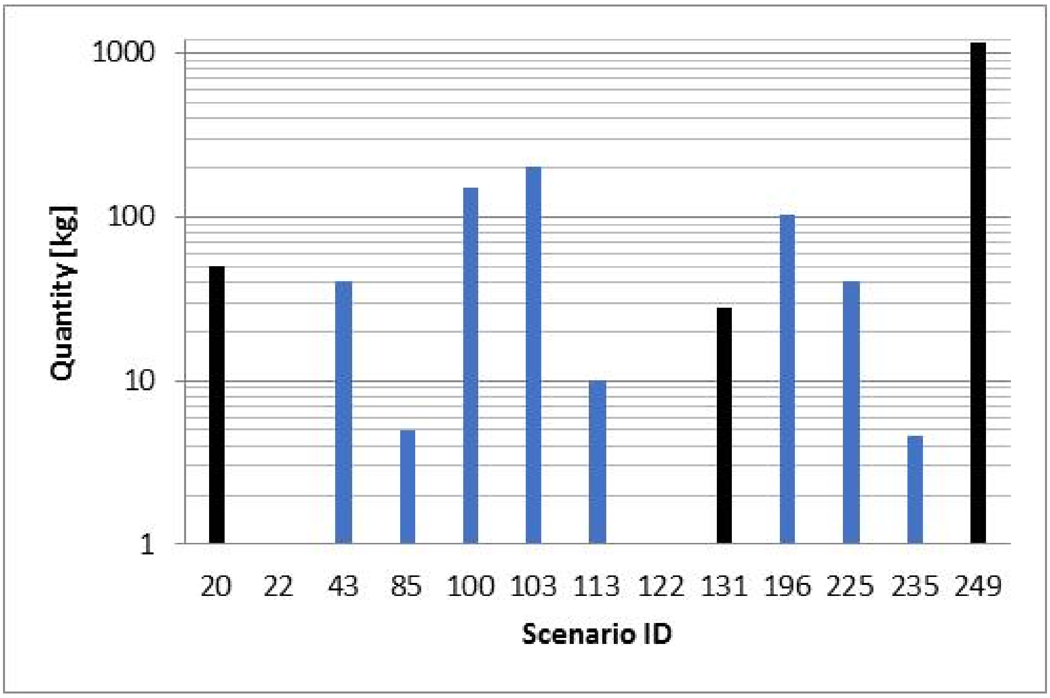


Figure 3.28 - Released quantity for hose leaks recorded on NCS 2001 – 2017. The y-axis is in logarithmic scale

4 NCS population dataset

4.1 General

Population data has been collated for 85 installations based on equipment counts extracted from the QRAs for the installations. 6 out of the 85 installations have not been set in operation by 31.12.2017. Hence, population data is available for 79 installations being in operation in the period 01.01.2001 – 31.12.2017.

For the remaining 25 installations, where equipment counts have not been available, the population data (*i.e.* equipment counts) has been estimated by defining an equivalent installation in the NCS population dataset. The equivalent installation has been based on an overall evaluation of the installation characteristics. Only 11 out of the 25 installations have been in operation in the period 01.01.2001 – 31.12.2017, while 14 installations have either been decommissioned before 2001 (13 installations) or not been set in operation yet (1 installation). The 11 installations that have been in operation in 2001 - 2017 are listed in Table 4.1 together with the installation assessed as representative/equivalent. Names of the installations are anonymized throughout the report, and the age of the installations as wells as the years in production in the period 01.01.2001 – 31.12.2017 are not reported to ensure that the installations cannot be identified. In total equipment counts for 109 installations have been established. The population data set for the 109 installations is denoted "NCS population dataset".

Population data on topside producing wells, producing wells equipped with gas lift and number of hose operations have been established based on input from the two operators operating the major fraction of installations on the NCS.

Table 4.1 - Installations where equipment counts are not available together with the installation used as representative for establishing NCS population dataset. The number of years in operations in the period 01.01.2001 – 31.12.2017 is given in the rightmost column

Installation	Representative installation
Platform 70	Platform 24
Platform 72	Platform 25
Platform 73	Platform 10
Platform 74	Platform 24
Platform 75	Platform 42
Platform 82	Platform 24
Platform 83	Platform 20
Platform 85	Platform 24
Platform 89	Platform 4
Platform 105	Platform 20
Platform 107	Platform 106

The number of equipment years and cumulative number of equipment years at NCS are given as function of time in Figure 4.1 and Figure 4.2. About 62% of all equipment years logged on NCS are logged in the time period 2001 – 2017.

Population data on topside producing wells, producing wells equipped with gas lift and number of hose operations have been established based on input from the two operators operating the major fraction of installations on the NCS.

Counts of steel pipe length are available for 28 installations out of the 109 installations, of which 24 has been in operation in the period 01.01.2001 – 31.12.2017.

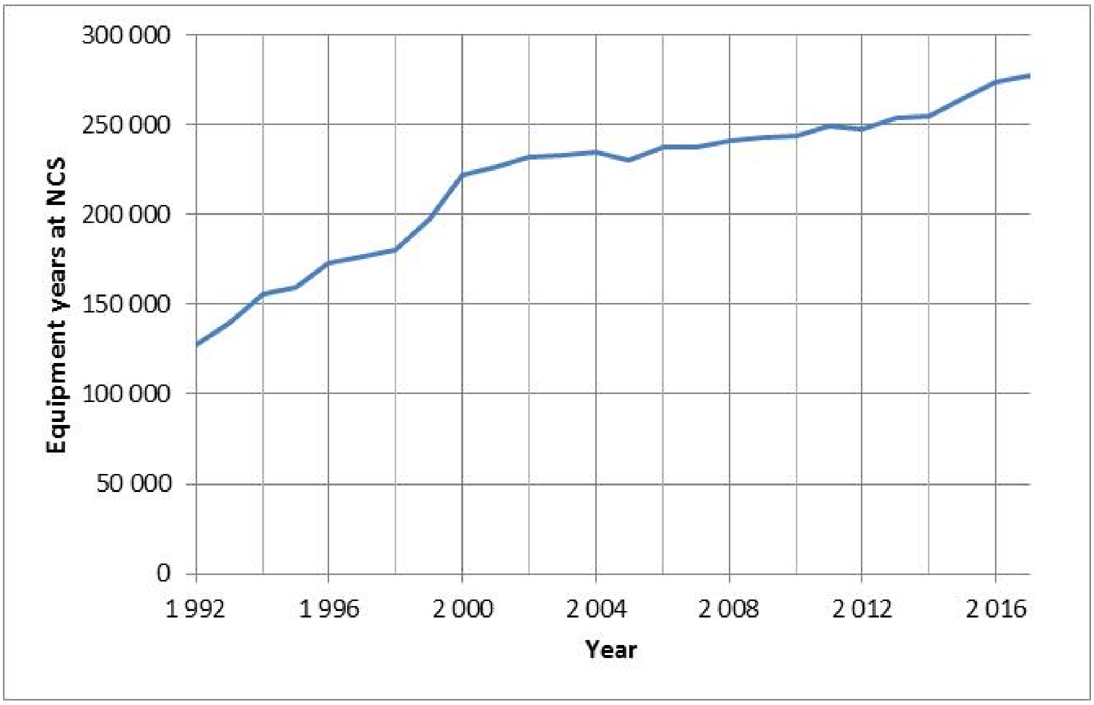


Figure 4.1 – The number of equipment year per year, i.e. the number of equipment in operation on NCS per year.

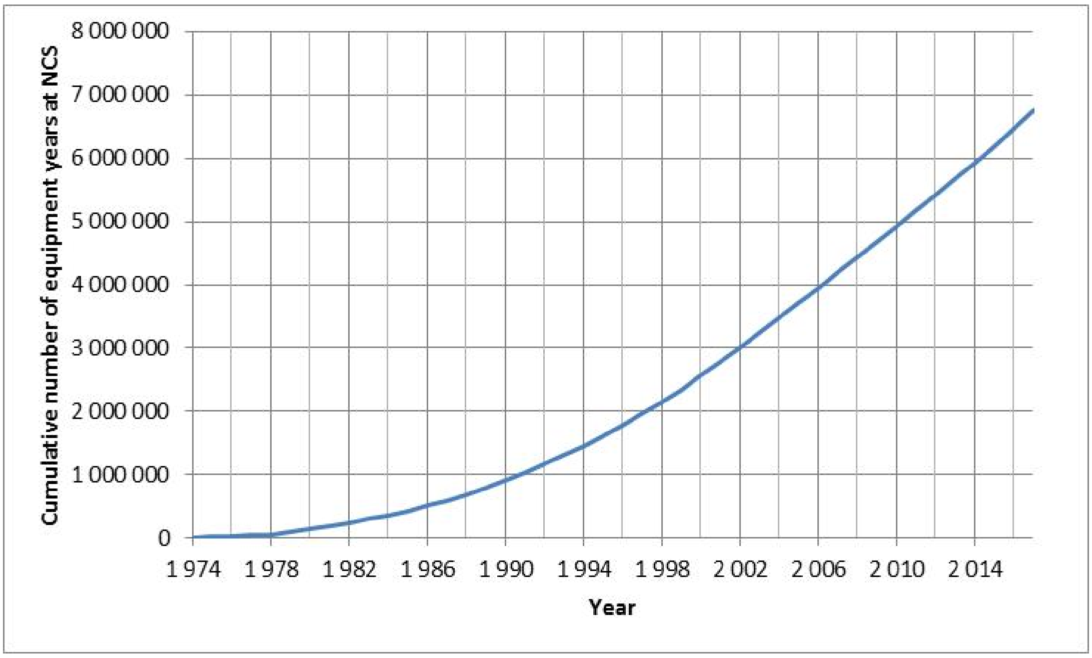


Figure 4.2 – Cumulative number of equipment years on NCS

4.2 Number of process equipment units

Figure 4.3 through Figure 4.6 shows the overall equipment counts for the dominant types of equipment; namely valves, standard flanges and instruments, for the 90 installations that have been in operation in the period 2001 – 2017 (full period or part of the period). Steel pipe, the number of wells and number of hose operations are not included.

Standard flanges include all types of flanges. The number of special types of flanges, such as SPO compact flanges and graylock, are in any case judged to be negligible relative to the number of standard ASME flanges. The model for compact flanges is based on a separate evaluation of available population data on compact flanges, which is presented in TN-6. No model has been developed for graylock flanges.

98 % of the equipment in terms of number of units is valves, flanges or instruments (hose operations not included).

Of the remaining equipment, vessels and heat exchangers have the highest number.

The equipment type air-cooled heat exchanger registered in the HCR database has not been registered in the equipment counts.

The count of atmospheric vessels are only two in the whole population, which means that such equipment units and the systems such equipment units are associated with are generally not included in offshore QRAs.

The equipment types air-cooled heat exchangers and atmospheric vessels can therefore not be validated with the validation model.

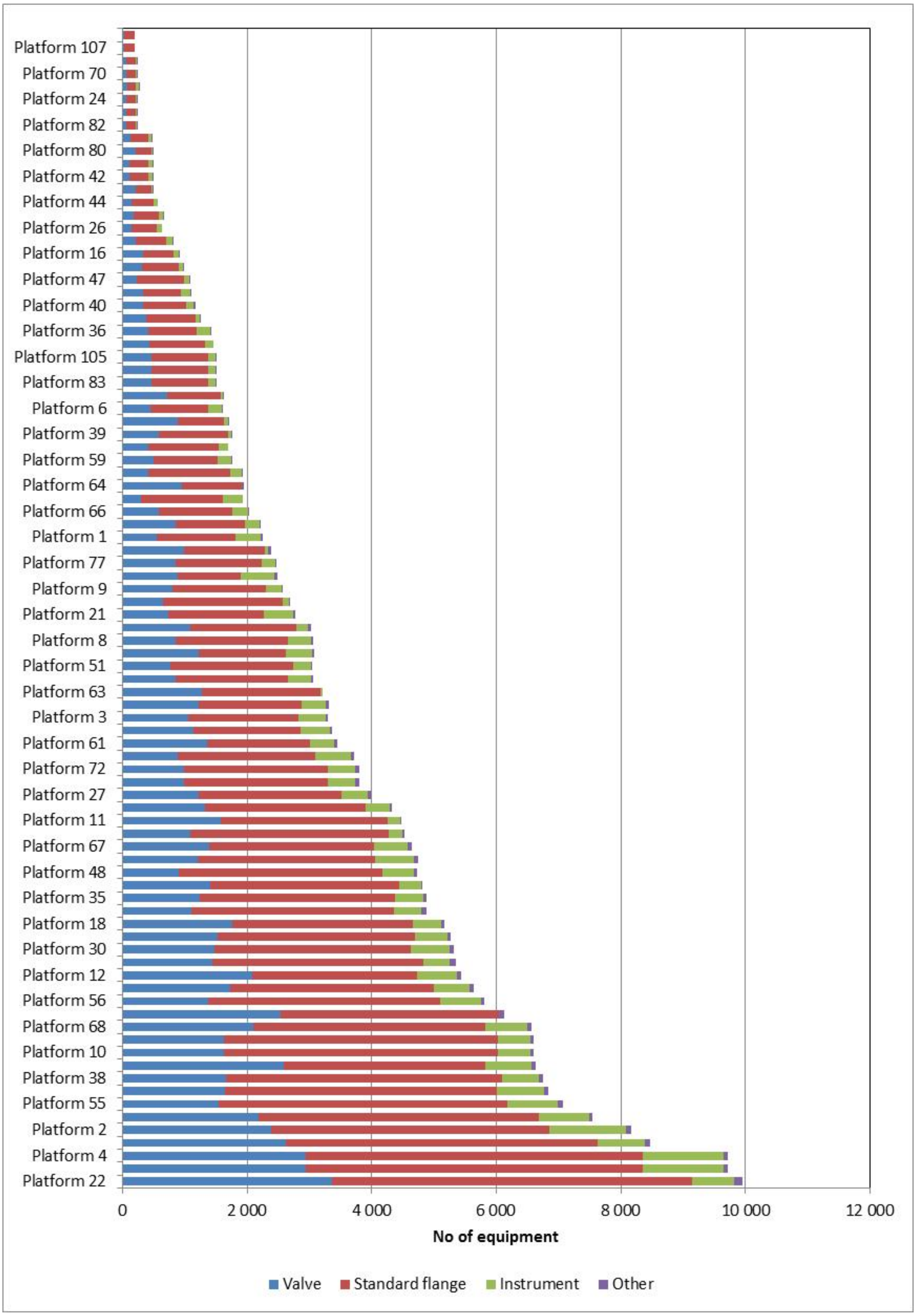


Figure 4.3 - Distribution equipment counts for dominant type of equipment (standard flange, valve and instrument) for the 90 installations being in operation in the period 2001 - 2017. Steel pipe, well and hose operations are not included as part of the category "Others"

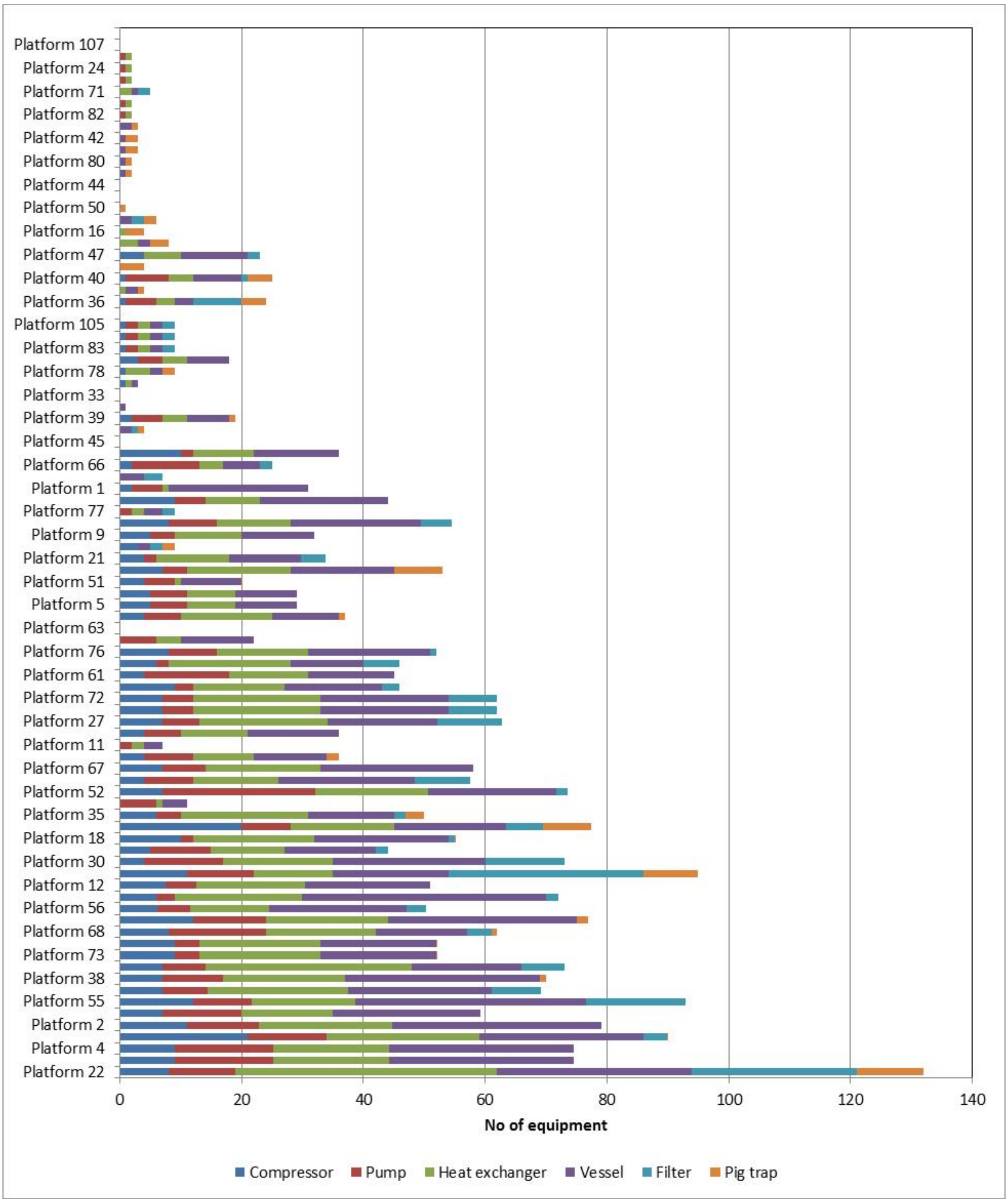


Figure 4.4 - Distribution equipment counts for compressors, pumps, heat exchangers, vessels, filters and pig traps for the 90 installations that have been in operation in the period 2001 – 2017

