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UKCS-data

TN-3

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Summary

UKCS-data

TN-3

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1 Introduction

1.1 General

This technical note describes incident data and population data for installations located on UKCS extracted from HCRD for the period 1992-2017. In addition, leak frequencies and complementary cumulative hole size distributions based on the UKCS data for the period 1992-2014 is presented.

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

1.2 Application of UKCS data as basis for PLOFAM

The UKCS data has not been used directly to set the parameters in PLOFAM. Under the development of the first version of PLOFAM, much work was carried out to derive a parameter set solely based on UKCS data. However, due to shortcomings in the quality of the UKCS data (*e.g.* incomplete population data and inconsistent reporting of initial leak rate and hole size relative to recorded inventory and duration as well as inconsistencies in the equipment type tagged to the incident), it was concluded to mainly apply the NCS data to set the ultimate parameters in PLOFAM. In the process of updating the PLOFAM model, it has been concluded to apply the UKCS data only for reference and support when evaluating certain aspects in the parameterisation process (see Chapter 7).

The current technical note describing UKCS data has therefore not been completely updated covering UKCS data in the period Q2 2015- Q4 2017. This TN does mainly present UKCS data for the period Q3 1992 - Q1 2015, including Appendix A through to Appendix C. The additional UKCS data for Q2 2015 – Q4 2017 is presented on a high level focusing on the updated population data and the total number of leaks according the definition of the various relevant leak scenarios. The relevant UKCS leaks found in the HCR database for the last three years is summarized in Appendix D.

1.3 Availability statistical data

Information about offshore releases of hydrocarbons at United Kingdom Continental Shelf (UKCS), are collected in Hydrocarbon Release Database (HCRD). The database is operated by Health and Safety Executive (HSE).

Lilleaker Consulting AS (hereafter denoted Lilleaker) built a databasis in excel format with all HCR-data for the period Q3 1992 – Q1 2015, and developed additional data fields (based on the existing data fields), filters and tools for data analysis. The HCR databasis is documented in Appendix A, which contains Lilleaker's documentation of the HCR-data, documentation of the developed databasis and also general assessments of the data fields in HCRD.

The data for the period Q2 2015 – Q4 2017 has been extracted directly from the original data that can be downloaded at the HCR website. The relevant incidents with respect to the definition of a process leak in PLOFAM are presented in Appendix D.

The developed databasis has been made available to all project participants, but is not publicly available. Important parts of the data extracted from HCR data is given in Appendix B. Note also that all data in the databasis, except exact hole sizes for holes >100 mm and exact equipment dimensions are publically available as described in Appendix A. Exact hole sizes for holes >100 mm and exact equipment dimensions have been made available to this project by HSE.

2 Recorded incidents at UKCS in the period 1992-2014 relevant for the modelled leak scenarios

In total 4561 events occurring in the period Q3 1992 - Q1 2015 are recorded in HCRD. Not all of the incidents are relevant for the defined leak scenarios (see TN-4). A thorough analysis has been necessary to extract the relevant incidents for the model. In this chapter, filters are defined and described to explain how the relevant incidents are filtered out. This is done separately for process leaks fed through process systems, process leaks fed through utility systems, producing well leaks and gas lift well leaks, in Chapter 2.1, 2.2 and 2.3, respectively.

2.1 Extracting relevant process leaks fed through process system

This chapter describes the applied filters to extract process leaks fed through process systems from HCRD. Further the number of incidents extracted by applying the filters is given in detail in Appendix B, while a summary of the extracted data is presented here.

2.1.1 Filters used to extract data

An illustration of the applied filters is given in Figure 2.1. The figure shows the number of incidents removed from the databasis in each filter operation, and how many that remains in each step. The resulting databasis contains 2855 recorded incidents from the period Q3 1992 - Q1 2015, and 1597 recorded incidents from the period Q1 2001 - Q1 2015. These incidents are further divided into the following categories:

- Incidents with total recorded released amount ≤10 kg and >10 kg.
- Incidents with recorded initial pressure ≤0.01 barg and >0.01 barg
- Incidents with recorded hole size ≤1 mm, >1 mm, and incidents where the recorded hole size is recorded as N/A (Not Applicable). In Appendix A in Lilleaker's report, given in TN-3 Appendix A, the HCR definitions of the data fields are presented. For hole diameters it is stated: "*It is important to note that N/A in this field indicates that hole size is not applicable to the mode of release involved*". An example of incidents from HCRD where hole size is recorded as N/A is if oil is carried up the HP flare, where not all of the oil is burned and some drops as droplets to the sea or platform topside

The detailed results are given in Appendix B.

The filters applied to HCRD to extract relevant process leaks fed through process systems are described in detail in the following sections. An overview of the evaluated data-fields is given in Table 2.1.

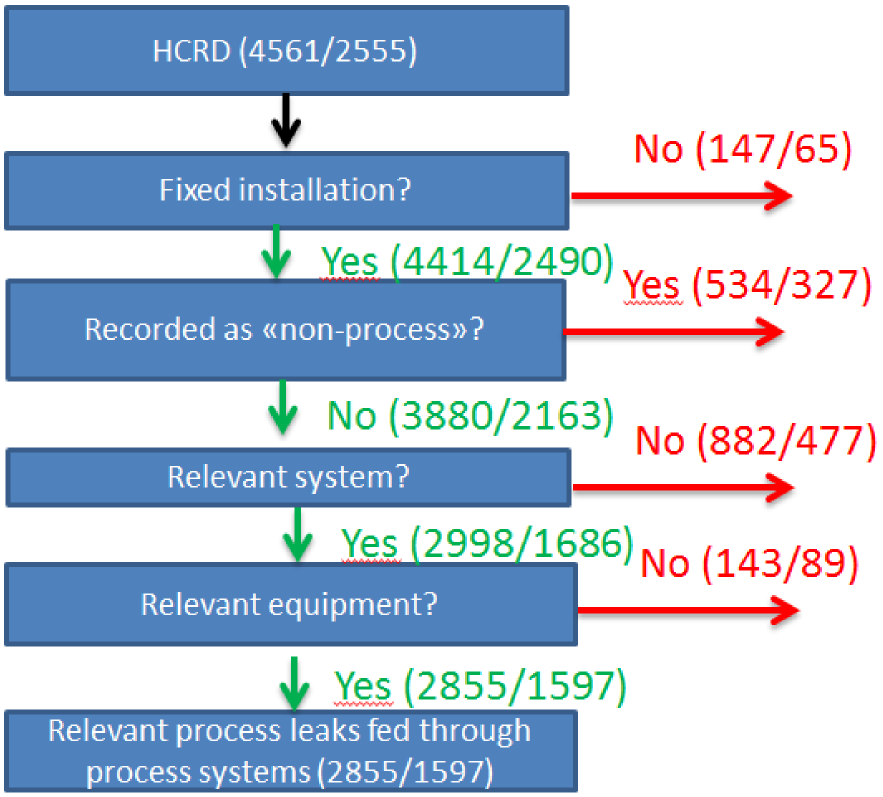

Figure 2.1 - Illustration of the filters used to extract relevant process leaks fed through process systems from HCRD. The numbers with green font represent incidents that are kept after the filter is applied. The numbers in red font are the number of incidents that are taken out. The number at the left side of the slash are resulting from the period Q3 1992 - Q1 2015, while the number at the right side of the slash are resulting from the period Q1 2001 – Q1 2015

Table 2.1 - HCR data fields evaluated and described in more detail in the below sub-sections.

HCR field no.	HCR data field	HCR Description
2	CATEGORY	Installation type: FIXED, MOBILE, SUBSEA. The installation may have a subsea satellite (recorded in field 16 subsea)
19	PROCESS	This is the type of Hydrocarbon released, i.e. NON-PROCESS, OIL, CONDENSATE, GAS and 2-PHASE
28	SYSTEM	This field contains either a full description of the system involved or a Drilling or Well Operation activity description where appropriate.
32	EQUIPMENT	This gives the full equipment item description. For Drilling/Well Operations activities (see item 28 above) this will be left blank.
43	HAZ_CLASS	This field contains the Hazardous Area Classification for the location of the incident, where 1 and 2 represent areas 1 and 2 respectively, and 3 represents unclassified.
47	MOD_VOLUME	This contains the volume of the module involved, in m3, and will show 'NOT KNOWN' where not reported.
53	INVENTORY	This is the isolatable hydrocarbon inventory contained in the system, in kg. And will show 'NOT KNOWN' where not reported.
58	DETECTION_OTHER	Leak detected by "other" means

2.1.1.1 Relevant installations (CATEGORY)

HCRD distinguish on 3 different types of installations: Fixed, mobile and subsea installations. Only incidents at fixed installations are regarded as relevant for the model.

2.1.1.2 Relevant leaks medium (PROCESS)

HCRD distinguish on NON-PROCESS, OIL, CONDENSATE, GAS and 2-PHASE leaks. Leak medium categorized as "non-process" is regarded as not relevant for the model.

2.1.1.3 Relevant systems (SYSTEM)

HCRD describes the system involved. The systems regarded as relevant and irrelevant for the model are listed in the table below.

Table 2.2 - Systems (as defined in HCRD) regarded as relevant and not relevant for the process leaks fed through process system. For definitions of the systems it is referred to Appendix A

Relevant systems	Not relevant systems
• Export • Metering • Flowlines • Compression • Fuel gas • Processing • Import • Separation	• Blowdown and flare • Subsea well • Vent • Closed drain • Open drain • Surface well • Well control • Turbines • Drilling • Utilities

2.1.1.4 Relevant equipment (EQUIPMENT)

The equipment that is regarded as relevant and irrelevant, for the model is listed in Table 2.3. Note that the naming convention is in accordance with HCRD.

Table 2.3 - Equipment regarded as relevant and not relevant for the model. Valves, flanges and pipes are given in HCRD as three equipment size intervals; small (≤3"), medium (3-11") and large (>11"). The model equipment naming is given in parenthesis

Table Heading	
• Actuated valve L (Valve) • Actuated valve M (Valve) • Actuated valve S (Valve) • Manual valve L (Valve) • Manual valve M (Valve) • Manual valve S (Valve) • Centrifugal Compressors (Centrifugal Compressor) • Reciprocating Compressor (Reciprocating Compressor) • Filters (Filter) • Flanged joints L (Standard flange) • Flanged joints M (Standard flange) • Flanged joints S (Standard flange)	• Degasser • Expanders • Drain • Flexible pipelines • Pipeline valve • Flexible risers • Steel risers • Steel pipeline

Table Heading	
• Heat exchanger plate (Plate heat exchanger) • Heat exchanger HC in tube (Tube side heat exchanger) • Heat exchanger HC in shell (Shell side heat exchanger) • Fin fan cooler (Air-Cooled Heat Exchanger) • Instruments (Instrument) • Pig traps (Pig trap) • Process vessel (Process vessel) • Centrifugal pump (Centrifugal pump) • Reciprocating pump (Reciprocating pump) • Steel piping large (Steel pipe) • Steel piping medium (Steel pipe) • Steel piping small (Steel pipe) • Atmospheric vessel (Atmospheric vessel) • Flexible piping (Flexible pipe)	• Turbines • Xmas trees • BOP • Shale shakers • Recompressor • Wellhead • Mud pumps • Mud tanks • Workover • #N/A

2.1.1.5 Relevant area classification (HAZ_CLASS)

No incidents are removed from the database based on recorded area classification.

2.1.1.6 Relevant module volume

The term module is not defined in HCRD, but it is stated: "3000m3 explosive clouds are enough to fill an entire module or deck area". Module volumes are sometimes reported to be very small, maybe inside confinements such as separate rooms (e.g. for pumps) or under hood of turbines. No incidents are removed from the database based on recorded module volume.

2.1.1.7 Relevant inventory

Many recorded inventories are reported being very small. One could claim that the inventory of a standard isolatable segment should be significant in order to the leak to be relevant for the model. However, incidents are not removed from the database based on recorded inventory.

2.1.1.8 Relevant detection method

The recorded detection method may indicate that the leak was not a process leak. For instance; ROV detection or pressure drop may indicate subsea leak, which is possibly indicate leaks that should be considered irrelevant for the model. However, incidents are not removed from the database based on recorded detection method.

2.1.1.9 Hole size

The existing model is valid for hole sizes >1mm. The uncertainty related to hole sizes <1mm is significant, and the same model validity range as assumed in the previous model is suggested for the updated model. However, these incidents are included in the analysis, but separated from incidents with hole size > 1 mm.

2.1.1.10 Initial leak rate

Incidents are not removed from the database based on initial leak rate boundary.

2.1.2 Extracted data for process leaks fed through process systems

The data extracted from HCRD by applying the filters described in Section 2.1.1 Figure 2.1, are given in detail in Appendix B. Figures that show the most important observations related to process leaks fed through process systems are given in the below figures.

In total there are 2855 relevant incidents in the period Q3 1992 – Q1 2015 in HCRD, and 1597 relevant incidents in the period Q1 2001 – Q1 2015. About 50 % of these incidents are recorded with hole size ≤1 mm. Also a significant fraction of the leaks are recorded with a total leaked quantity ≤10 kg, which are classified as Marginal leaks in accordance with the definitions in TN-4. Figure 2.2 shows the number of relevant Marginal and Significant leaks with hole size > 1 mm or N/A and hole size ≤1 mm for the periods Q3 1992 – Q1 2015 and Q1 2001 – Q1 2015. Note that Significant leaks with initial pressure >0.01 barg and ≤ 0.01 barg are given separately and shows that the number of significant leaks with initial pressure ≤ 0.01 barg is low. This is also seen in Figure 2.3 that shows the relative contribution from all these leak scenarios. Figure 2.4 gives the fractions of relevant leaks recorded in HCRD with hole size >1 mm or with hole size N/A, for Marginal and Significant leaks.