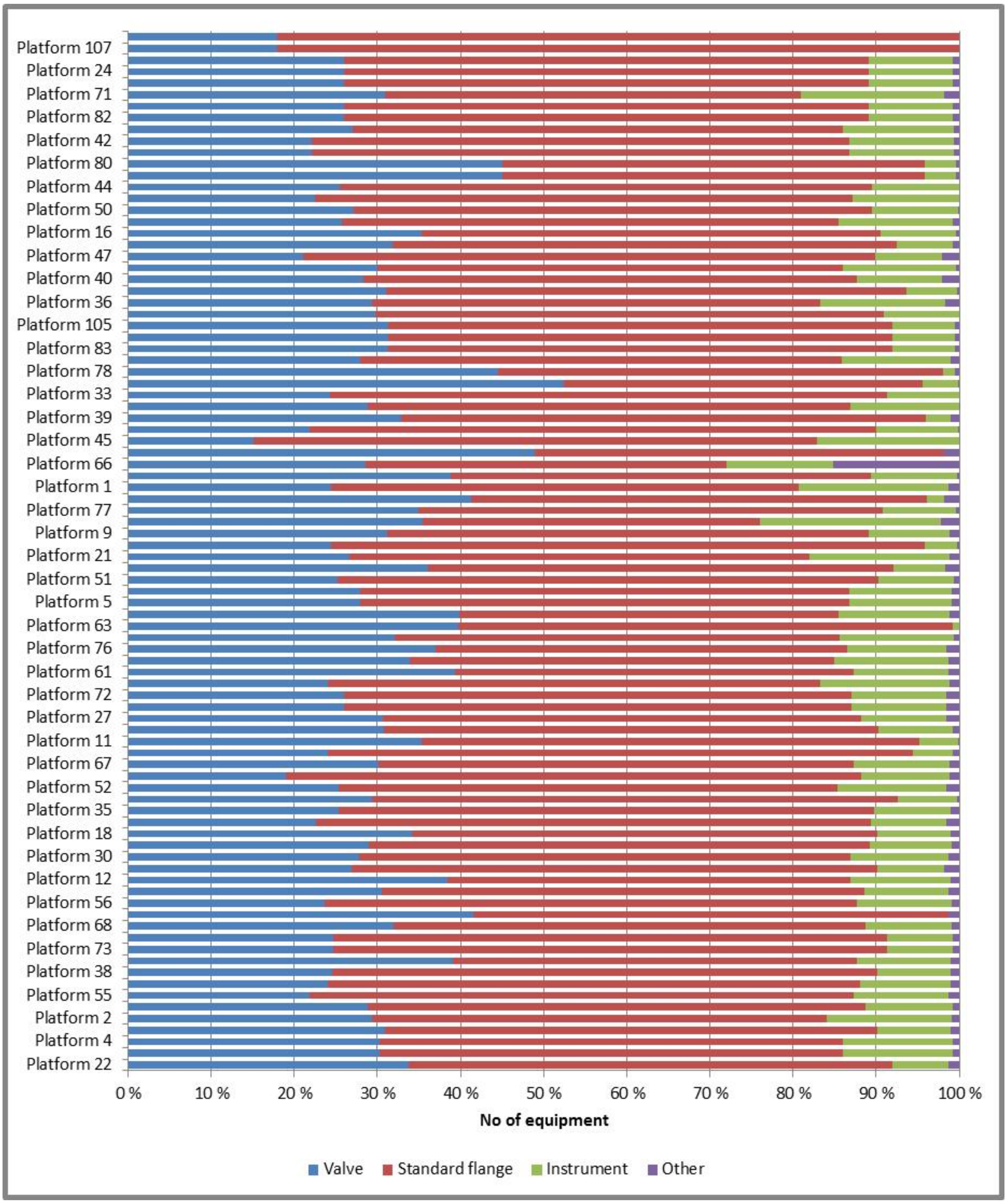


Figure 4.5 - Relative distribution equipment counts for dominant type of equipment (standard flange, valve and instrument) for the 90 installations that have been in operation in the period 2001 – 2017. Steel pipe, well and hose operations are not included as part of the category "Others"

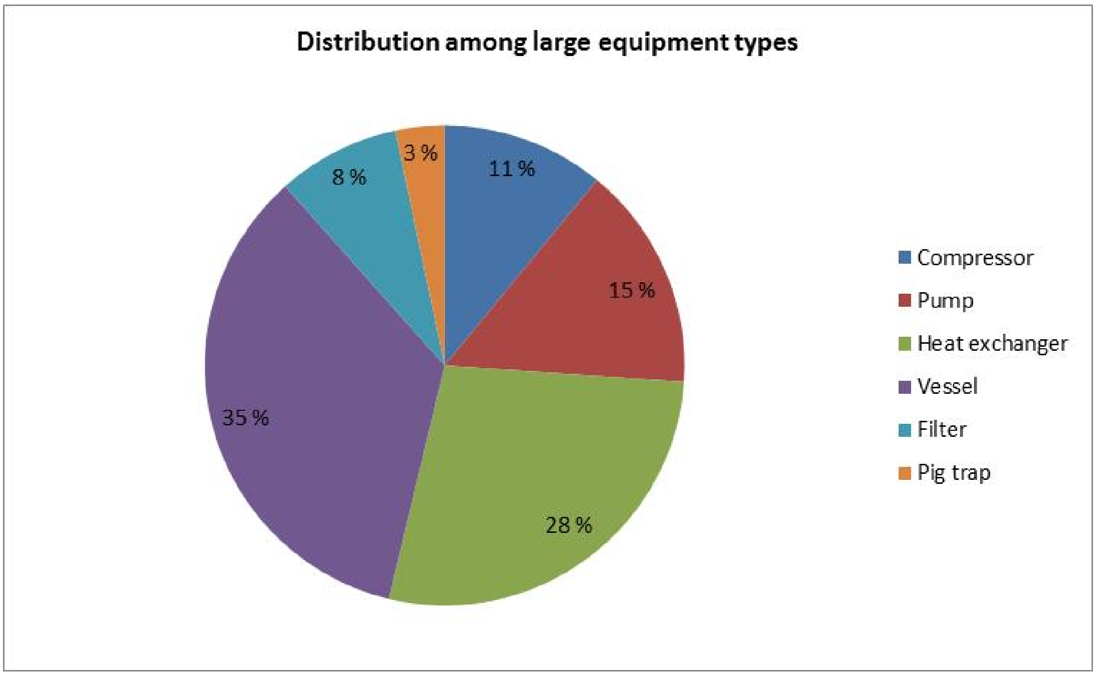


Figure 4.6 - Relative distribution of number of equipment for compressors, pumps, heat exchangers, vessels, filters and pig traps.

4.3 Steel piping

The count of steel pipe length per platform (24 installations) being in operation in the period 01.01.2001 – 31.12.2017 is shown in Figure 4.7.

The equipment counts are in general based on either of the following methodologies:

a) Measurement based on iso-view drawings of piping layout

b) Assessment of pipe length based on general equipment layout and platform layout.

The accuracy of method a) is considered significantly better than method b).

Figure 4.9 displays the ratio of steel pipe length divided by number of valves. The results demonstrate that there is a considerable variance. The number of counts of valves is generally judged to be the most accurate number. It is also reasonable to expect that the ratio should not vary too much. It is hard to assess whether the variation represent actual difference in design or are a result observed due to inaccurate counting. Furthermore, it is difficult argue whether the counts of steel pipe length generally represents an overprediction or underprediction relative to actual design.

Hence it is judged that the use of the counts of steel pipe length in the validation model must account for some uncertainty when concluding on steel pipe leak frequency.

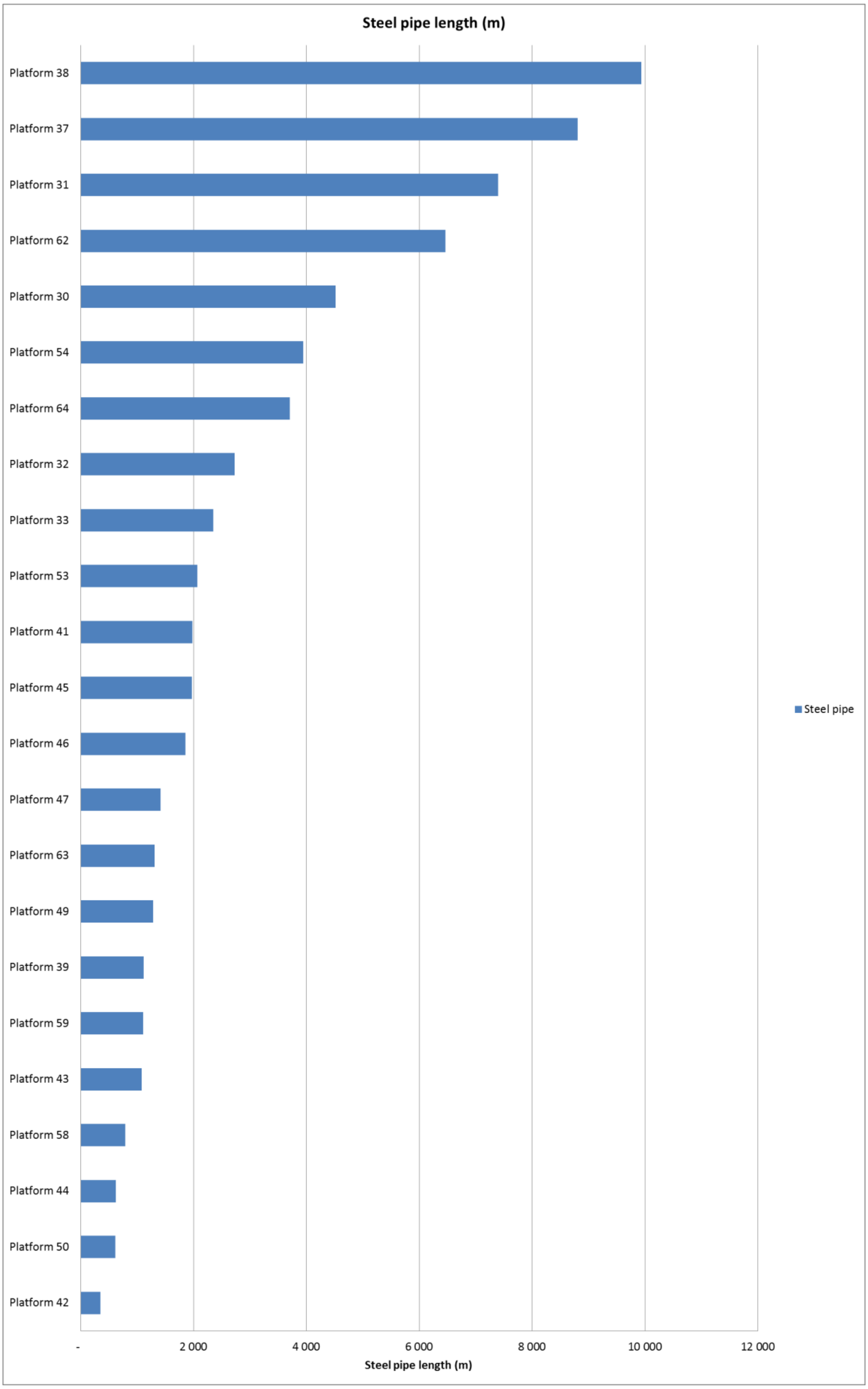


Figure 4.7 - Steel pipe per platform for installations where counts of steel piping is included

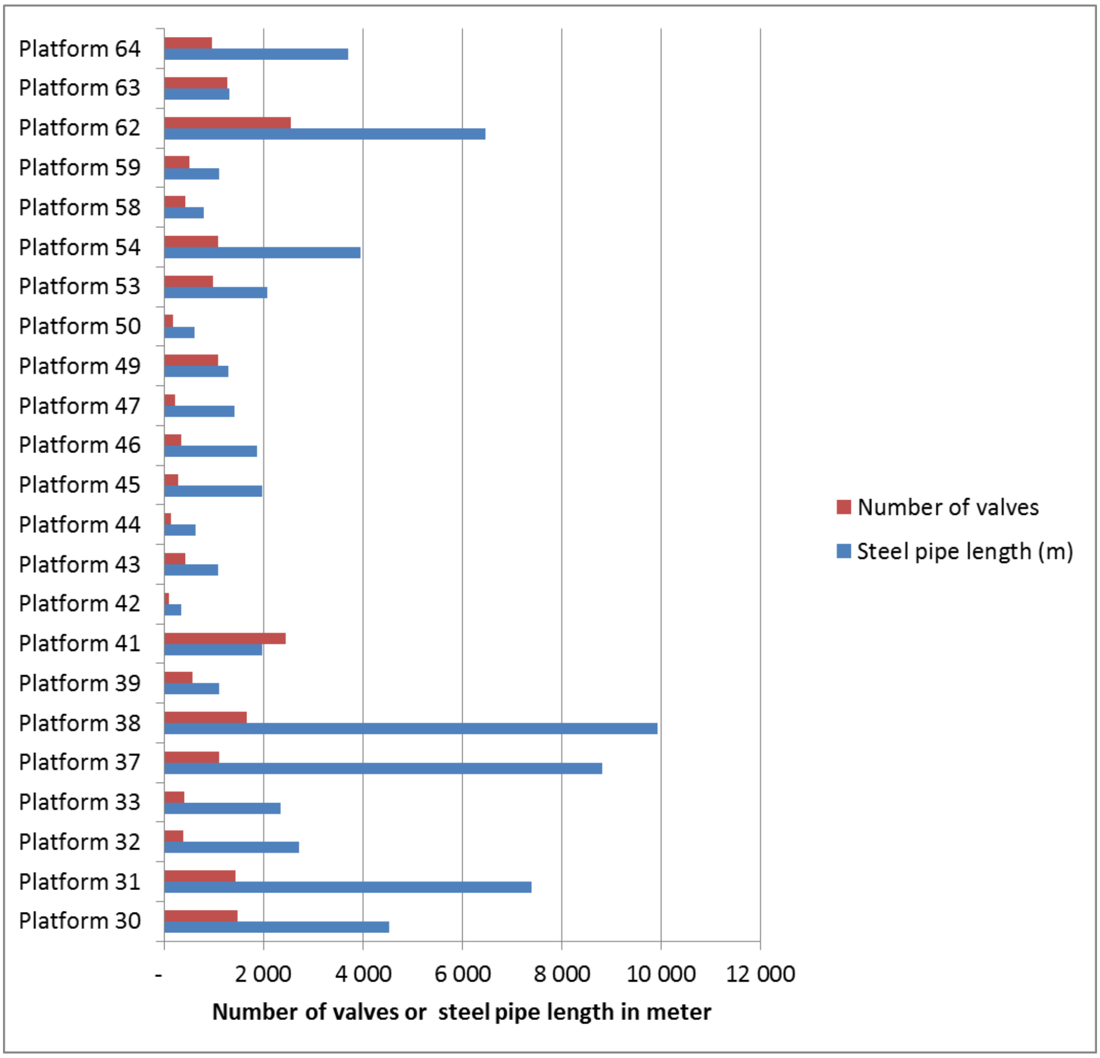


Figure 4.8 - Number of valves and steel pipe for installations where counts of steel piping is included in the NCS population dataset

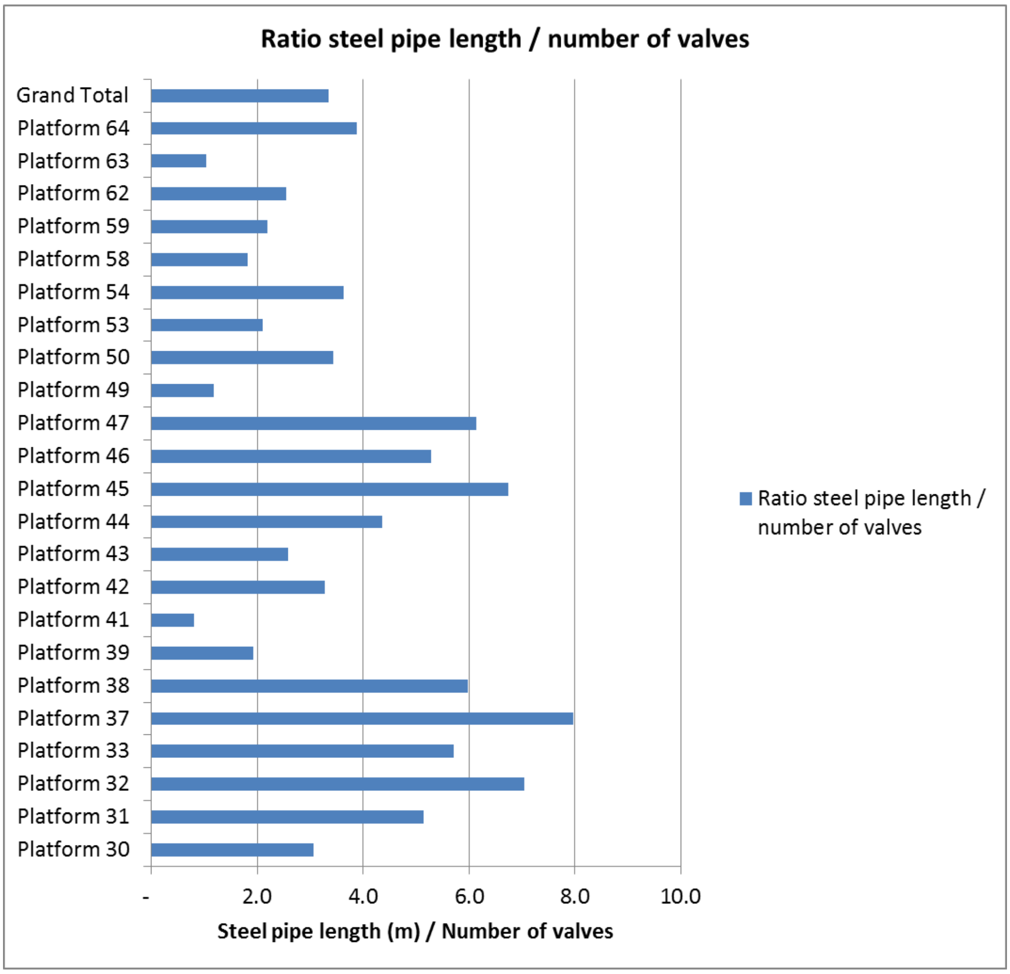


Figure 4.9 - Ratio steel pipe length divided by number of valves for installations where counts of steel piping are included in the NCS population dataset

4.4 Producing wells and gas lift wells

The number of wells at NCS is estimated for Equinor's and ConocoPhillips' installations, by the respective operators, based on QRAs and for a few installations based on the number of wells on equivalent installations. For Equinor's installations, only the total number of well are given. They are assumed to be distributed homogenously among Equinor's installation, resulting in equal number of wells at different installations.