Figure 2.5 and Figure 2.6 give the equipment type distribution for the period Q3 1992 – Q1 2015 and Q1 2001 – Q1 2015 for Significant and Marginal leaks, respectively, while Figure 2.7 gives the equipment type distribution for Marginal and Significant leaks for the period Q3 1992 – Q1 2015.

Reported leaks at NCS (see TN-2) only comprise leaks with initial leak rate >0.1 kg/s. Therefore it is of interest to see the fraction of incidents recorded at UKCS that has an estimated initial leak rate >0.1 kg/s. This is given in Figure 2.8 for significant leaks with hole size > 1 mm recorded in the period Q3 1992 – Q1 2015.

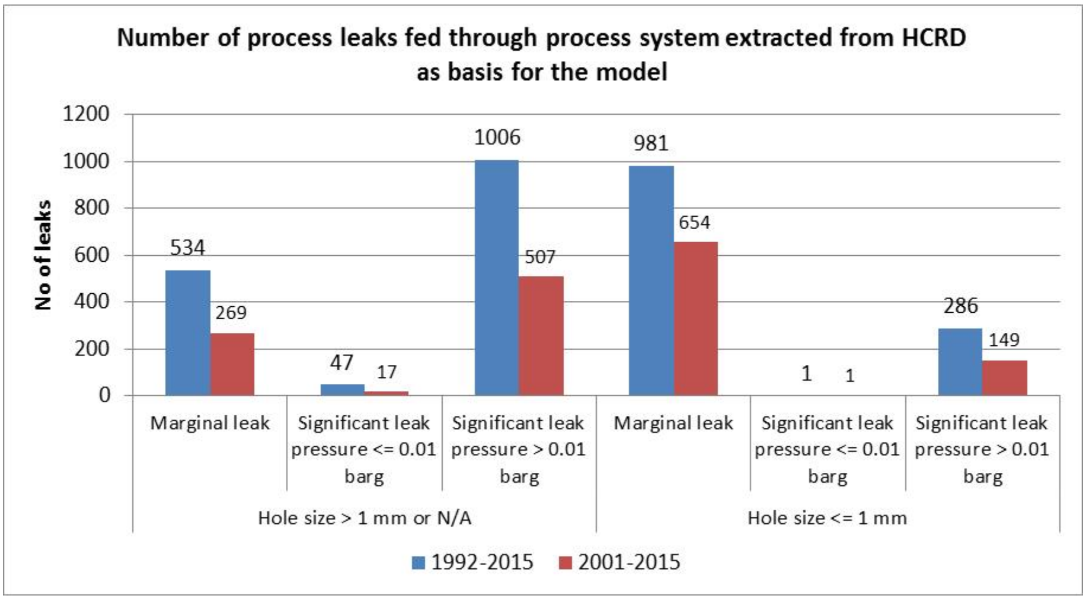

Figure 2.2 - Number of process leaks fed through process systems recorded on UKCS relevant for the defined leak scenarios

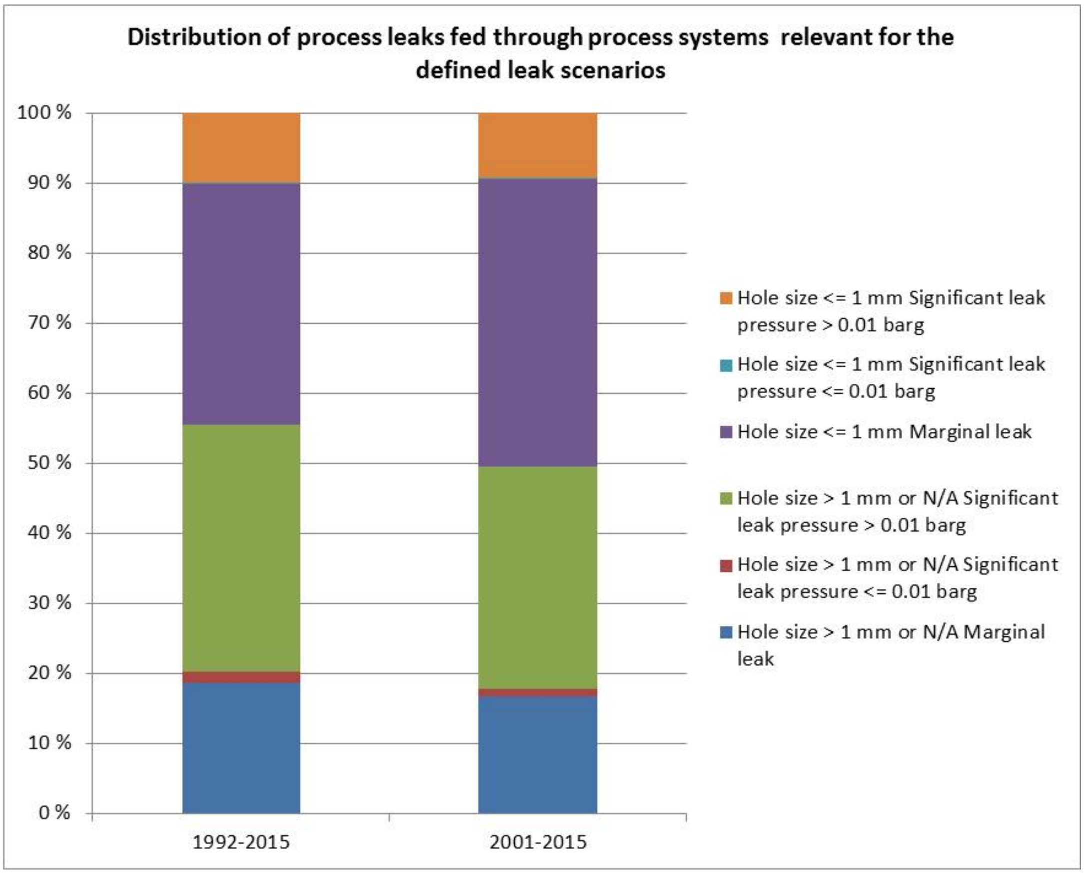

Figure 2.3 - The fraction of leaks that are relevant for the defined leak scenarios

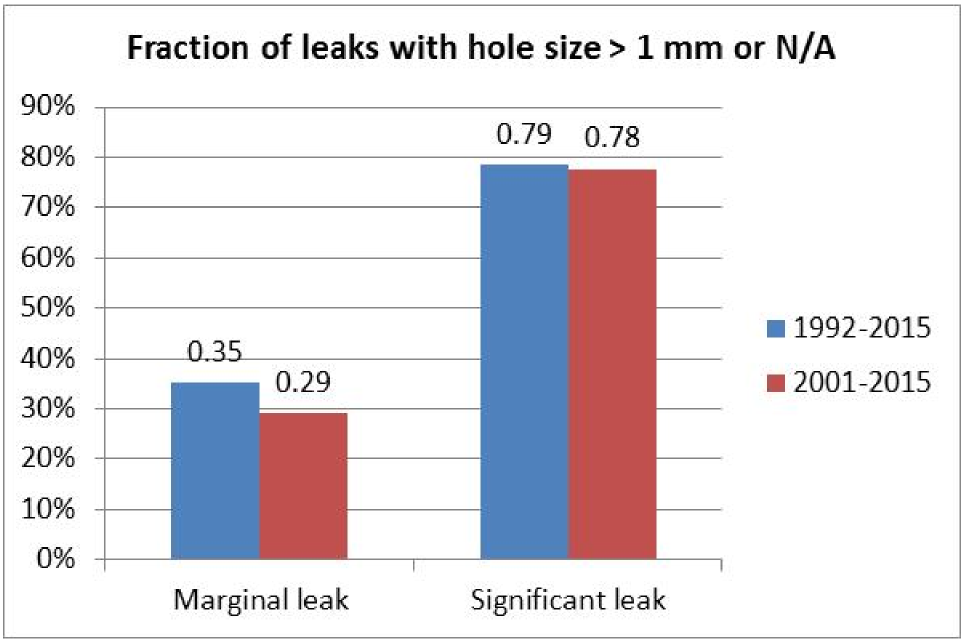

Figure 2.4 - Fractions of relevant leaks recorded in HCRD with hole size >1 mm or with hole size N/A, for Marginal and Significant leaks

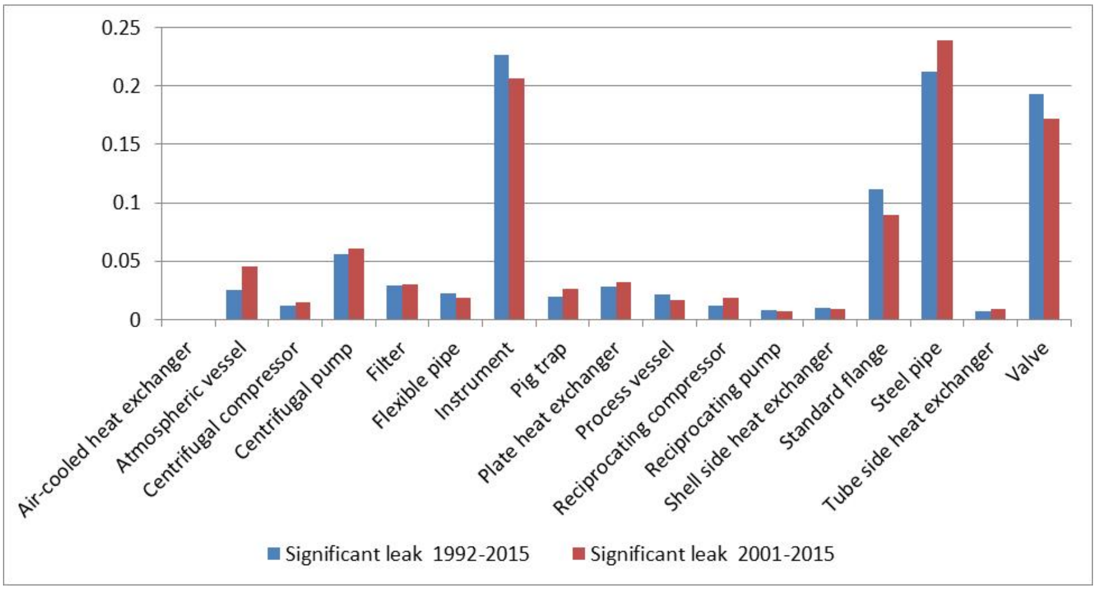

Figure 2.5 - Equipment type distribution for Significant leaks, given both for the time period Q3 1992 – Q1 2015 and Q1 2001-2015

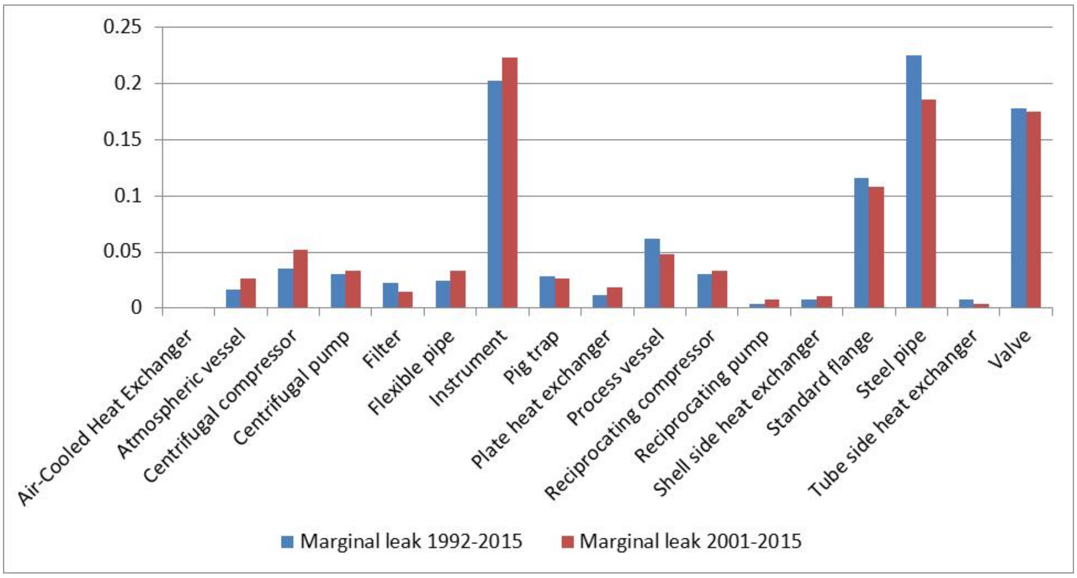

Figure 2.6 - Equipment type distribution for Marginal leaks, given both for the time period Q3 1992 – Q1 2015 and Q1 2001- Q1 2015

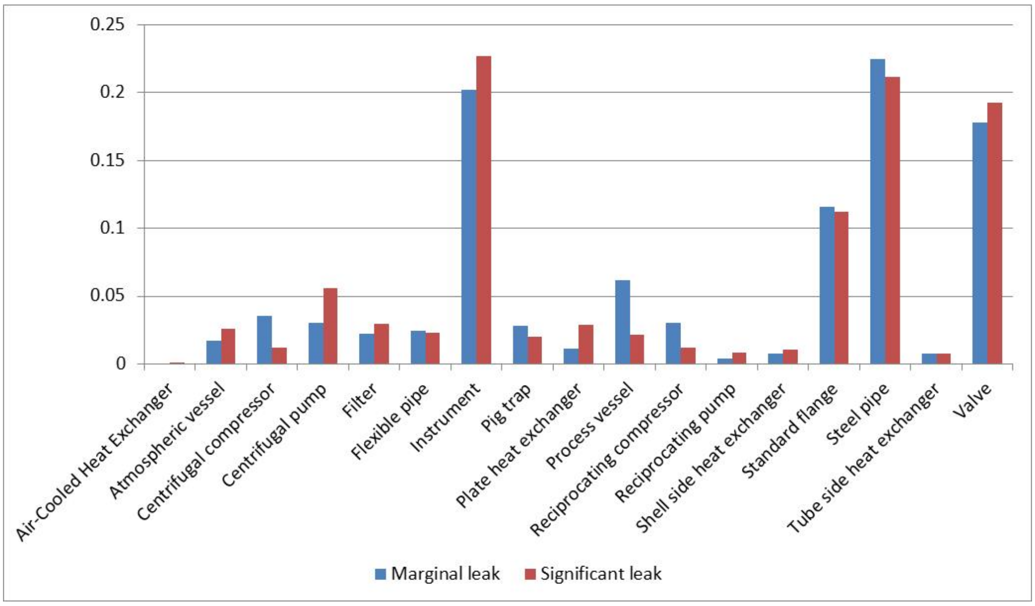

Figure 2.7 - Equipment type distribution for Significant and Marginal leaks for the period Q3 1992 – Q1 2015