The number of topside wells and wells with gas lift for the various installations per platform in the NCS population dataset are shown Figure 4.10. The total number of wells is summarized in Table 4.2.

Topside wells are the total of gas injection wells and producing wells (both wells with and without gas lift are included). Wells with gas lift are the producing wells equipped with gas lift.

The uncertainty related to the estimate of the number of wells is considered to be small.

Table 4.2 – Number of topside wells on the 90 installations that have been in operation in the period 2001 – 2017

Row Labels	Total number of topside wells	Wells with gas lift
NCS population dataset	987	392

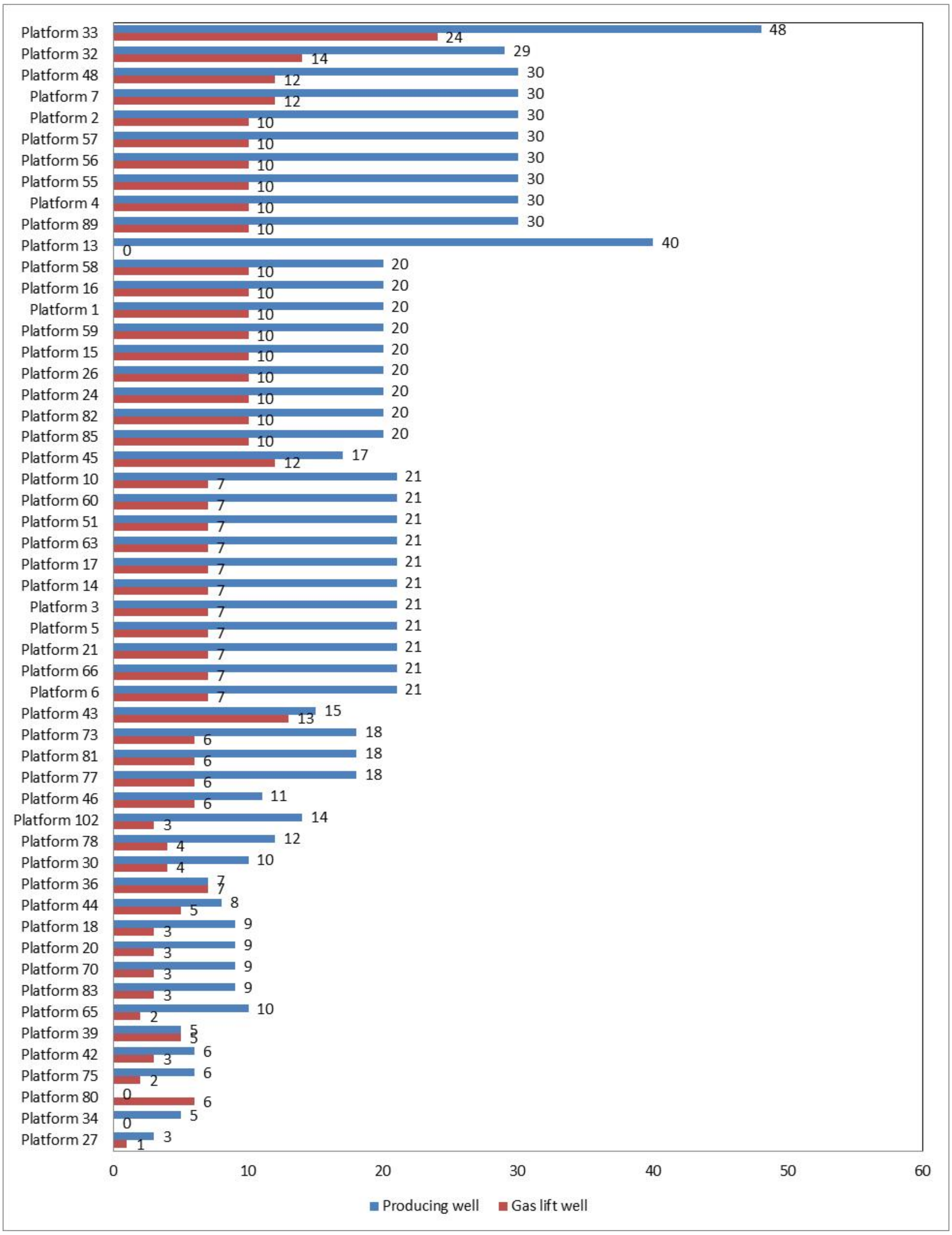


Figure 4.10 - The total number of topside producing wells (wells with and without gas lift) and the number of producing wells with gas lift on the installations in the NCS population dataset being in operation in 2001 – 2017 (90 installations). Only installations with wells are included

4.5 Hose operations

Hose operations are defined as operations involving temporary use of hose(s). Examples of such operations are:

- Bleed off of well annulus to flare system
- Washing/flushing of systems

The number of yearly temporary operations involving use of hose for 5 installations in the NCS population dataset is shown in Figure 4.11. The average number of hose operations for these 5 installations are 170.

In addition to data from these 5 installations, data from three more installations are available (Ref. /2/). The average number of hose operations per annum for those three installations are 214 (average of 260, 371 and 12). The average in this case is weighted with the activity level on the various installations based on the total number of work orders on pressurized equipment. Work orders are gathered for the three installations for one year in the period (2001 - 2014).

The data demonstrates that the number of operations involving use of hoses varies considerably in the population. The use of hoses will depend on the design of the well and process systems. It is also judged that it will depend on the type of installation. It is expected that platforms with topside wells will have more hose operations than platforms with subsea wells.

The uncertainty associated with the estimate is significant, which must be accounted for when validating the leak frequency associated with hose operations. Both the overall average and the median for the two data sets presented above become about 191. It is concluded that using 150 hose operations per installation per year will adequately account for uncertainty when validating the model for hose operations towards the total number of observed leaks from hoses in the full NCS population data set (i.e. 14 leaks). The actual average number of hose operations is judged to rather be 200. Using 150 instead of 200 implies that the estimated frequency for leaks stemming from hoses becomes 33 % higher than the best estimate.

The dimension of all hoses in the population data base is set to ¾". It is expected that most operations are performed with pressurized gas. The assumed number of operations involving gas and liquid included in the database, as well as the assumed density and pressure under the operations are presented in Table 4.3, which are based on typical conditions under hose operations, and based on data from recorded incidents, see Chapter 3.6.

Table 4.3 - Pressure and density in hose operations for various fluid phases

Fluid phase	No of operations	Pressure (bara)	Density (kg/m3)
Gas	120	80	70
Liquid	30	15	800

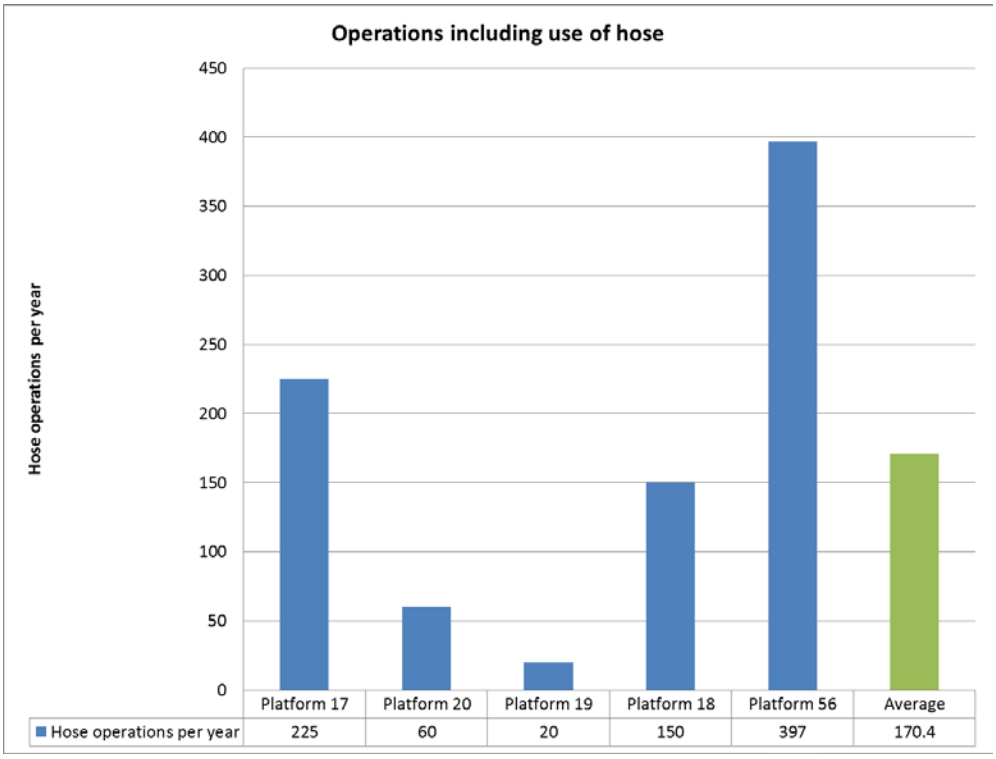


Figure 4.11 - Hose operations per year. The green pole is the average of the 5 installations

4.6 Comparison of equipment containing gas and liquid

The distribution of equipment size for the main components, split on equipment containing gas and liquid are presented in Figure 4.12 and Figure 4.13. Figure 4.14 gives the equipment size distribution for valves and standard flange, while Figure 4.15 gives the ratio between them.

The following can be extracted from the data:

- The relative distribution is about the same for both gas and liquid equipment
- The number of equipment containing liquid is considerable less than the number of equipment containing gas, and the difference increases with increasing equipment dimension. This means that the total number of leaks above a certain hole size are to be dominated by equipment containing gas. In terms of distribution with respect to initial leak rate, this may not be the case for the population as also the operating pressure and density affects the distribution.
- Most flanges and valves are 2-4", while most other equipment types (excluding hose and instrument as they are all set to 3/4") have dimension between 10-20"
- The ratio between the number of flanges and valves in the population data is increasing with increasing equipment size. One reason is that flanges between piping and "other" equipment types often have large dimensions and are not associated with valves. However, this effect is small due to the small fraction of "other" equipment relative to valves and flanges (see Figure 4.5). Another explanation can be that many small valves are closed, hence only one flange is counted per valve. A third reason may be that small flanges are not shown on the P&IDs to the same extent that large flanges. Note however that P&IDs are in general not suited for counting of flanges, and even though most (all?) counting guidelines used in the industry specifies that the number of flanges should be estimated based on information related to the fraction of valves that are welded, there may be different ways of estimating the number of flanges used in the industry. Hence, the observed trend may be correct, but it may also be misleading and related to wrong estimation of the number of flanges.

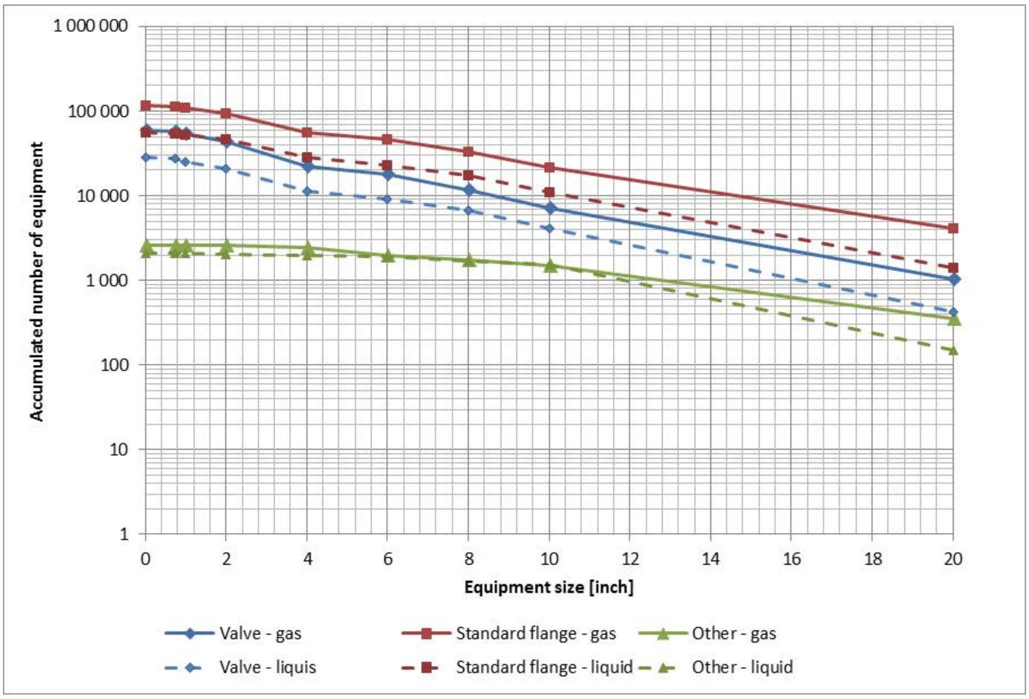


Figure 4.12 - Accumulated number of equipment versus equipment dimension (i.e . the number of leak from equipment with dimension larger than the x-value), equipment containing gas and liquid separately. All 90 installations being in operation in the period 2001 – 2017 are included. Other equipment excludes hose and instrument (and valve and standard flange) as they are all ¾"

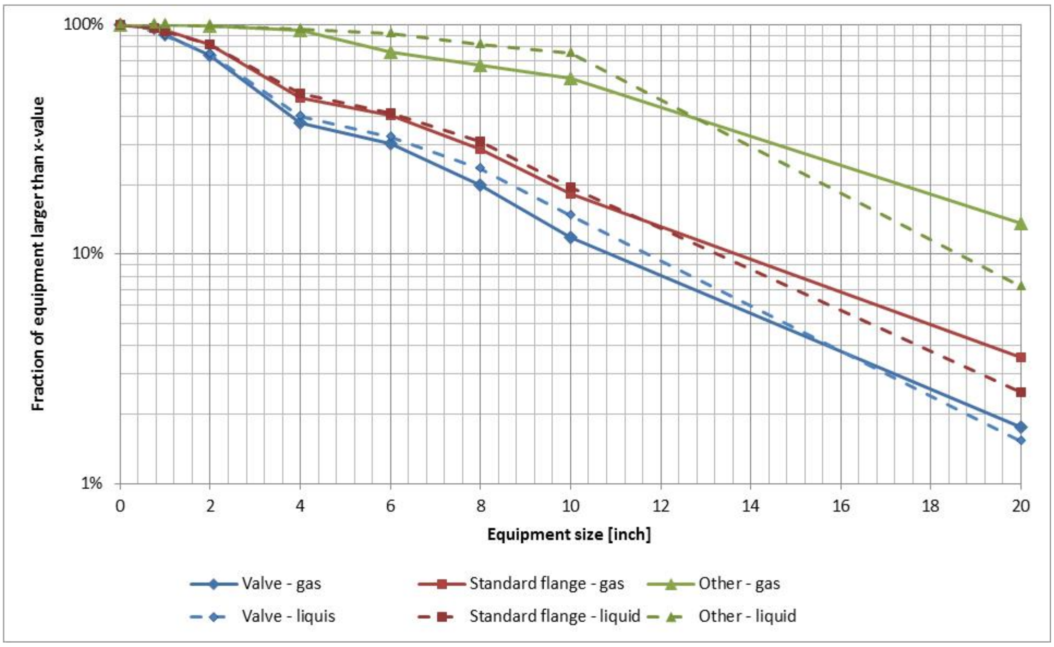


Figure 4.13 – Fraction of equipment that have a larger dimension than specified on the x-axis. Equipment containing gas and liquid separately. All 90 installations being in operation in the period 2001 – 2017 are included. Other equipment excludes hose and instrument (and valve and standard flange) as they are all ¾"