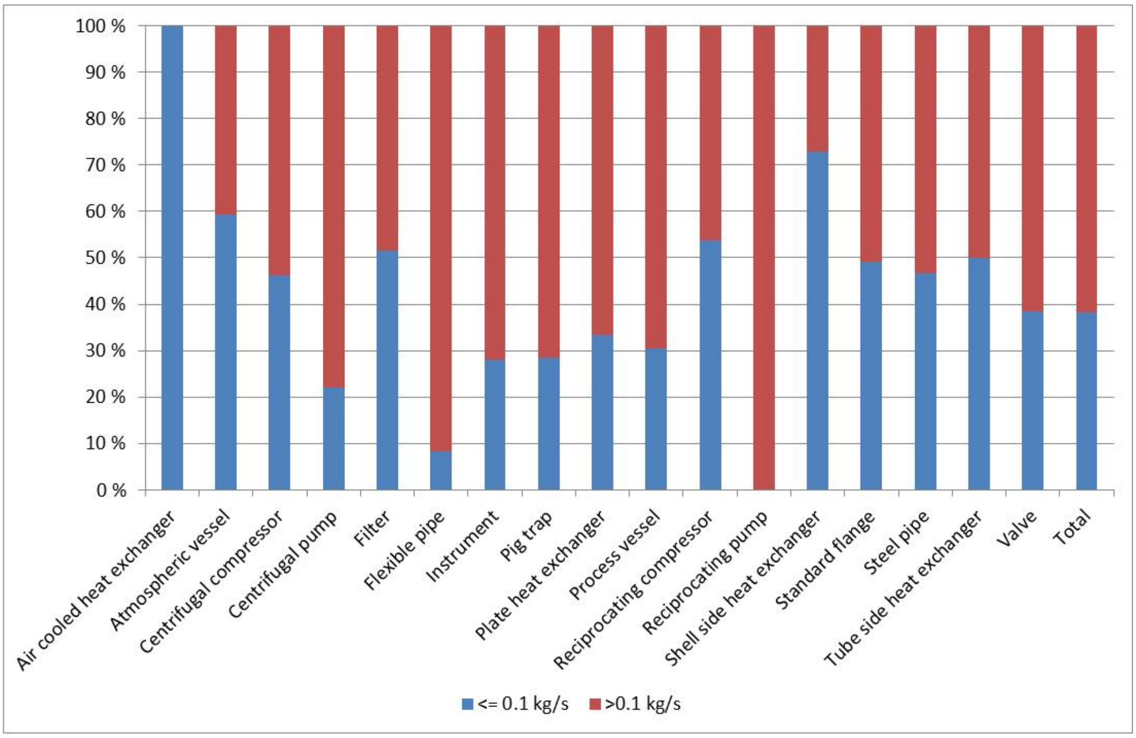

Figure 2.8 - Fraction of Significant leaks in the period Q3 1992 – Q1 2015 that has initial leak rate ≤ 0.1 kg/s, and > 0.1 kg/s. Only hole sizes >1 mm or N/A are included

2.1.2.1 Effect of reducing the data collection period

HCR-data is available from Q3 1992, but the latest data are most likely more representative for the future than the oldest data. Therefore it is of interest to study the number of incidents remaining if the start date for the collection period is changed. This is given in Figure 2.9 for all steps in the defined filter in Figure 2.1, and also if incidents with recorded hole size < 1 mm are removed. The numbers of incidents are reduced linearly, indicating that the number of leaks per year is relatively constant before 2001. This is confirmed in Figure 2.11 that gives the number of relevant recorded leaks in HCRD in for every year in the period 1993 – 2014. The years 1992 and 2015 are not included as data for the full year is not available. The figure displays a decreasing trend after 2004. As corresponding exposure data are not given per year, leak frequency trend with time cannot be analysed.

For every step in the defined filter in Figure 2.1, Figure 2.10 gives the fraction of process incidents as a function of the first year in the data collection period relative to using 1992 as the first year. All filter steps show similar trend (they are on top of each other) except for the hole size filter, indicating that the frequency of process leaks at fixed installations, from relevant systems and from relevant equipment is constant in before 2001. The figure also shows that the fraction of these leaks with hole size >1 mm is decreasing, which indicates that there is a decreasing trend in frequency for leaks relevant for modelling of process leaks in Quantitative Risk Analysis (i.e. initial leak rate > 0.1 kg/s).

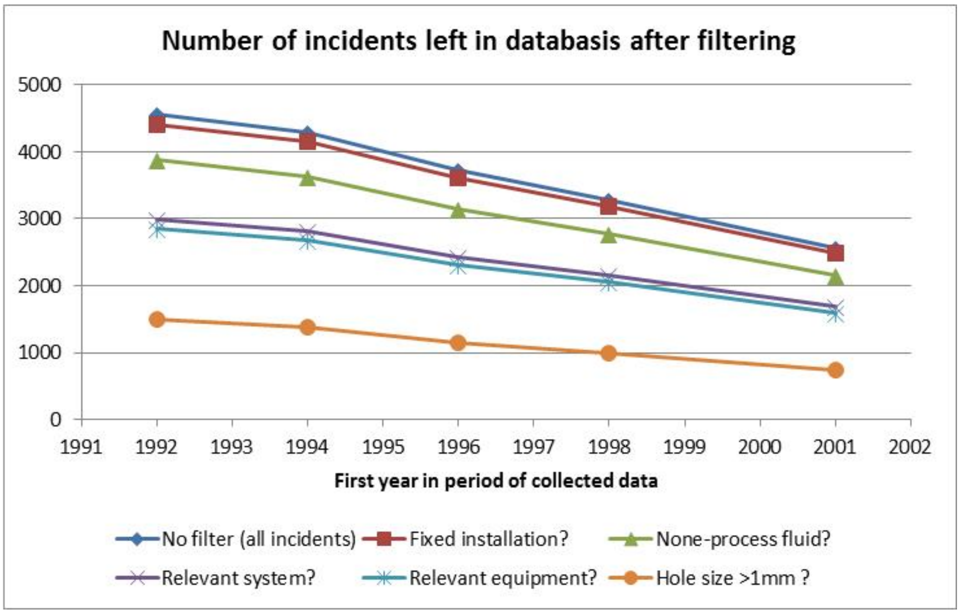

Figure 2.9 - Number of process leak incidents left after the applied filters as a function of the first year in the period of collected data (end year of period is 2015)

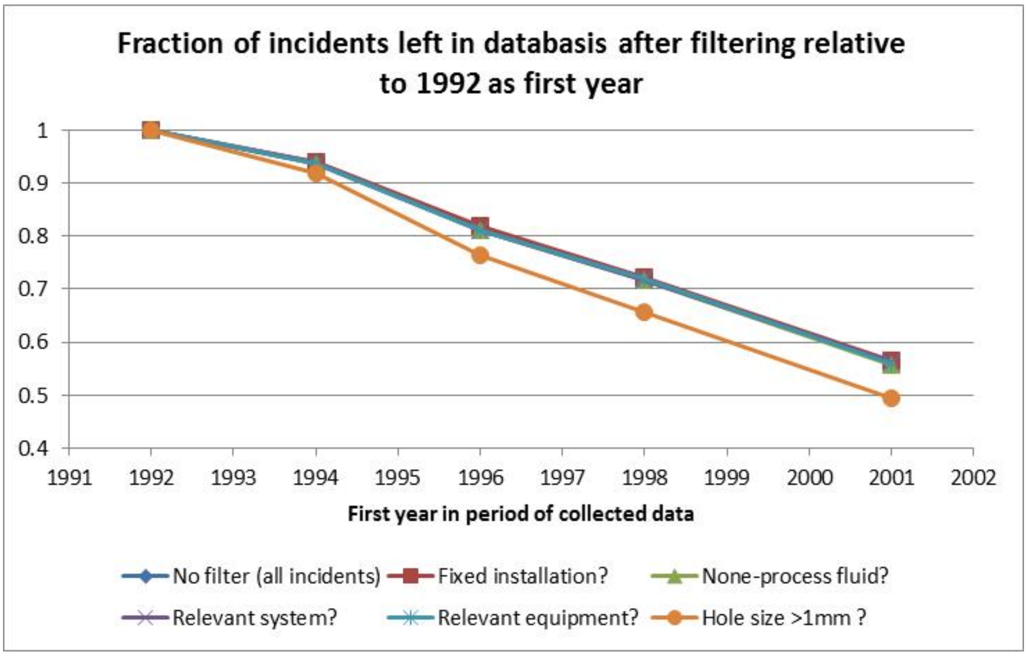

Figure 2.10 - Fraction of process incidents left after the applied filters as a function of the first year in the period of collected data (end year of period is 2015)

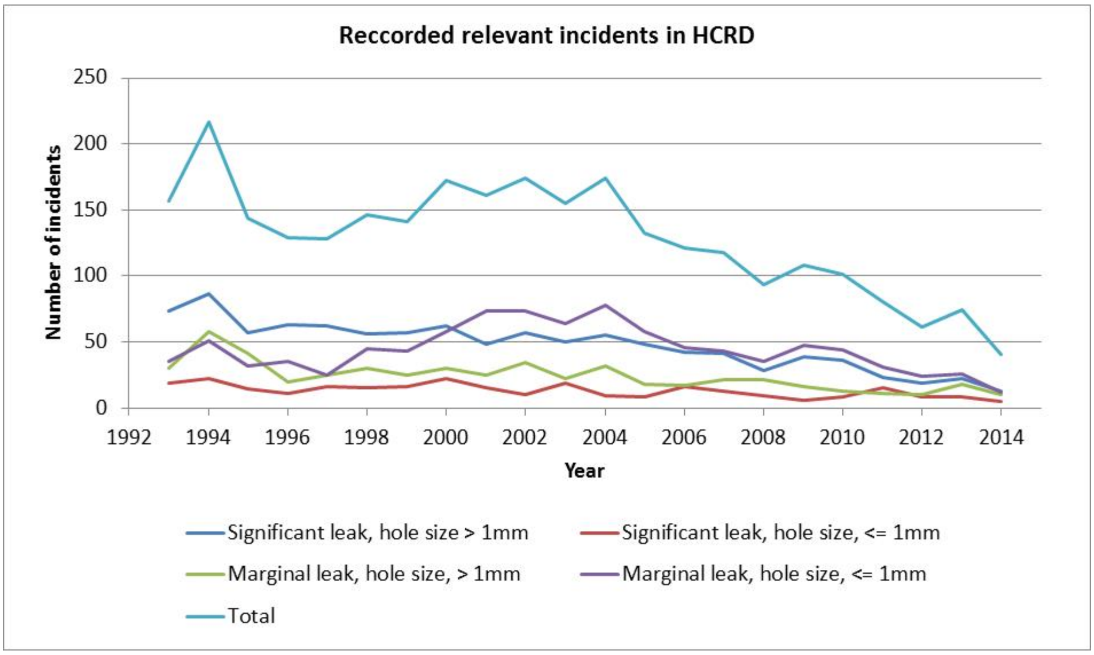

Figure 2.11 - Number of relevant process incidents recorded in the period 1993-2014. The total number of recorded leaks in this period is 2826

2.2 Extracting relevant process leaks fed through utility system

In this chapter, the filters used to extract process leaks fed through utility systems are described. The number of incidents extracted by applying the filters is given in detail in Appendix B, while a summary of the extracted data is presented here.

2.2.1 Description of filters

In the following sub-sections the filters used to extract process leaks fed through vent, drain and flare are described. These scenarios are in accordance with the leak scenarios covered by the model as described in TN-4. Note that process leaks fed through injection systems should also be included. In HCRD there is one incident that could be a relevant process leak fed through an injection system. However, this incident has been disregarded. It is unclear whether this leak is relevant. In any case, the contribution from this single incident is negligible.

2.2.1.1 Vent leaks

To extract incidents where process fluid has been released through vents, due to overfilling or other maloperations that represent a potential major accident hazard have been done by applying the following filter to the HCR-data

- Process: All except non-process
- Category: Only fixed installation
- My system: Only vent
- My equipment: All relevant equipment in Table 2.3
- Act pressure/max_pressure: Only 1-10. This represents leaks where the recorded pressure is higher than the design pressure, which indicates that the incident occurred due to maloperation

2.2.1.2 Drain leaks

To extract incidents where process fluid has been released through drain systems, the following filter to the HCR-data

- Process: All except non-process
- Category: Only fixed installation
- My system: Closed drain + Open drain
- My equipment: All relevant equipment in Table 2.3

2.2.1.3 Flare leaks

To extract incidents where process fluid has been released through flare systems, the following filter to the HCR-data

- Process: All except non-process
- Category: Only fixed installation
- My system: Blowdown & Flare
- My equipment: All relevant equipment in Table 2.3

2.2.2 Extracted data for process leaks fed through utility systems

The data extracted from HCRD by applying the filters described in Section 2.2.1, are given in detail in Appendix B. A summary is given in the following figures. In total 253 leaks with hole size > 1 mm (or N/A) are included for the period 1992-2015, while for the period 2001-2015, the corresponding number is 145 leaks. The distribution per leak scenario is shown in Figure 2.12 and Figure 2.13.