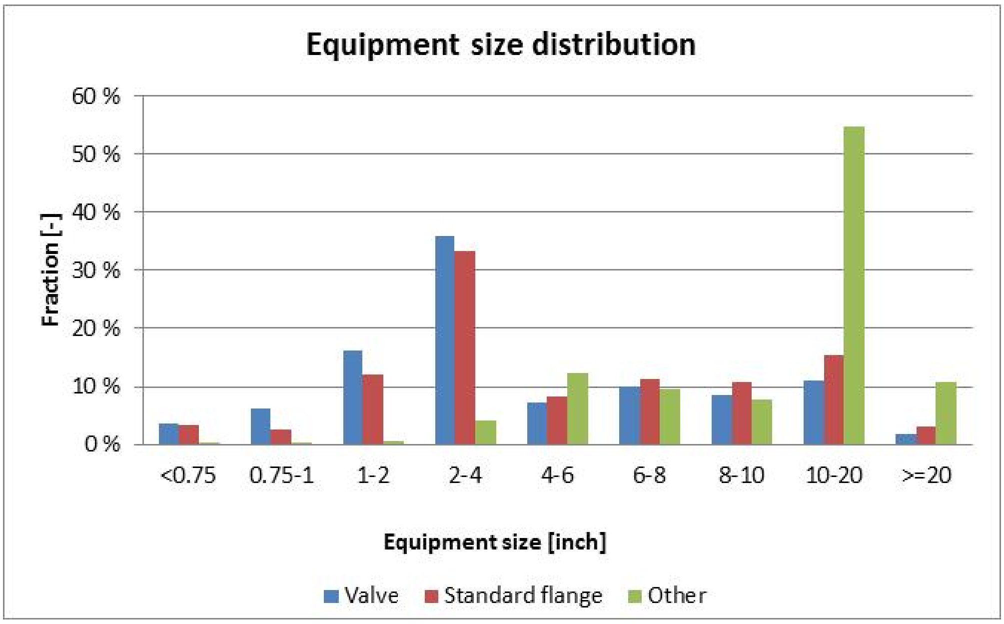


Figure 4.14 – Equipment size distribution for valve, standard flange and other equipment. Other equipment excludes hose and instrument (and valve and standard flange) as they are all ½" or ¾". All 90 installations being in operation in the period 2001 – 2017 are included

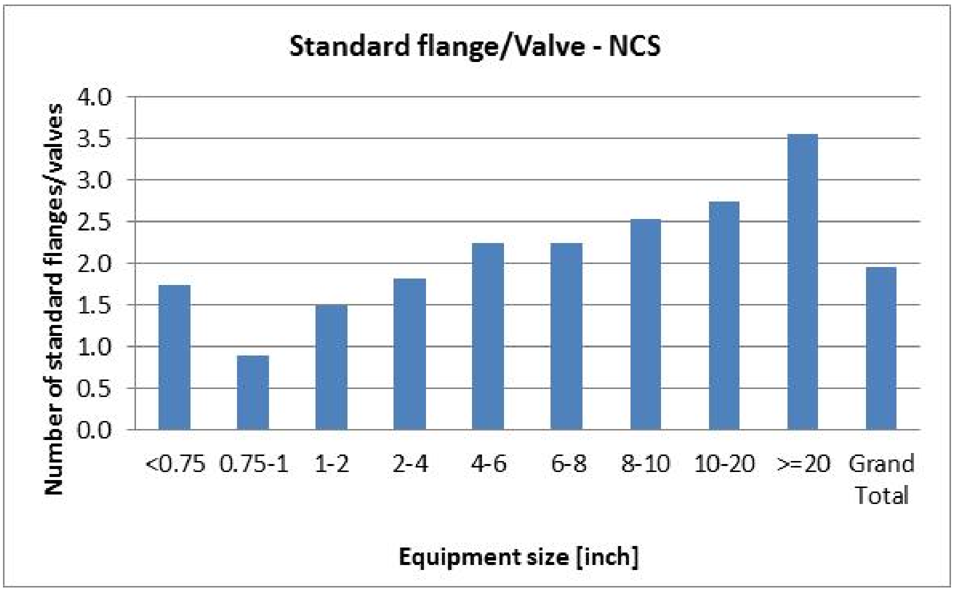


Figure 4.15 – The number of standard flange per valve (for the whole installation) for different equipment size intervals. All 90 installations being in operation in the period 2001 – 2017 are included

4.7 Equipment years

The total number of equipment years per year is presented in Figure 4.16 and Figure 4.17. Figure 4.18 presents the total number of equipment years per equipment type in NCS.

The equipment years are calculated per year by multiplication of the fraction of the year the platform has been in operation. The fraction of the year the platform has been in operation does only reflect the commissioning and decommissioning date. Accordingly, temporary installation shut downs due to turn around or modification projects have not been reflected.

Based on information provided by the service providers and a brief review of the equipment counts received, equipment only used (i.e. pressurized) part of the time are to some extent reflected. A typical example is pig launchers and pig receivers. In any case, equipment being pressurized temporarily is expected to have negligible effect to the number of equipment years.

The aggregated number of installation years in the two population datasets is shown in Table 4.4. The additional number of installation years in the full NCS population dataset is about 17 %, whilst the additional number of equipment years is 8 %. The reason is that the additional installations in the full NCS population dataset are smaller than the average installations in the NCS population dataset.

Table 4.4 - Installation years in population datasets in period 01.01.2001-31.12.2017

Population dataset	Installation years	Equipment years
01.01.2001 - 31.12.2017	1237	4 188 267
01.01.2006 - 31.12.2017	899	3 032 390

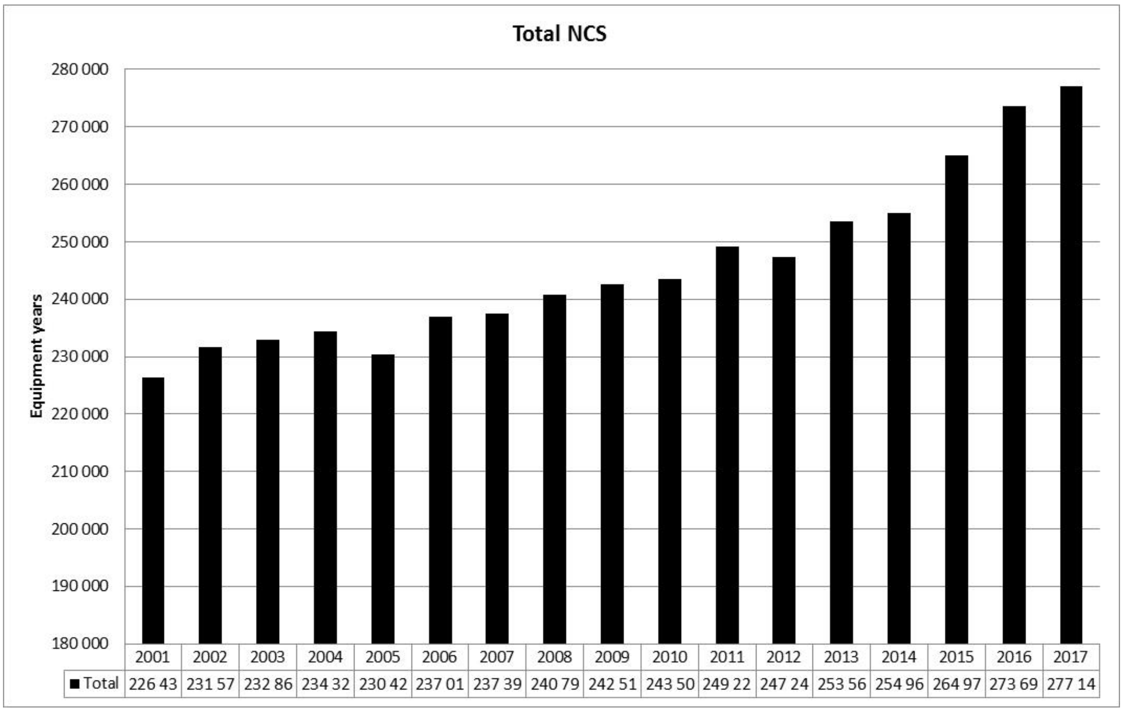
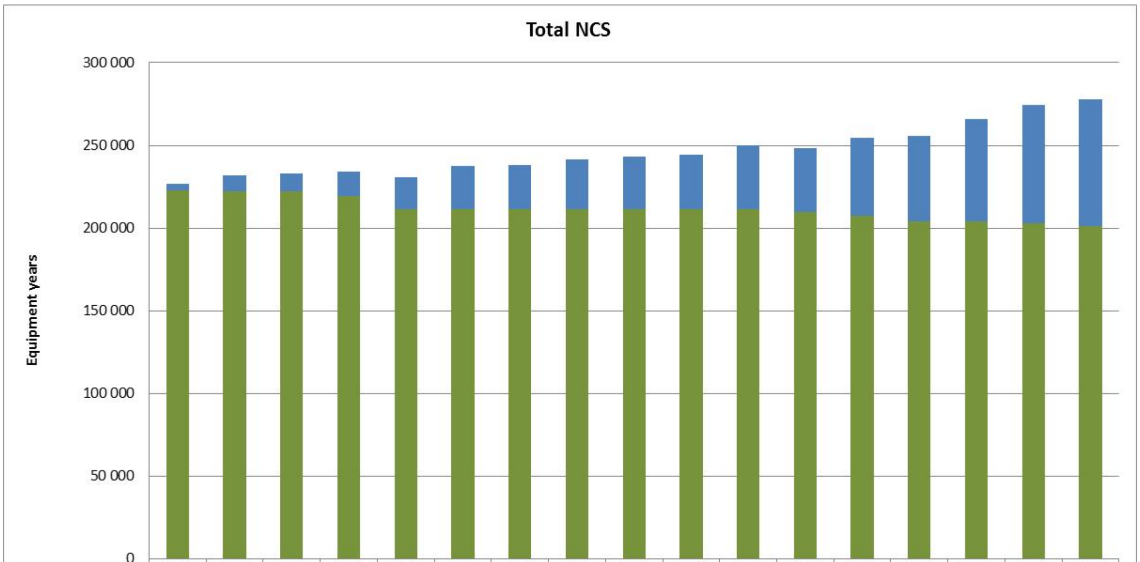


Figure 4.16 – Equipment years per year in NCS population dataset 2001 – 2017. Note that the y-axis is cut at 180 000



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Com after 2001	3840	9525	10806	14875	18873	26137	26701	30110	31824	32818	38541	38541	47039	51691	61711	71795	76614
Com before 2001	222 669	222 119	222 119	219 487	211 564	211 564	211 564	211 564	211 564	211 564	211 564	209 586	207 403	204 150	204 150	202 774	201 420

Figure 4.17 - Equipment years per year in NCS population dataset 2001 – 2017, separated on installations commissioned before and after 2001

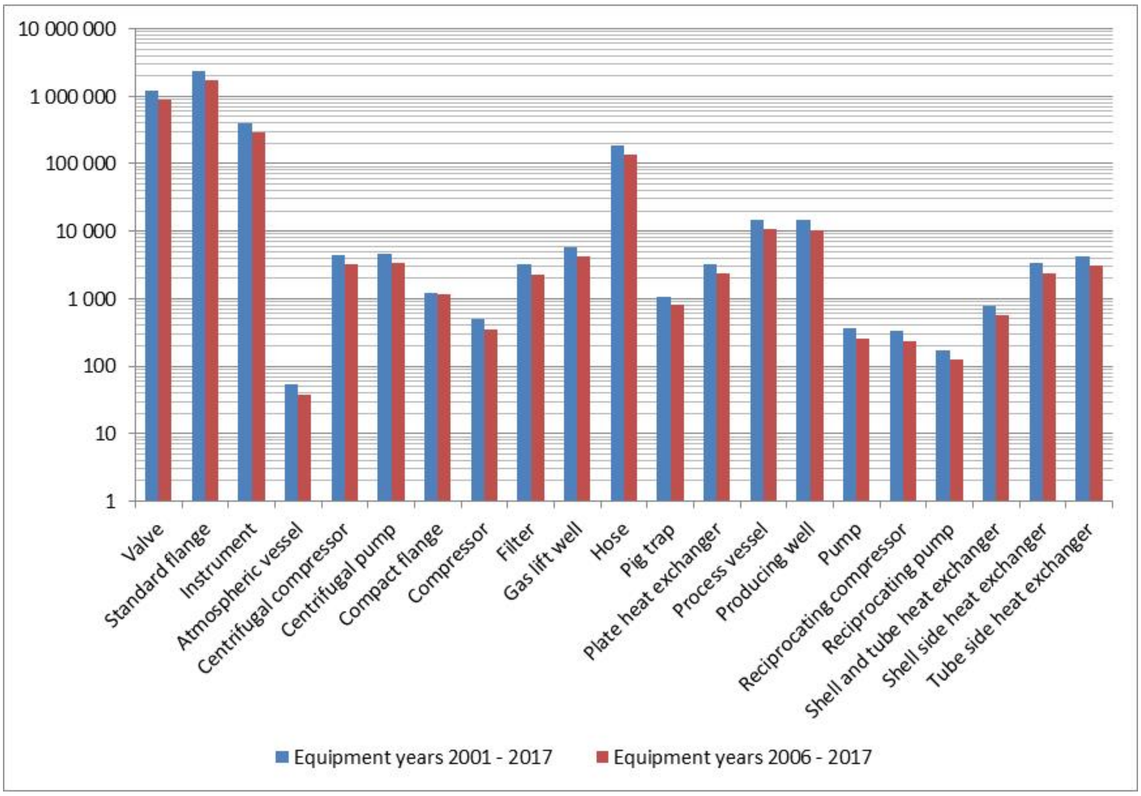


Figure 4.18 - Equipment years per equipment type in NCS population dataset in the period 2001-2017. The y-axis is in logarithmic scale

4.8 Assessment of quality

4.8.1 General

The quality of the equipment counts are considered to be high. The data are gathered from QRAs performed by 4 different service providers. In general, the variation between the different service providers is small, which indicates that the industry practice on counting of equipment is quite homogenous. This is interpreted as an argument why the quality of the population data is regarded as good.

This quality of the counts of producing wells is also considered to be high.

There is significant uncertainty related to steel piping and hose operations, which is addressed in section 4.3 and section 4.5.

The following aspects related to the quality of the population data is discussed in this section

- Relative distribution between valves, flanges and instruments
- Modification projects
- Time in operation

4.8.2 Valves, flanges and instruments

The main difference between the various service providers (consultancies delivering QRAs to the industry in Norway) is a slight variation with regard to the relative distribution of valves, flanges and instruments (results are not shown). However, the difference between the various services providers are small relative to the difference between the overall results from the NCS population dataset compared with the HCR population data (see Figure 4.19 and Figure 4.20. According to the results, the number of flanges per valve is somewhat less in the UKCS population data compared to the NCS population data.

In HCRD, a flanged joint is counted as two flanges, opposed to the equipment counts in QRAs in the industry in Norway, where a flanged joint is counted as one flange. In order to compare the data with the NCS population data, the number of flanges in HCRD is divided by a factor of 2. That will lead to a somewhat underestimation of the number of flanges in UKCS installations because also the contribution single flanges are divided by a factor of two. This is interpreted as the main reason for the observed deviation, even though other reasons are given below.

The observed difference between the two datasets can to some extent be explained by difference in the practice on how instruments have been logged. The practice on how flanges and valves associated with instruments are counted in the industry in Norway may be slightly different from how instruments are logged as basis for the HCRD population data (see Chapter 3.3). In total it is hard to evaluate the total effect of inconsistency in terms of counting of instruments.

A hypothesis can be that fewer flanges per valves at UKCS are due to flanges associated with instruments being represented by the counted instrument in HCRD in general, and hence left out of the equipment count.

On the other hand, the NCS population dataset may be affected by the counting methodology in general tending to only rely on flanged connections displayed on P&ID’s. Generally, P&ID’s does not indicate all flanged connections, particularly flanged small units. This means that the number of flanged connections may be somewhat under predicted in the NCS population data. This underestimation is expected also in future QRAs as the counting will still be based on P&IDs.

The difference displayed may also represent an actual difference in design, i.e. in the use of flanged connections. Installations on UKCS are in general older than installations on NCS. The application of welded connections have increased over the recent years, and it is found reasonable that flanged connections (on average) are more common at UKCS that at NCS. These points towards an even greater difference between NCS and UKCS in terms of number of flanges relative to the number of valves and instruments.

The uncertainty related to the counting of valves is judged to less, but may also be affected by inconsistency related to counting of valves associated with instruments.

It is hard to conclude on the total effect of the above, but the most likely situation is that there are counted slightly too few standard flanges in the NCS population dataset, which appears to be the case for the data in HCRD from UKCS as well. The general effect of lack of equipment in the population data is that the failure frequency per component will be overestimated (the denominator is too small).

The overall uncertainty related to the population data is however considered small. Broadly, the relative distributions for NCS and UKCS are similar, which is interpreted as an argument for the good quality of both datasets. It is concluded that the total number of equipment counts for instruments, flanges and valves are very reliable. Hence, when validating the model (see TN-6), the contribution from instruments, flanges and valves should be considered together as well as separately. In other words, a moderate variation in the estimated contribution from valves, flanges and instruments can be accepted as long as the total contribution from these components relative to the observed number is acceptable.