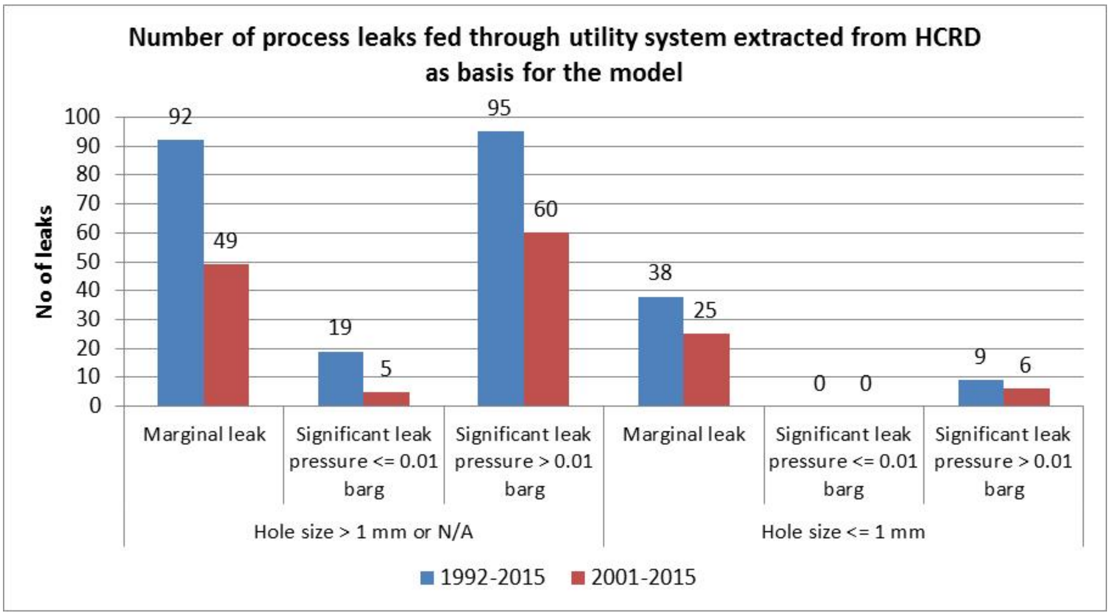

Figure 2.12 - Number of process leaks fed through utility systems recorded on UKCS considered relevant for the defined leak scenarios

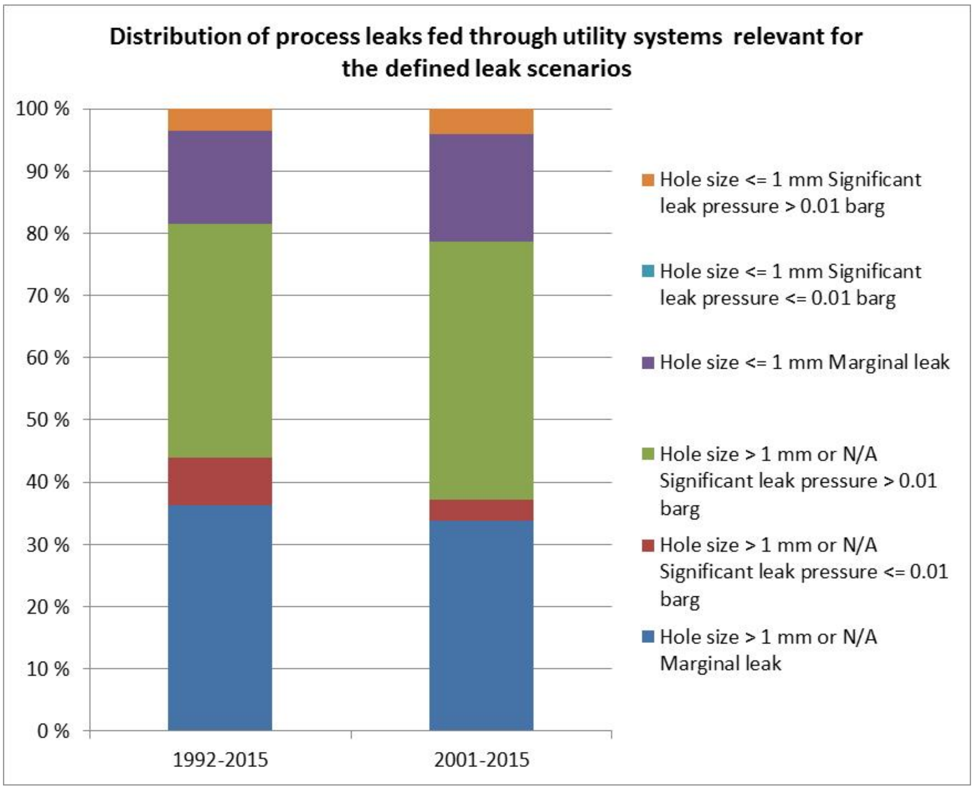

Figure 2.13 - Distribution of process leaks fed through utility systems

2.3 Extracting relevant process leaks from well system

In this section the filters used to extract gas lift well leaks and producing well leaks (see TN-4 for definition of gas lift well leak and producing well leak) from HCRD are defined. Filtering of relevant incidents is done by extracting

- gas leaks from oil wells
- oil leaks from oil wells
- leaks from gas wells
- leaks from X-mas trees

separately by the filters described in the below sub-chapters. Gas leaks stemming from oil wells are assumed to be leaks from the gas lift system, while all other leaks are assumed to be leaks from the producing well. Note that the incidents extracted has not been studied in detail, and therefore it is a significant uncertainty related to the estimation of well leak frequencies based on the extracted incidents from HCRD.