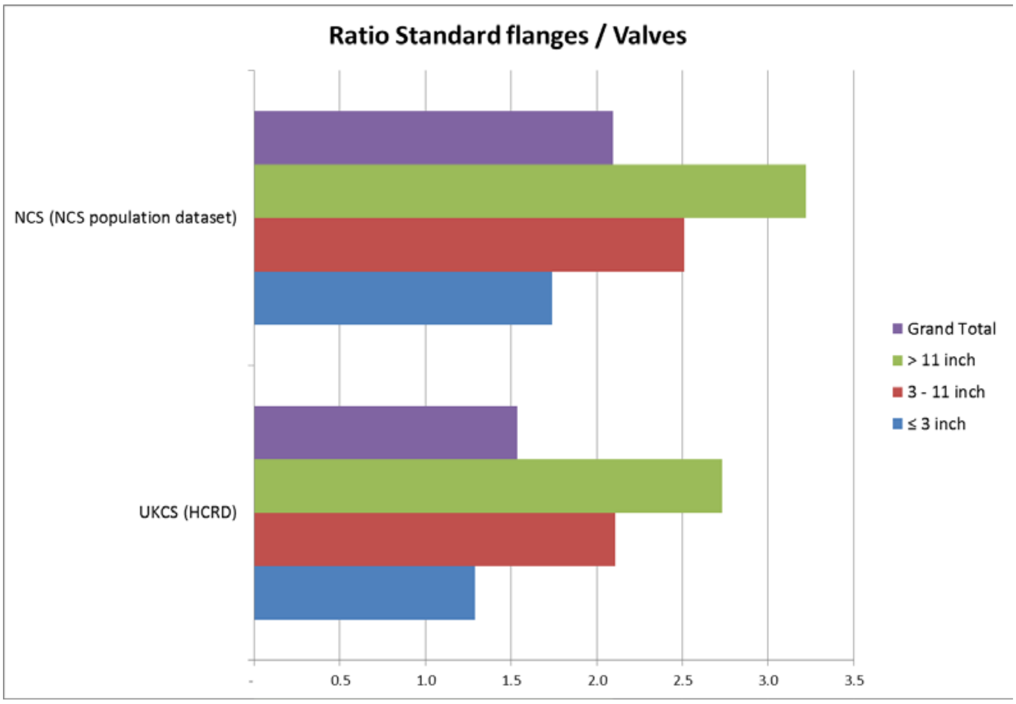


Figure 4.19 - Overall ratio number of flanges divided by number of valves for various equipment size categories for NCS population dataset and . UKCS HCRD population data set

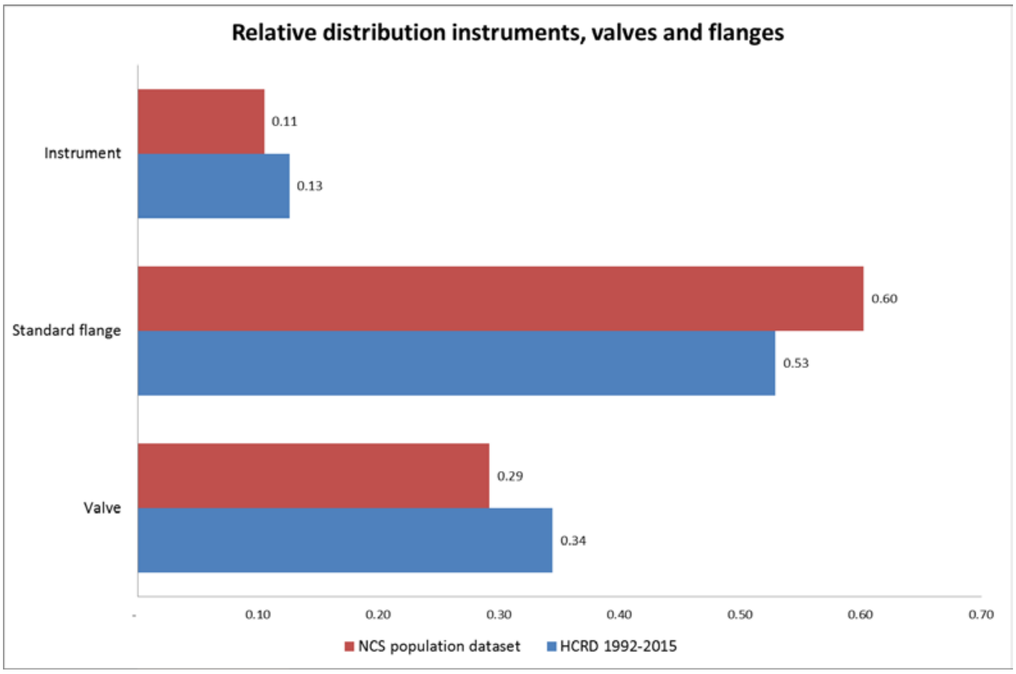


Figure 4.20 - Relative distribution instruments, valves and flanges in NCS population dataset and UKCS population data set

4.8.3 Modification projects and equipment years

Major modifications to the installations in the period 2001-2014 are not systematically handled in the NCS population dataset. A major modification in this context is installation of a new process module or a compression module.

The equipment counts from the most recent QRA have been used as basis for establishment of the population data. For installations that have been subjected to major modifications, it is expected that the recent QRA in most cases includes the equipment counts related to the modification project. The operational time of the new equipment installed in the period is less than for the other equipment on the installation. As this is not reflected, the number of equipment years may be somewhat overestimated for a few installations. On average, this is not judged to affect the total number of equipment years very much. A conservative assessment of the effect is to assume that 10 % has been added to 10 % of the installations in the period. Assuming that all this equipment was set in operation in later half of the last year of the period (in 2014) on installations that was commissioned before 2001 (and that the average number of equipment on these installations equals the number of equipment on the average installation in the NCS population dataset) gives a total effect on the number of equipment years of 1 % (10 % times 10 %). The actual effect is less as there also will be cases where the equipment counts are not updated with modifications that have been in operation for a significant time in the observation period. Hence, it can be concluded that modification projects adds marginal uncertainty to the NCS population dataset and the validation model in TN-6.

4.8.4 Time in operation

The equipment counts are gathered from QRAs performed by 4 different service providers. The procedures for how to take into account that equipment is not in operation the entire year may differ across these companies. One common way of doing this is to adjust the quantity parameter, i.e. the number of equipment in the equipment counts. In the gathered equipment counts it is seen that some equipment is registered with a quantity different from an integer number. It is likely that this indicates that adjustments have been made to take reduced operational time into account.

To get an impression of the uncertainty this may give, pig traps have been analysed in more detail. As all pig traps are in operation only a small fraction of the full operational time, all pig traps should have been adjusted. About 30% of the registered pig traps are registered with a quantity less than 1. Thus, this check may indicate that only about 30% of the equipment counts have been adjusted, i.e. the equipment counting database is dominated by equipment counts that are not adjusted. Hence, there is inconsistency in the way this is done in the equipment counts collected from the different service providers. TN-5 Appendix B gives guidelines for use of the model and suggests not adjusting for time in operation.

5 Time distribution

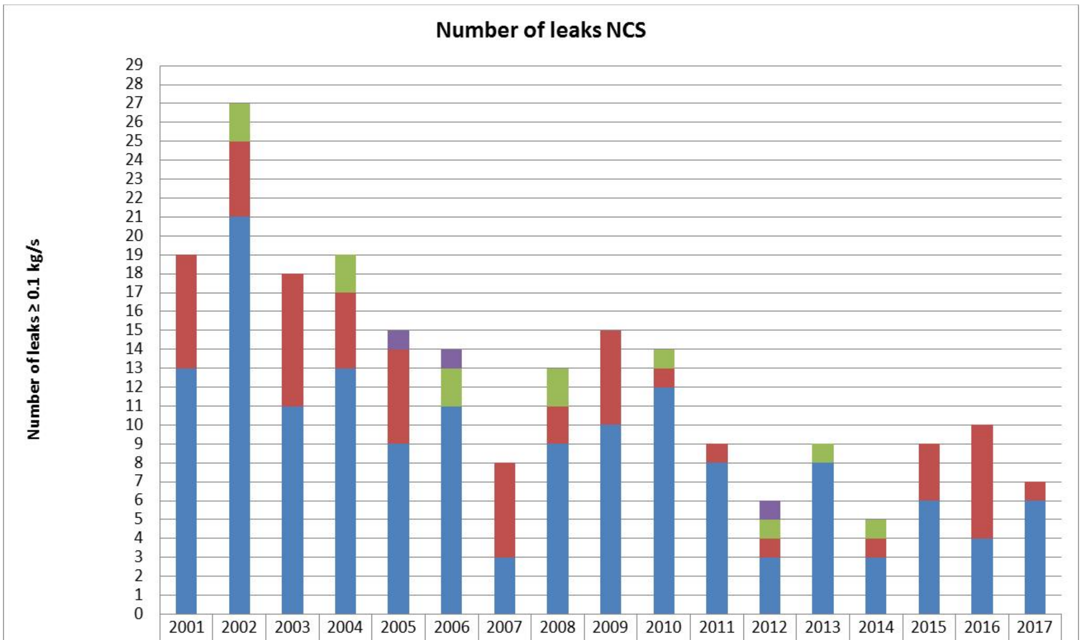
5.1 Overall trend leaks

The occurrence of leaks versus time is displayed in Figure 5.1 through Figure 5.3. The results demonstrate that there is a clear trend with time. The number of leaks per year having an initial leak rate of 0.1 kg/s or greater has decreased considerably.

The trend is not apparent for installations that have been set in operation in the period (the trend seems to be opposite), but cannot be assessed by just studying the occurrence of leaks per year as the number of installation set in operation per year affects the results to a large degree.

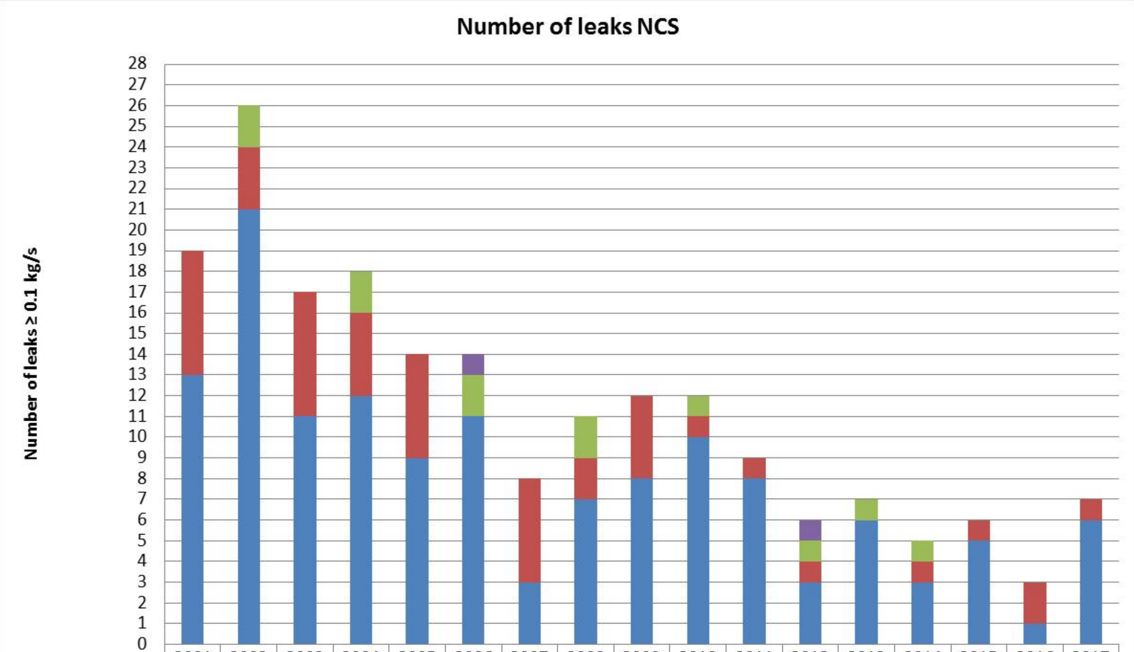
From Figure 5.1 and Figure 5.2 it is hard to claim that there is an obvious time trend for leaks greater than 10 kg/s.

In order to fully understand the trend with time, also the trend in equipment years should be taken into account. In the following chapter, the combined effect of occurrence of leaks and equipment years is studied.



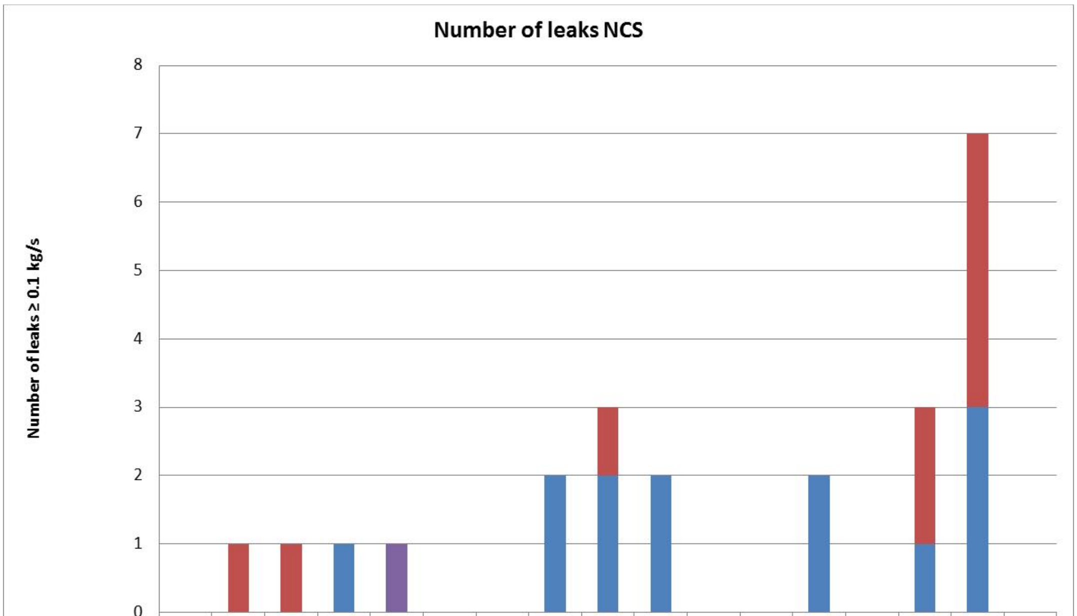
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
e(>100 kg/s)					1	1						1					
d(10-100 kg/s)		2		2		2		2		1		1	1	1			
c(1-10 kg/s)	6	4	7	4	5		5	2	5	1	1	1		1	3	6	1
b(0.1-1 kg/s)	13	21	11	13	9	11	3	9	10	12	8	3	8	3	6	4	6

Figure 5.1 - Distribution of leaks (≥ 0.1 kg/s) versus time for installations in the NCS population dataset (217)



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
e(>100 kg/s)						1						1					
d(10-100 kg/s)		2		2		2		2		1		1	1	1			
c(1-10 kg/s)	6	3	6	4	5		5	2	4	1	1	1		1	1	2	1
b(0.1-1 kg/s)	13	21	11	12	9	11	3	7	8	10	8	3	6	3	5	1	6

Figure 5.2 - Distribution of NCS leaks (194) versus time for installations set in operaion before 01.01.2001



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
e(>100 kg/s)					1												
d(10-100 kg/s)																	
c(1-10 kg/s)		1	1						1						2	4	
b(0.1-1 kg/s)				1				2	2	2			2		1	3	

Figure 5.3 - Distribution of NCS leaks (23) versus time for installations set in operation in the period 01.01.2001 – 31.12.2017

5.2 Analysis of time trend

In Figure 5.4 through Figure 5.9 the average frequencies per component in the NCS population datasets are presented. The figures are obtained by dividing the number of leaks per year with the number of equipment years per year. Results are shown for two different subsets in terms of date of commissioning relative to first day of the period studied (01.01.2001). This is to evaluate whether the time trend is explained by a difference between new installations set in operation in the period 01.01.2001 – 31.12.2017, and older installations set in operation prior to 01.01.2001.

In addition to the results per year, which displays the variation in observed frequency throughout the period, the average frequency for the entire period plus 5 year average floating average is shown. Note that the floating average is plotted for the middle year in the 5 year period, i.e. the 5 year average for year 2012 is the average for the period 01.01.2010 – 31.12.2014.

The following are extracted from the results:

- The average leak frequency per equipment is around $5.2 \cdot 10^{-5}$ per year for the period 2001 - 2017 for leaks ≥ 0.1 kg/s and $3.6 \cdot 10^{-6}$ per year for leaks ≥ 10 kg/s. The average for the last 5 years of the period for leaks having an initial leak rate >0.1 kg/s, is about 40 % less than the average for the entire period. For leaks having an initial leak rate >10 kg/s the corresponding number is about 55%. The average for the recent three years is even less. This means that a model that is benchmarked towards the average for the entire period will result in a model that is very likely to overpredict the future average leak frequency for installations on the Norwegian Continental Shelf. This aspect is taken into account when the model is parameterized and validated (see next chapter)
- Despite the large difference in the variation in leak frequency (per equipment per year), the difference in average frequency between installations commissioned before and after 2001 is small. The 5 year floating average reveals that the average for the subsets (commission date relative to 01.01.2001) is quite similar the recent years. The difference is attributed to randomness without any further statistical analysis of the significance of the difference. The subsets are therefore pooled in the validation model presented in TN-6
- The trend with time seems to be similar for both leaks >0.1 kg/s and leaks >10 kg/s

See also discussion in the next chapter.

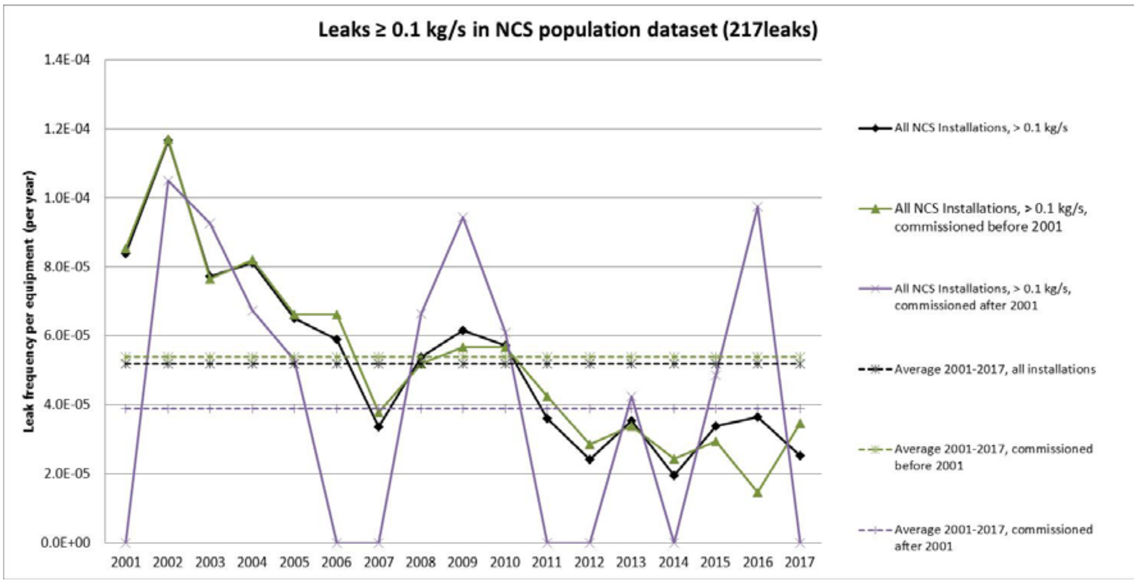


Figure 5.4 - Average frequency for leaks (≥ 0.1 kg/s) per component versus time for installations in the NCS population dataset (217)

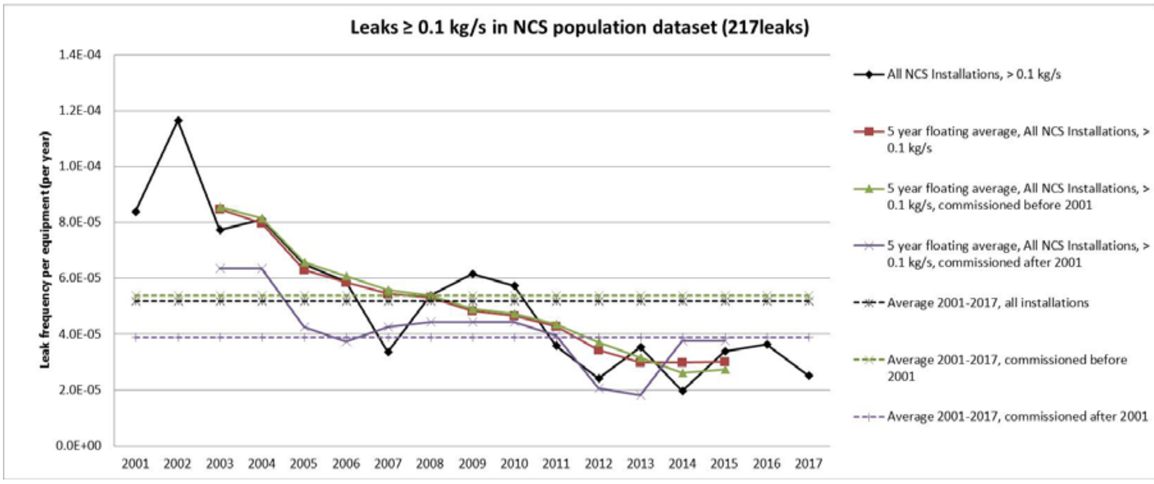


Figure 5.5 - Average frequency and floating average for leaks (≥ 0.1 kg/s) per component versus time. Floating average plotted versus the middle year of the period that is averaged (*i.e.* the data point for year 2012 applies for the period 2010-2014)

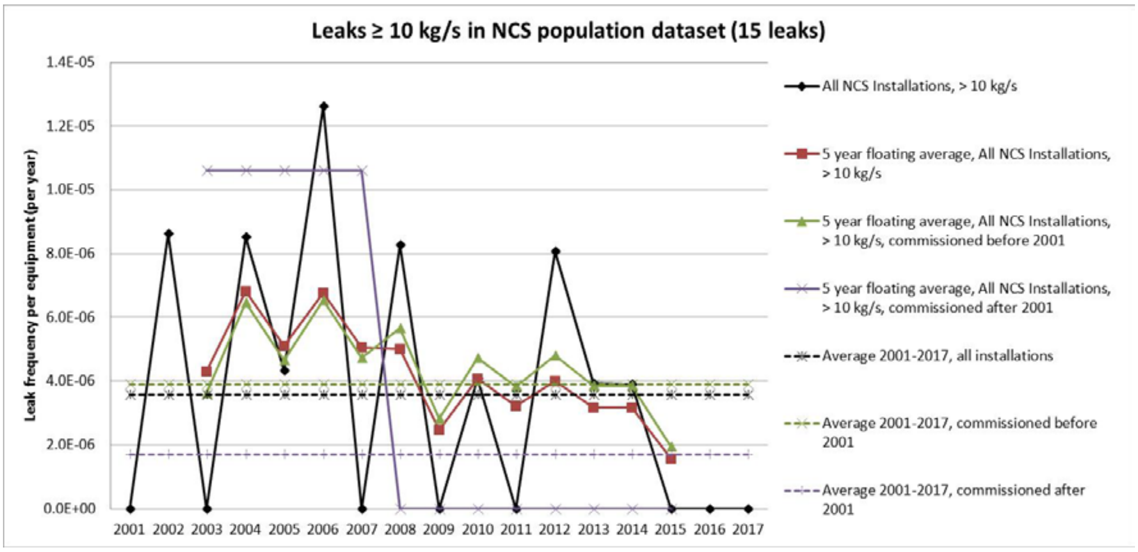


Figure 5.6 - Average frequency and floating average for leaks (≥ 10 kg/s) per component versus time. Floating average plotted versus the middle year of the period that is averaged (*i.e.* the data point for year 2012 applies for the period 2010-2014)

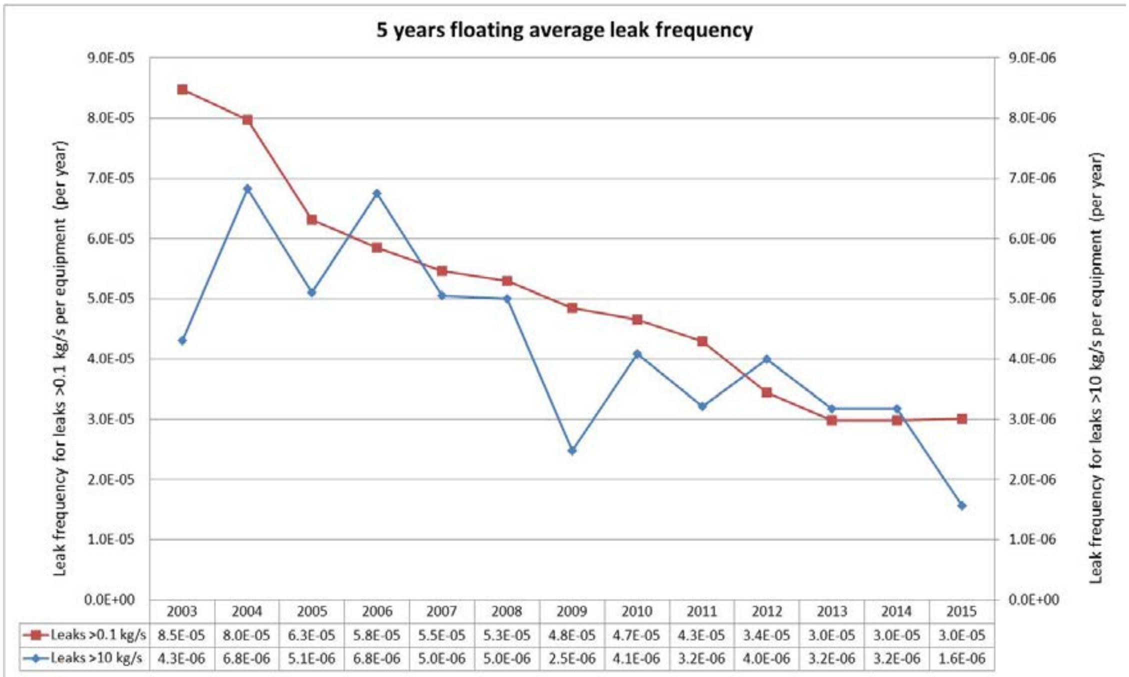
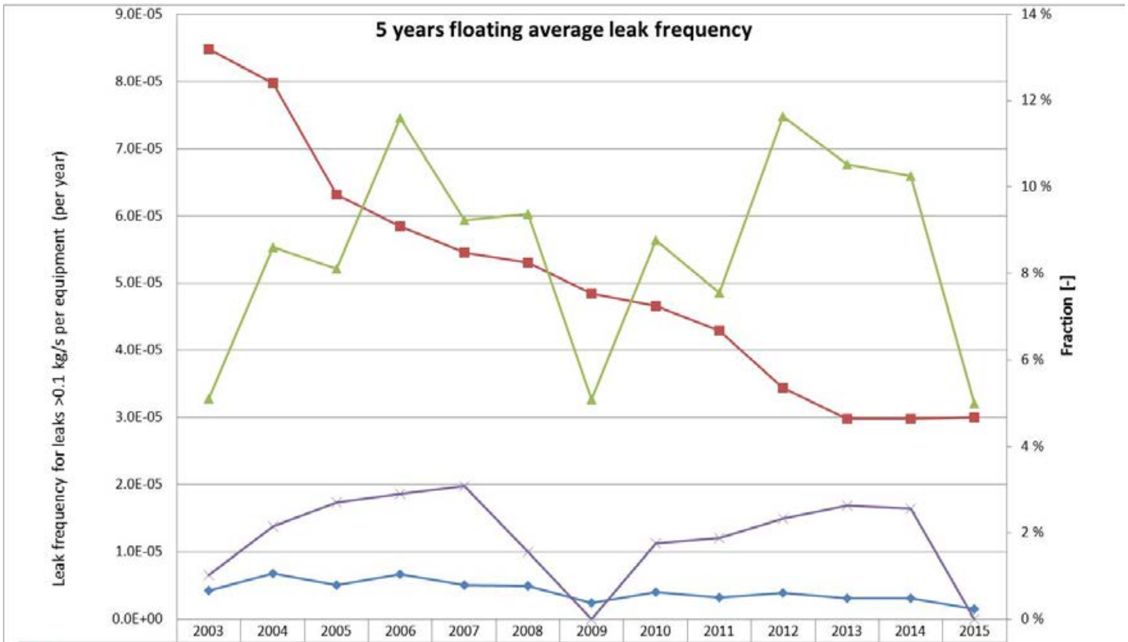


Figure 5.7 – 5 years floating average frequency for leaks ≥ 0.1 kg/s and ≥ 10 kg/s per equipment for various time periods. Floating average plotted versus the middle year of the period that is averaged (*i.e.* the data point for year 2012 applies for the period 2010-2014). Note that the blue curve relates to the right axis

Figure 5.8 – Average leak frequency from year x to 2017 (red curve). The x- value is the value on the x-axis. The average for 2006 – 2017 is marked with a large marker. The green curve shows the average leak frequency for year x – 2017 relative to the average leak frequency for 2006 – 2017 (right y-axis)



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Leaks >0.1 kg/s	8.5E-05	8.0E-05	6.3E-05	5.8E-05	5.5E-05	5.3E-05	4.8E-05	4.7E-05	4.3E-05	3.4E-05	3.0E-05	3.0E-05	3.0E-05
Leaks >10 kg/s	4.3E-06	6.8E-06	5.1E-06	6.8E-06	5.0E-06	5.0E-06	2.5E-06	4.1E-06	3.2E-06	4.0E-06	3.2E-06	3.2E-06	1.6E-06
Fraction> 10 kg/s	5 %	9 %	8 %	12 %	9 %	9 %	5 %	9 %	8 %	12 %	11 %	10 %	5 %
Fraction, > 100 kg/s	1 %	2 %	3 %	3 %	3 %	2 %	0 %	2 %	2 %	2 %	3 %	3 %	0 %

Figure 5.9 – 5 years floating average frequency for leaks ≥ 0.1 kg/s and ≥ 10 kg/s per equipment for various time periods. Floating average plotted versus the middle year of the period that is averaged (*i.e.* the data point for year 2012 applies for the period 2010-2014). Furthermore the fraction of leaks ≥ 10 kg/s and ≥ 100 kg/s is given (green and violet curve). Note that the these curves are read on the right axis

6 Target for validation of the model based on NCS data

The data presented in this TN shows a clear time trend where the leak frequency is decreasing with time. The ratio between frequency of leaks ≥ 0.1 kg/ in the period 1992-2000 (1.5·10-4 per year per equipment) and the frequency for the last 5 years ($3.0 \cdot 10^{-5}$) is about 5, representing a significant reduction that cannot be explained by stochastic variations. Considering only leaks after 2001 the corresponding ratio between the maximum 5 years average in the start of the period and the minimum in the end of the period is almost 3. The reduction is also consistent with the UKCS data (see TN-3), and support the conclusion above about the time trend for the total leak frequency. This can be explained by technology development where leaks due to known failure modes have been reduced or even eliminated. Based on this it is judged that a reasonable estimate for future leak frequency would be if the model is able to reproduce the total number of leaks on NCS in the period 2006 - 2017. Targeting this frequency level would imply that the model will estimate about 30% lower leak frequency than the average leak frequency in the period 2001 – 2017, but also 30% higher leak frequency than seen for any years after 2011, and about 50% higher leak frequency than recorded in 2017 (see Figure 5.8). This is regarded as a reasonable estimate for future leak frequency for a model aiming at the best estimate slightly from the conservative side.

Figure 5.9 shows the 5 years average leak frequency ≥ 0.1 kg/s and ≥ 10 kg/s, and the fraction of leaks being ≥ 10 kg/s and ≥ 100 kg/s. The number of leaks ≥ 10 kg/s varies between 2 and 6 in the 5 year periods between 2001 and 2017. Hence the ratio between the highest and lowest frequency in a 5 year period is about 3, which is consistent with Figure 5.7. Leaks can be assumed to be independent incidents that can be modelled as a Poisson process. The probability of observing 2 leaks or less given that the mean is 6, is about 6% (see Figure 6.1), while the probability of observing 6 leaks or more given that the mean is 2 is less than 0.5% (see Figure 6.2). Furthermore, if the mean is 4.5 the probability of observing 2 leaks or less or 6 leaks or more are about 17% and 30%, respectively (see Figure 6.3). Hence, a mean values of 4.5 cannot be ruled out for any of the years 2001 - 2017. Based on this it is hard to find support in the historical data after year 2000 for a time trend in the number of leaks ≥ 10 kg/s. However, taking into account that the number of equipment in operation has increased by about 20% during the period makes a time trend more likely, but the observed variations can also be explained by stochastic variation.

It is also interesting to note that the frequency for leaks ≥ 10 kg/s per equipment year in the period 1992-2000 is about 2.9·10-6 per year (4 significant leaks (see Table 3.6 and assuming 10% marginal leaks) divided by about 1 500 000 equipment years (see chapter 4.7)), which is very close to the 5 year floating average after 2013 (including leaks in 2011) in Figure 5.7. This may indicate that the underlying frequency for large leaks is quite constant and that the observed elevated 5 year floating average for the period 2003 – 2010 is caused by randomness.

The leak frequency for leaks ≥ 0.1 kg/s in the period 1992 -2000 is about 1.5·10-4 per equipment per year, which is about three times as high as the corresponding frequency in the period 2001 – 2017, it becomes clear that the fraction of leaks ≥ 10 kg/s is significantly lower in the period 1992 – 2000 than in 2001 – 2017 (also seen in Figure 3.20), which cannot be explained by stochastic variation. However, it is hard to find support in the data for any trends for this fraction after year 2000. Based on this it is concluded that the relative leak rate distribution should be higher than seen for the period 1992 – 2001. Furthermore, the relative leak rate distribution used as target for the model should be based on a long enough data period to reduce the effect of stochastic effects. Therefore the historical relative leak rate distribution seen in the period 2001 – 2017 is set as target for the model (blue curve in Figure 3.17 - Figure 3.20). The fraction of leaks above about 50 kg/s becomes very sensitive to stochastic effects as the number of leaks above this leak rate is few. Data periods do exist where both higher and lower fractions of large leaks are seen. Considering only data after 2007 will give lower fraction of large leaks than put as target for the model, while considering only data from the period 2006 – 2017 gives a higher fraction of large leaks. Based on this the target represented by the data period 2001 – 2017 are considered reasonable and a best estimate for the model.

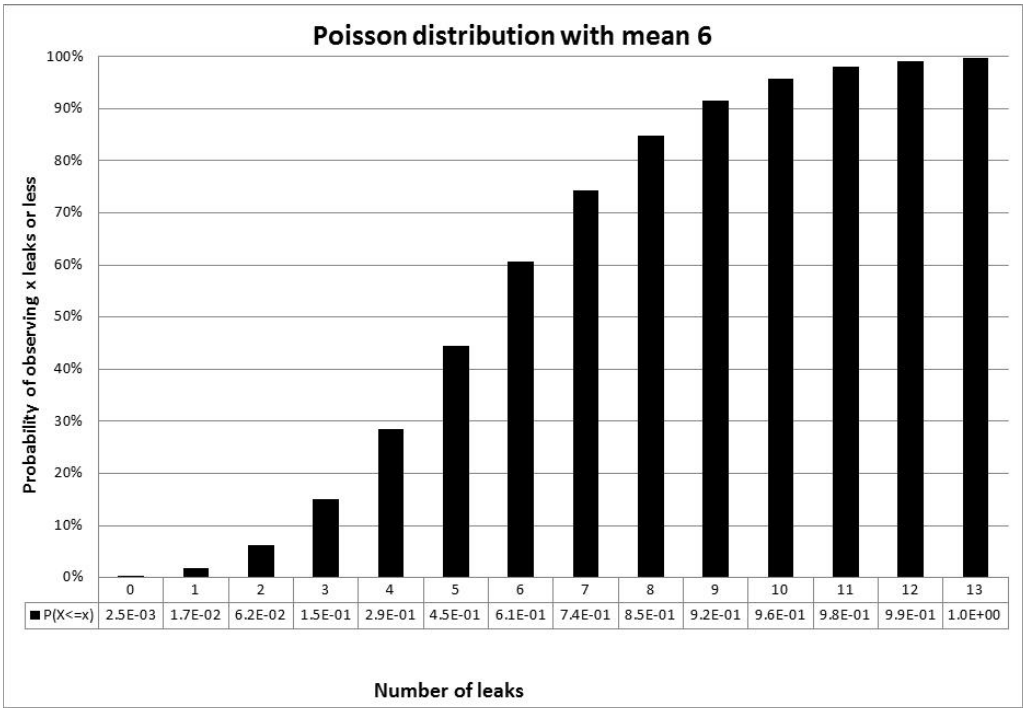


Figure 6.1 – Probability of observing x number of leaks or less with leak rate >10 kg/s, given expected number of leaks is 6

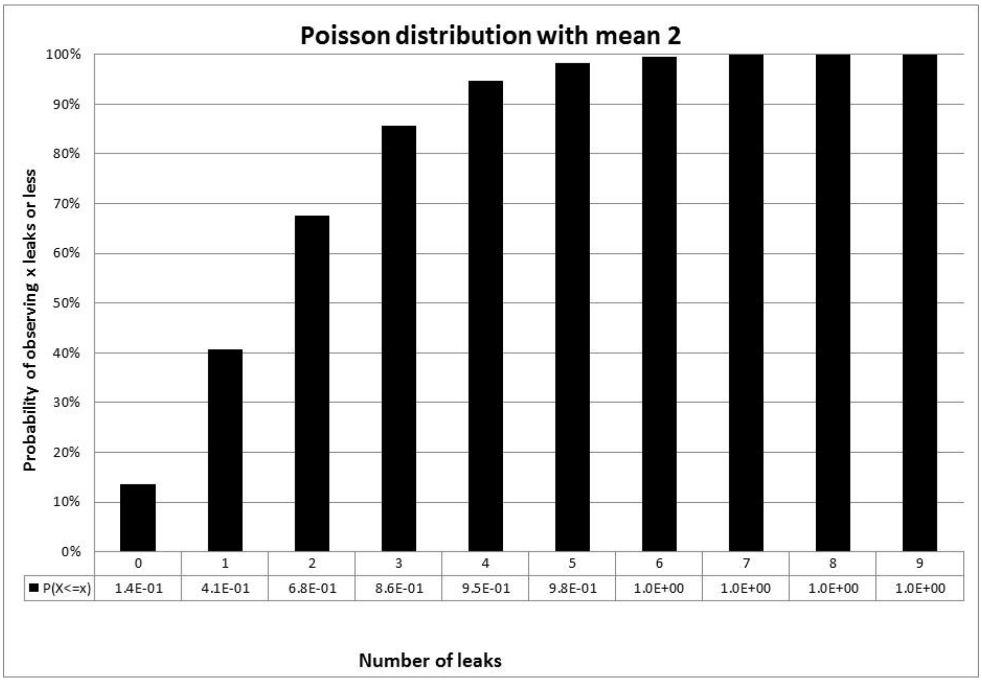


Figure 6.2 – Probability of observing x number of leaks or less with leak rate >10 kg/s, given expected number of leaks is 3

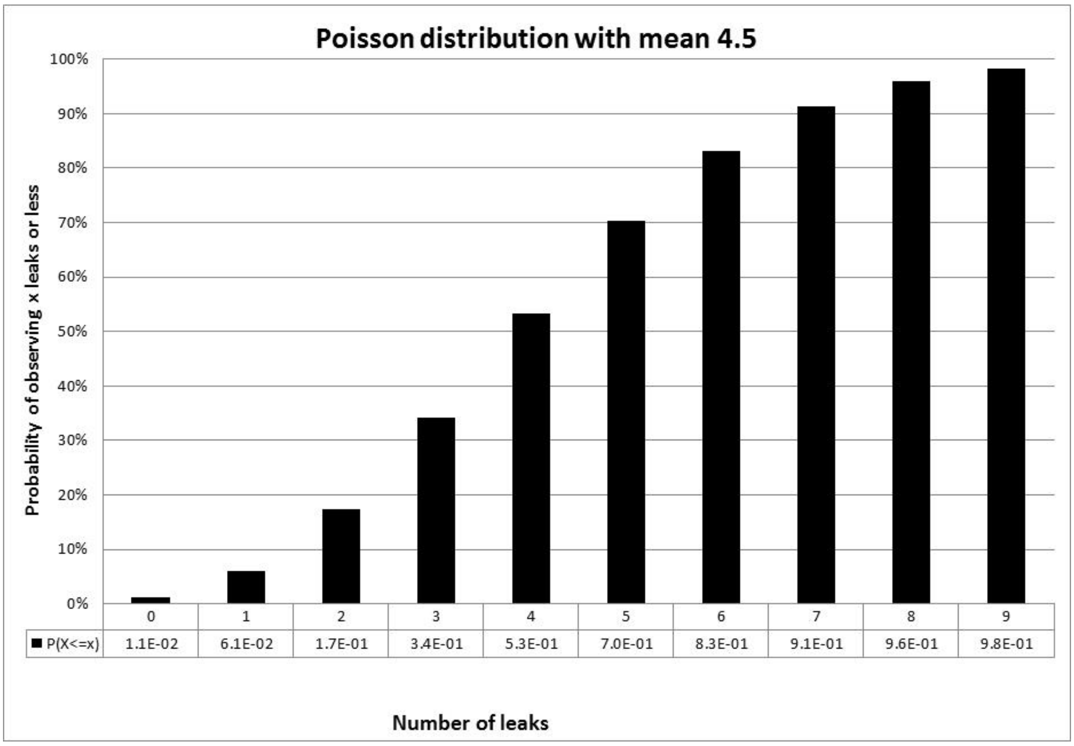


Figure 6.3 – Probability of observing x number of leaks or less with leak rate >10 kg/s, given expected number of leaks is 4.5

The historical leaks recorded on installations on NCS used as basis for validation of the model described in TN-6 is enclosed in Appendix A.

There are two notifications to be made when evaluating the validation model:

- The equipment type causing the leak is unknown for two incidents. Those two incidents are not included when benchmarking the leak frequency for the various types of incidents, but accounted for when benchmarking the overall frequency (see TN-6)
- It is 8 incidents where the fluid phase is unknown (see Chapter 3.5). 6 out of these incidents have a release rate less than 1 kg/s. The last two incidents have a release rate between 1 and 5 kg/s. The fluid phase in these cases is set randomly according to the overall distribution of leaks with respect to fluid phase. Hence, 6 out of the leaks are assumed to be gaseous. Thus the fluid phase for two of the leaks is assumed to be liquid. The effect of this assumption on the validation model is marginal

7 References

/1/ Lloyd's Register "Modelling of ignition sources on offshore oil and gas facilities - MISOF2", report No: 107566/R2, Final version, Date: November 2018

/2/ Email from Jon Andreas Hestad (Safetec) received September 25th 2015.

Appendix A

Recorded incidents at NCS

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Page

1 Introduction

This appendix is a part of TN-2. It lists every relevant incidents recorded at NCS, with initial leak rate ≥ 0.1 kg/s, in the period 01.01.2001 – 31.12.2017. In total 254 incidents are recorded. They are given a unique ID ranging from 1 – 254. 217 of the 254 incidents are regarded as relevant, and are listed in Table 2.1. Detailed description of the data fields in Table 2.1 are given in Table 1.1.

Table 1.1 - Detailed description of the data fields in Table 2.1

Heading	Description
ID	ID running from 1 to 254.
Year	The year that the leak occurred
Installation	Anonymized name of the installation
Equipment counted	"Yes", if the leak occurred at an installation where counting of equipment has been performed and included in the population database. "No" if the equipment counts are estimated based on an equivalent installation. See TN-2
Initial leak rate 2015 [kg/s]	Initial leak rate based on a thorough review of investigation reports performed by LRC and Safetec in 2015, by LR/Equinor in 2018
Medium	"G"=Gas, "L" = Liquid
Equipment type	The equipment type associated with the leak
Leak scenario	Leak scenario according to PLOFAM (see TN-4)
Commissioned before 01.01.2001	"Yes" if the leak occurred at an installation commissioned before 01.01.2001. No otherwise
Decommissioned before 31.12.2017	"Yes" if the leak occurred at an installation decommissioned before 31.012.2017. No otherwise
System	The system associated with the leak.

2 Recorded incidents at NCS

Table 2.1 – All relevant incidents recorded at NCS, with initial leak rate ≥0.1 kg/s, in the period 01.01.2001 – 31.12.2017. In total 254 incidents are recorded. They are given a unique ID ranging from 1 – 254. 217 of the 254 incidents are regarded as relevant, and are listed in this table

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
3	2001	Platform 57	YES	0.2	L	Valve	Significant leak	YES	NO	Process system
4	2001	Platform 55	YES	0.2	G	Valve	Significant leak	YES	NO	Process system
5	2001	Platform 48	YES	0.15	G	Valve	Significant leak	YES	NO	Process system
6	2001	Platform 22	YES	0.5	L	Valve	Significant leak	YES	NO	Process system
8	2001	Platform 41	YES	0.2	G	Valve	Significant leak	YES	NO	Process system
9	2001	Platform 41	YES	0.2	G	Valve	Significant leak	YES	NO	Process system
10	2001	Platform 56	YES	5	G	Valve	Significant leak	YES	NO	Open drain system
11	2001	Platform 56	YES	0.2	G	Valve	Significant leak	YES	NO	Process system
12	2001	Platform 22	YES	0.5	G	Standard flange	Significant leak	YES	NO	Fuel gas system
13	2001	Platform 2	YES	0.125	G	Valve	Significant leak	YES	NO	Process system
14	2001	Platform 21	YES	1.5	G	Flexible pipe	Significant leak	YES	NO	Process system
15	2001	Platform 2	YES	1	G	Instrument	Significant leak	YES	NO	Process system
17	2001	Platform 9	YES	0.7	G	Valve	Significant leak	YES	YES	Process system
18	2001	Platform 53	YES	1.5	G	Instrument	Significant leak	YES	NO	Process system
19	2001	Platform 7	YES	0.6	G	Steel pipe	Significant leak	YES	NO	Flare system
20	2001	Platform 51	YES	0.9	L	Hose	Significant leak	YES	NO	Unknown
21	2001	Platform 23	YES	1.6	G	Unknown	Significant leak	YES	NO	Unknown
22	2001	Platform 45	YES	4.7	G	Hose	Significant leak	YES	NO	Unknown

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
23	2001	Platform 42	YES	0.1	G	Unknown	Significant leak	YES	YES	Unknown
24	2002	Platform 55	YES	0.2	G	Steel pipe	Significant leak	YES	NO	Process system
25	2002	Platform 64	YES	0.5	G	Instrument	Significant leak	YES	NO	Process system
26	2002	Platform 22	YES	0.2	G	Valve	Marginal leak	YES	NO	Process system
27	2002	Platform 22	YES	2.5	G	Vent	Significant leak	YES	NO	Fuel gas system
29	2002	Platform 60	YES	0.8	G	Instrument	Significant leak	YES	NO	Process system
31	2002	Platform 8	YES	0.3	G	Valve	Significant leak	YES	NO	Process system
32	2002	Platform 1	YES	0.15	G	Valve	Significant leak	YES	NO	Process system
33	2002	Platform 29	YES	22	G	Valve	Significant leak	YES	NO	Flare system
34	2002	Platform 54	YES	2	G	Vent	Significant leak	NO	NO	Produced water system
36	2002	Platform 4	YES	0.36	G	Instrument	Significant leak	YES	NO	Process system
37	2002	Platform 29	YES	0.5	G	Instrument	Significant leak	YES	NO	Process system
38	2002	Platform 55	YES	0.84	G	Standard flange	Significant leak	YES	NO	Process system
39	2002	Platform 9	YES	0.8	G	Valve	Significant leak	YES	YES	Process system
40	2002	Platform 57	YES	10	G	Valve	Significant leak	YES	NO	Process system
41	2002	Platform 62	YES	0.13	L	Valve	Significant leak	YES	NO	Process system
42	2002	Platform 2	YES	0.15	G	Standard flange	Marginal leak	YES	NO	Process system
43	2002	Platform 17	YES	1.51	G	Hose	Significant leak	YES	NO	Process system
44	2002	Platform 56	YES	0.55	G	Valve	Significant leak	YES	NO	Process system
45	2002	Platform 18	YES	0.6	G	Steel pipe	Significant leak	YES	NO	Process system
47	2002	Platform 57	YES	0.17	G	Steel pipe	Significant leak	YES	NO	Process system

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
48	2002	Platform 57	YES	0.4	G	Valve	Significant leak	YES	NO	Process system
49	2002	Platform 4	YES	0.4	L	Valve	Marginal leak	YES	NO	Process system / Well system
51	2002	Platform 60	YES	0.8	G	Valve	Significant leak	YES	NO	Process system
52	2002	Platform 60	YES	0.3	G	Valve	Significant leak	YES	NO	Process system
53	2002	Platform 2	YES	0.2	G	Valve	Significant leak	YES	NO	Process system
54	2002	Platform 55	YES	1.16	G	Valve	Significant leak	YES	NO	Process system
56	2002	Platform 22	YES	0.1	G	Valve	Significant leak	YES	NO	Process system
57	2003	Platform 56	YES	0.4	G	Instrument	Significant leak	YES	NO	Process system
60	2003	Platform 7	YES	0.3	L	Standard flange	Marginal leak	YES	NO	Process system
61	2003	Platform 22	YES	2	G	Valve	Significant leak	YES	NO	Process system
63	2003	Platform 51	YES	0.1	L	Standard flange	Marginal leak	YES	NO	Process system / Well system
64	2003	Platform 27	YES	0.34	L	Standard flange	Significant leak	YES	NO	Process system
65	2003	Platform 17	YES	0.34	L	Standard flange	Significant leak	YES	NO	Process system
67	2003	Platform 44	YES	9.5	L	Valve	Significant leak	YES	NO	Flare system
68	2003	Platform 8	YES	0.5	G	Valve	Significant leak	YES	NO	Closed drain
69	2003	Platform 62	YES	0.3	G	Instrument	Significant leak	YES	NO	Process system
70	2003	Platform 7	YES	1	G	Standard flange	Significant leak	YES	NO	Process system / Fuel gas system
71	2003	Platform 7	YES	2.1	G	Valve	Significant leak	YES	NO	Process system
72	2003	Platform 48	YES	0.2	G	Filter	Significant leak	YES	NO	Process system
73	2003	Platform 41	YES	0.2	G	Instrument	Significant leak	YES	NO	Process system

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
74	2003	Platform 7	YES	1	G	Valve	Marginal leak	YES	NO	Process system / Well system
75	2003	Platform 47	YES	0.1	G	Pig trap	Significant leak	YES	NO	Process system
76	2003	Platform 2	YES	1.41	G	Valve	Significant leak	YES	NO	Process system
77	2003	Platform 69	YES	1.2	G	Standard flange	Significant leak	NO	YES	Process system
79	2003	Platform 56	YES	0.1	G	Valve	Significant leak	YES	NO	Process system / Open drain
80	2004	Platform 70	NO	0.16	L	Filter	Significant leak	YES	NO	Process system
81	2004	Platform 71	YES	0.2	L	Storage tank	Significant leak	YES	NO	Process system / Storage
82	2004	Platform 64	YES	3	L	Filter	Significant leak	YES	NO	Process system
83	2004	Platform 17	YES	2.8	G	Standard flange	Significant leak	YES	NO	Flare system
84	2004	Platform 62	YES	17.2	L	Steel pipe	Significant leak	YES	NO	Process system
85	2004	Platform 57	YES	0.71	G	Hose	Marginal leak	YES	NO	Process system / Well system
86	2004	Platform 69	YES	0.3	G	Steel pipe	Significant leak	NO	YES	Process system
87	2004	Platform 10	YES	0.8	G	Valve	Significant leak	YES	NO	Process system
89	2004	Platform 43	YES	1.65	L	Steel pipe	Significant leak	YES	NO	Process system
90	2004	Platform 46	YES	0.22	G	Standard flange	Significant leak	YES	NO	Process system
91	2004	Platform 72	NO	0.1	L	Valve	Significant leak	YES	YES	Process system
92	2004	Platform 20	YES	0.25	L	Valve	Significant leak	YES	NO	Process system
93	2004	Platform 10	YES	0.8	G	Steel pipe	Significant leak	YES	NO	Process system
94	2004	Platform 22	YES	0.2	G	Process vessel	Significant leak	YES	NO	Process system

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
95	2004	Platform 23	YES	0.4	G	Instrument	Significant leak	YES	NO	Process system
96	2004	Platform 19	YES	10	G	Standard flange	Significant leak	YES	NO	Flare system
97	2004	Platform 17	YES	0.35	G	Valve	Marginal leak	YES	NO	Process system
98	2004	Platform 57	YES	0.6	G	Valve	Significant leak	YES	NO	Process system / Well system
100	2004	Platform 17	YES	2.4	G	Hose	Significant leak	YES	NO	Process system
101	2005	Platform 45	YES	0.1	G	Valve	Significant leak	YES	NO	Process system / Well system
102	2005	Platform 27	YES	0.7	G	Steel pipe	Significant leak	YES	NO	Process system
103	2005	Platform 28	YES	1.8	G	Hose	Significant leak	YES	NO	Process system
104	2005	Platform 5	YES	240	L	Standard flange	Significant leak	NO	NO	Process system
105	2005	Platform 8	YES	0.8	G	Standard flange	Significant leak	YES	NO	Closed drain / Process system
106	2005	Platform 2	YES	1.6	G	Valve	Significant leak	YES	NO	Process system
107	2005	Platform 27	YES	0.12	G	Steel pipe	Significant leak	YES	NO	Process system
108	2005	Platform 21	YES	0.3	G	Valve	Marginal leak	YES	NO	Process system
109	2005	Platform 57	YES	0.68	G	Compressor	Significant leak	YES	NO	Process system
110	2005	Platform 2	YES	2	G	Vent	Significant leak	YES	NO	Produced water / Sea water / Open drain
113	2005	Platform 27	YES	8.03	G	Hose	Marginal leak	YES	NO	Process system
114	2005	Platform 70	NO	1.7	L	Producing well	Marginal leak	YES	NO	Well system
115	2005	Platform 7	YES	0.6	G	Valve	Significant leak	YES	NO	Process system / Flare system
117	2005	Platform 8	YES	0.21	G	Steel pipe	Significant leak	YES	NO	Process system

ID	Year	Installation	In NCS populatio n dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
118	2005	Platform 46	YES	0.5	G	Valve	Significant leak	YES	NO	Process system
119	2006	Platform 8	YES	930	G	Steel pipe	Significant leak	YES	NO	Flare system
121	2006	Platform 28	YES	0.28	G	Valve	Significant leak	YES	NO	Process system
122	2006	Platform 33	YES	0.15	G	Hose	Significant leak	YES	NO	Process system
123	2006	Platform 62	YES	11.11	G	Standard flange	Marginal leak	YES	NO	Closed drain
124	2006	Platform 9	YES	0.52	G	Valve	Significant leak	YES	YES	Process system
125	2006	Platform 1	YES	0.15	G	Valve	Marginal leak	YES	NO	Process system
127	2006	Platform 56	YES	0.6	G	Instrument	Significant leak	YES	NO	Process system
128	2006	Platform 39	YES	0.5	L	Process vessel	Significant leak	YES	NO	Flare system
129	2006	Platform 44	YES	0.7	G	Instrument	Significant leak	YES	NO	Process system
130	2006	Platform 27	YES	0.2	G	Instrument	Significant leak	YES	NO	Process system
131	2006	Platform 61	YES	0.1	L	Hose	Significant leak	YES	NO	Process system
132	2006	Platform 18	YES	80	G	Standard flange	Significant leak	YES	NO	Flare system
133	2006	Platform 27	YES	0.87	L	Valve	Significant leak	YES	NO	Process system
134	2006	Platform 59	YES	0.14	G	Steel pipe	Significant leak	YES	NO	Process system
136	2007	Platform 62	YES	0.25	G	Valve	Significant leak	YES	NO	Process system
137	2007	Platform 63	YES	1.8	G	Standard flange	Significant leak	YES	NO	Process system
138	2007	Platform 12	YES	0.15	G	Steel pipe	Significant leak	YES	NO	Fuel gas system
140	2007	Platform 56	YES	0.3	G	Instrument	Significant leak	YES	NO	Process system
141	2007	Platform 18	YES	2.83	G	Standard flange	Significant leak	YES	NO	Process system
142	2007	Platform 43	YES	2.5	L	Valve	Significant leak	YES	NO	Process system / Well system

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
143	2007	Platform 43	YES	1	G	Valve	Significant leak	YES	NO	Process system / Well system
144	2007	Platform 47	YES	1.93	G	Standard flange	Significant leak	YES	NO	Fuel gas system
146	2008	Platform 55	YES	10	L	Steel pipe	Significant leak	YES	NO	Process system / Storage
147	2008	Platform 4	YES	1.2	G	Valve	Significant leak	YES	NO	Process system
148	2008	Platform 41	YES	0.4	G	Instrument	Significant leak	YES	NO	Process system
149	2008	Platform 17	YES	0.4	G	Steel pipe	Significant leak	YES	NO	Process system
150	2008	Platform 60	YES	0.2	G	Steel pipe	Significant leak	YES	NO	Process system / Well system
151	2008	Platform 7	YES	0.3	G	Valve	Significant leak	YES	NO	Process system / Flare system
152	2008	Platform 37	YES	0.26	G	Steel pipe	Significant leak	NO	NO	Process system / Flare system
153	2008	Platform 37	YES	0.5	G	Standard flange	Significant leak	NO	NO	Process system / Produced water?
154	2008	Platform 10	YES	26	G	Valve	Significant leak	YES	NO	Process system
155	2008	Platform 4	YES	2.8	L	Valve	Significant leak	YES	NO	Process system / Utility system
156	2008	Platform 22	YES	0.24	G	Standard flange	Significant leak	YES	NO	Fuel gas system
157	2008	Platform 22	YES	0.9	G	Valve	Significant leak	YES	NO	Process system
159	2008	Platform 2	YES	0.8	G	Steel pipe	Marginal leak	YES	NO	Process system / Seal oil system
160	2009	Platform 14	YES	0.5	G	Valve	Significant leak	NO	NO	Process system
161	2009	Platform 5	YES	9	G	Valve	Significant leak	NO	NO	Process system

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
163	2009	Platform 37	YES	0.44	G	Valve	Significant leak	NO	NO	Process system
164	2009	Platform 55	YES	2.8	L	Standard flange	Significant leak	YES	NO	Process system
165	2009	Platform 22	YES	0.5	G	Valve	Significant leak	YES	NO	Fuel gas system / Diesel system
166	2009	Platform 60	YES	3.42	G	Instrument	Significant leak	YES	NO	Process system / Gas lift system
167	2009	Platform 10	YES	0.815	L	Instrument	Significant leak	YES	NO	Process system
168	2009	Platform 57	YES	0.3	L	Valve	Significant leak	YES	NO	Process system
169	2009	Platform 57	YES	0.2	L	Valve	Significant leak	YES	NO	Process system / Closed drain
170	2009	Platform 2	YES	0.45	L	Valve	Marginal leak	YES	NO	Process system
171	2009	Platform 63	YES	0.66	L	Valve	Significant leak	YES	NO	Process system / Well system
172	2009	Platform 18	YES	1.5	G	Valve	Significant leak	YES	NO	Flare system
173	2009	Platform 72	NO	2	L	Steel pipe	Significant leak	YES	YES	Process system
174	2009	Platform 23	YES	0.25	L	Instrument	Significant leak	YES	NO	Process system
175	2009	Platform 60	YES	0.27	L	Valve	Significant leak	YES	NO	Process system
176	2010	Platform 63	YES	0.276	G	Valve	Marginal leak	YES	NO	Process system / Well system
177	2010	Platform 2	YES	0.4	G	Valve	Marginal leak	YES	NO	Process system
178	2010	Platform 69	YES	0.8	G	Valve	Significant leak	NO	YES	Process system
179	2010	Platform 2	YES	0.4	G	Valve	Significant leak	YES	NO	Process system
180	2010	Platform 21	YES	12.7	G	Valve	Significant leak	YES	NO	Process system
181	2010	Platform 8	YES	0.55	G	Instrument	Significant leak	YES	NO	Process system

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
182	2010	Platform 48	YES	0.1	G	Standard flange	Significant leak	YES	NO	Process system
183	2010	Platform 3	YES	1.3	L	Valve	Significant leak	YES	NO	Process system / Well system
184	2010	Platform 31	YES	0.5	L	Standard flange	Significant leak	YES	NO	Process system
185	2010	Platform 28	YES	0.22	G	Valve	Significant leak	YES	NO	Process system
186	2010	Platform 63	YES	0.1	G	Steel pipe	Marginal leak	YES	NO	Process system / Well system
188	2010	Platform 7	YES	0.62	L	Valve	Significant leak	YES	NO	Process system
189	2010	Platform 72	NO	0.8	L	Valve	Significant leak	YES	YES	Process system
190	2010	Platform 5	YES	0.1	G	Pump	Significant leak	NO	NO	Process system / Well system
191	2011	Platform 67	YES	3.9	L	Standard flange	Significant leak	YES	NO	Process system
192	2011	Platform 27	YES	0.5	G	Standard flange	Significant leak	YES	NO	Process system
193	2011	Platform 7	YES	0.51	G	Valve	Significant leak	YES	NO	Process system
194	2011	Platform 9	YES	0.6	G	Valve	Significant leak	YES	YES	Process system
195	2011	Platform 6	YES	0.9	G	Valve	Significant leak	YES	NO	Process system
196	2011	Platform 20	YES	0.25	G	Hose	Significant leak	YES	NO	Process system
197	2011	Platform 61	YES	0.58	L	Steel pipe	Significant leak	YES	NO	Process system
198	2011	Platform 10	YES	0.11	G	Valve	Significant leak	YES	NO	Process system
201	2011	Platform 16	YES	0.34	G	Valve	Marginal leak	YES	NO	Fuel gas system
202	2012	Platform 27	YES	16.9	G	Standard flange	Significant leak	YES	NO	Flare system
203	2012	Platform 22	YES	1.6	L	Standard flange	Significant leak	YES	NO	Process system
204	2012	Platform 7	YES	0.17	G	Compressor	Significant leak	YES	NO	Process system

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
205	2012	Platform 51	YES	0.48	L	Valve	Marginal leak	YES	NO	Process system
206	2012	Platform 25	YES	230	L	Valve	Significant leak	YES	NO	Process system
207	2012	Platform 73	NO	0.16	G	Standard flange	Significant leak	YES	NO	Process system
208	2013	Platform 48	YES	0.3	G	Valve	Significant leak	YES	NO	Process system / Well system
209	2013	Platform 37	YES	0.39	G	Valve	Significant leak	NO	NO	Process system / Well system
210	2013	Platform 62	YES	0.1	G	Steel pipe	Significant leak	YES	NO	Process system
211	2013	Platform 21	YES	0.83	G	Valve	Significant leak	YES	NO	Process system
212	2013	Platform 18	YES	0.75	G	Valve	Significant leak	YES	NO	Process system
213	2013	Platform 23	YES	20	G	Compressor	Significant leak	YES	NO	Process system
214	2013	Platform 32	YES	0.9	G	Valve	Marginal leak	NO	NO	Process system / Well system
215	2013	Platform 17	YES	0.73	G	Valve	Significant leak	YES	NO	Process system
216	2013	Platform 55	YES	0.131	L	Pump	Significant leak	YES	NO	Process system
217	2014	Platform 3	YES	0.15	G	Steel pipe	Significant leak	YES	NO	Process system / Flare system
219	2014	Platform 4	YES	0.65	L	Instrument	Significant leak	YES	NO	Process system
220	2014	Platform 57	YES	20.8	L	Vent	Significant leak	YES	NO	Closed drain / Open drain system
221	2014	Platform 17	YES	0.2	G	Valve	Significant leak	YES	NO	Process system
222	2014	Platform 10	YES	2.2	G	Valve	Marginal leak	YES	NO	Process system
224	2015	Platform 8	YES	0.7	G	Valve	Significant leak	YES	NO	Process system
225	2015	Platform 33	YES	0.11	G	Hose	Significant leak	YES	NO	Process system (Gas

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
										lift)
226	2015	Platform 54	YES	3.11	G	Standard flange	Significant leak	NO	NO	Process system
227	2015	Platform 9	YES	6.9	L	Instrument	Significant leak	YES	YES	Process system
228	2015	Platform 29	YES	0.28	G	Instrument	Significant leak	YES	NO	Process system
229	2015	Platform 66	YES	8	L	Steel pipe	Significant leak	NO	NO	Process system
230	2015	Platform 22	YES	0.21	G	Valve	Marginal leak	YES	NO	Process system
234	2015	Platform 52	YES	0.1	G	Valve	Marginal leak	NO	NO	Process system
235	2015	Platform 2	YES	0.31	G	Hose	Marginal leak	YES	NO	Well system
236	2016	Platform 64	YES	2	G	Shell and tube heat exchanger	Significant leak	YES	NO	Process system / Sea water
237	2016	Platform 37	YES	1.2	G	Instrument	Significant leak	NO	NO	Process system
238	2016	Platform 22	YES	0.5	G	Vent	Significant leak	YES	NO	Process system / Produced water?
239	2016	Platform 2	YES	1.9	G	Gas lift well	Marginal leak	YES	NO	Well system
241	2016	Platform 65	YES	4	G	Valve	Significant leak	NO	NO	Process system
243	2016	Platform 35	YES	0.58	G	Valve	Significant leak	NO	NO	Process
244	2016	Platform 35	YES	6.5	L	Valve	Significant leak	NO	NO	Process
245	2016	Platform 35	YES	1.11	G	Valve	Significant leak	NO	NO	Process
246	2016	Platform 35	YES	0.7	L	Pump	Significant leak	NO	NO	Process
247	2016	Platform 35	YES	0.1	G	Standard flange	Significant leak	NO	NO	Process
248	2017	Platform 2	YES	0.12	G	Instrument	Significant leak	YES	NO	Process
249	2017	Platform 57	YES	6.4	L	Hose	Significant leak	YES	NO	Process
250	2017	Platform 62	YES	0.25	G	Instrument	Significant leak	YES	NO	Process

ID	Year	Installation	In NCS population dataset	Initial leak rate 2018 [kg/s]	Medium	Equipment type	Leak scenario (see TN-4)	Commissioned before 01.01.2001	Decommissioned before 31.12.2017	System
251	2017	Platform 16	YES	0.62	G	Valve	Significant leak	YES	NO	Process
252	2017	Platform 17	YES	0.17	G	Standard flange	Significant leak	YES	NO	Process
253	2017	Platform 63	YES	0.16	G	Instrument	Significant leak	YES	NO	Process
254	2017	Platform 73	NO	0.79	G	Standard flange	Significant leak	YES	NO	Process

Appendix B

Email used as reference

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1 Introduction

This appendix gives email used as reference in TN-2. The email is written in Norwegian.

2 Email used as reference

Hei,

Midlertidig bruk av slanger

Vi har hatt ei internmøte med OMT- ekspertene i Safetec vedrørende modell for midlertidig bruk av slanger;

Vi fokuserte i møtet på utfordringen knyttet til å estimere lekkasjefrekvens for midlertidig bruk av slanger ut fra den tilgjengelige dataen fra 3 Statoil innretninger. De tre installasjonene er ikke nødvendigvis gode representanter for gjennomsnittet for Statoils innretninger på norsk sokkel. De tre kan for eksempel alle ha et veldig høyt aktivitetsnivå. Vi brukte derfor tilgjengelig informasjon om hvordan deres aktivitetsnivå forholder seg til gjennomsnittlig aktivitetsnivå til å lage et vektet gjennomsnitt.

Vektene ble bestemt ved å regne ut de tre installasjonenes relative aktivitetsnivå for arbeidsordre på normalt trykksatt utstyr, B1-B4, i forhold til gjennomsnittet for alle Statoils innretninger på norsk sokkel. Altså gjorde vi en implisitt antakelse om at for den enkelte installasjon vil aktivitetsnivå for B6 forholde seg til gjennomsnittlig nivå på samme måte som B1-B4. Dette vet vi ikke er riktig for den enkelte installasjon, fordi B6-nivå avhenger sterkt av design, men vi fant det allikevel rimelig å tro at denne vektingen gir et bedre estimat enn ved ikke å vekte snittet.

1) Vektet snitt B6 operasjoner i året for de 3 installasjonene :(260+371+12)/3=214
2) Lekkasjefrekvens B6 Statoil per år fra tabell 4.2: 1.07E-02
3) Lekkasjefrekvens per slangeoperasjon følger da med 1.07E-02/214=5.0E-05

Dette er det beste vi kan gi som input til ein aktivitetsbasert modell for bruk av midlertidige slanger. Vi mener dette er en ok fremgangsmåte, men ser at det er usikkerhet her. Vi kan utdypetallmaterialet bak det vektet snittet dersom dette er av interesse.

QA av norsk lekkasjedata.
Lekkasje-ID 20 og 22 som vi har latt stå som ukjent på type utstyr er klassifisert som B6 lekkasjer i BORA. B6 er definert som ; «Maloperation of temporary hoses». Vi har ikke granskingsrapport på disse lekkasjene, så vi kan dessverre ikke gå tilbake å verifisere at dette virkelig er B6 lekkasjer. Men det er altså gjort ein vurdering ein gang der dei har landa på at dette er B6 lekkasjar.

Berra ta kontakt om det er spm/kommentarar til dette.

God helg!

Mvh

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