2.3.1 Gas leaks from oil wells

Gas leaks from oil wells are assumed to be leaks from the gas lift system of the well. To extract these incidents from HCRD, the following filter is applied:

- Process: Only gas
- Category: Only fixed installation
- My system: Only Surface oil well
- My equipment: Only Wellhead
- Operational mode: All except well services (see definition of OP_MODE in Appendix A)

2.3.2 Oil leaks from oil wells

Oil leaks from oil wells are assumed to be leaks from the producing well. To extract these incidents from HCRD, the following filter is applied:

- Process: All except non-process and gas
- Category: Only fixed installation
- My system: Only Surface oil well
- My equipment: Only Wellhead
- Operational mode: All except well services (see definition of OP_MODE in Appendix A)

2.3.3 Leaks from gas wells

Leaks from gas wells are assumed to be leaks from the producing well. To extract these incidents from HCRD, the following filter is applied:

- Process: All except non-process
- Category: Only fixed installation
- My system: The following systems are included
    - Surface gas injection well
    - Surface gas producing well
    - Surface well other
- My equipment: Only Wellhead
- Operational mode: All except well services, welloptree and drillgas (see definition of OP_MODE in Appendix A)

2.3.4 Leaks from X-mas tree

Both oil and gas leaks from X-mas tree are assumed to be leaks from the producing well. To extract these incidents from HCRD, the following filter is applied:

- Process: All except non-process
- Category: Only fixed installation
- My system: The following systems are included
  - Surface gas injection well
  - Surface gas producing well
  - Surface oil well
  - Surface well other
- My equipment: X-mas tree
- Operational mode: All except well services, welloptree and drillgas (see definition of OP_MODE in Appendix A)

2.3.5 Extracted data for leaks from well system

The data extracted from HCRD by applying the filters described in Section 2.2.1 - 2.3.4, are given in detail in Appendix B. In total 100 (17 gas lift leaks and 83 producing well leaks) incidents are extracted for the period Q3 1992 – Q1 2015 while 38 (9 gas lift leaks and 29 producing well leaks) incidents from the period Q1 2001- Q1 2015 are identified as relevant for gas lift well leaks and producing well leaks. In Figure 2.14 and Figure 2.15, the leaks are sorted with respect to the defined Marginal and significant leak scenario and grouped depending on hole size. .

The results show that there has been a considerable decrease in leaks originating from well in the period after 2001. It should also be noted that the fraction of Marginal leaks is larger than for process leaks. The relative reduction in leaks after 2001 is most prominent for significant leaks, which results in a high fraction of Marginal leaks for the period after 2001. Moreover, the fraction of leaks resulting from a hole having a diameter less than 1 mm is larger than for leaks from process systems. It has not been attempted to explain the causes for this observation, i.e. the difference in fraction Marginal and Significant leaks originating from wells.

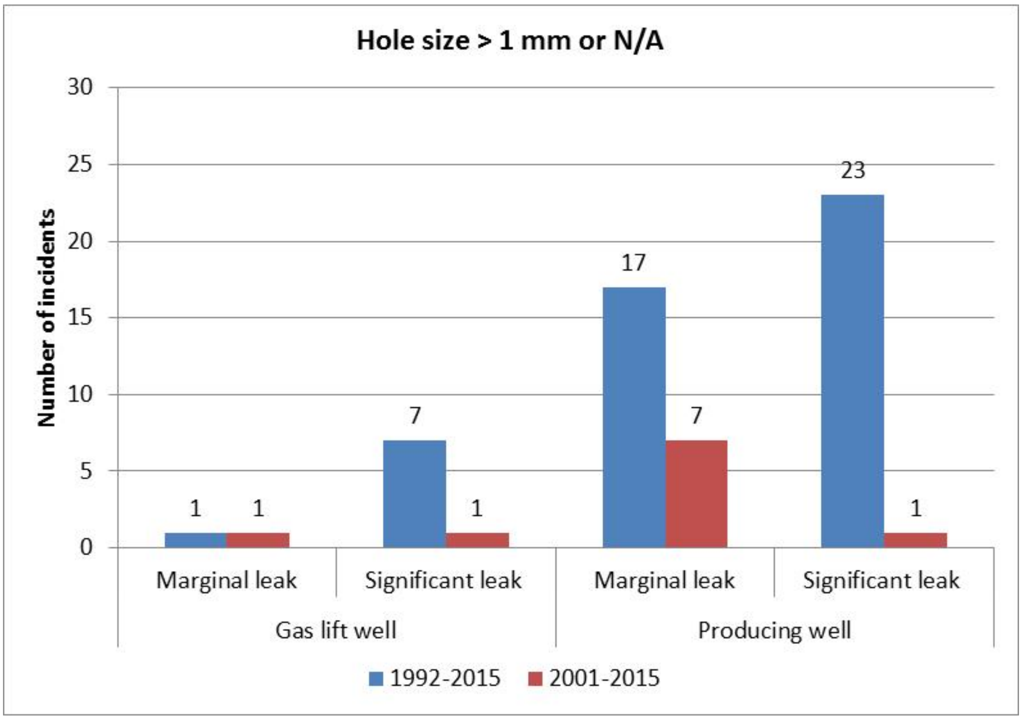

Figure 2.14 - Extracted leaks from well system with hole size >1 mm or N/A

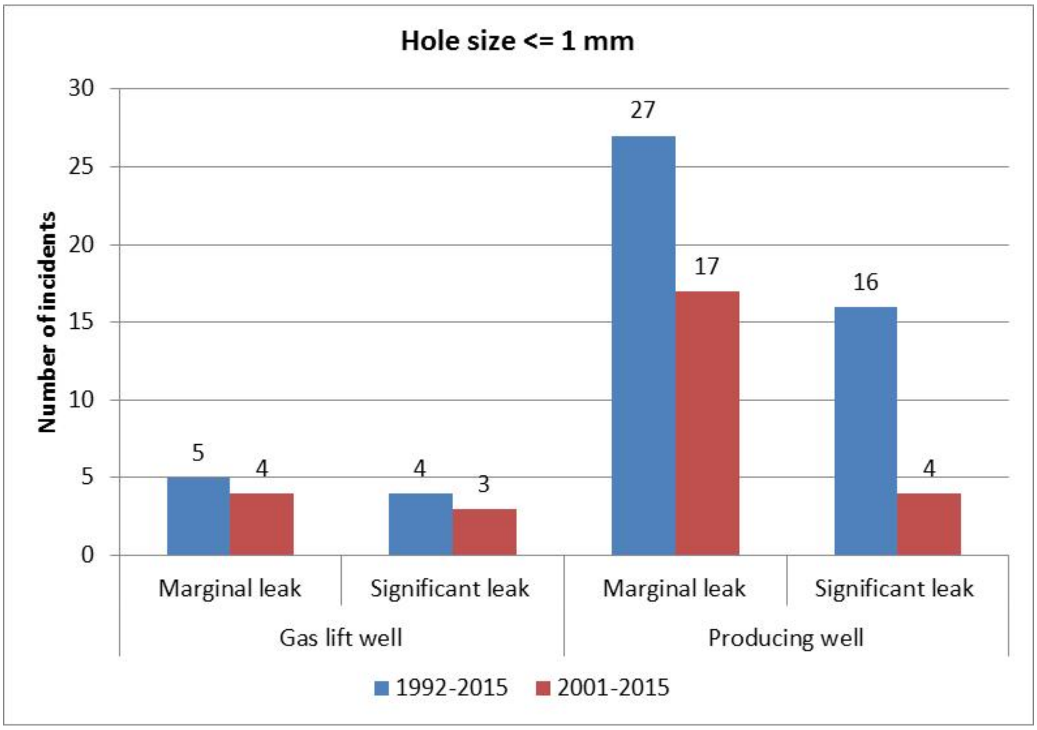

Figure 2.15 - Extracted leaks from well system with hole size ≤1 mm

2.4 Summary of relevant leaks extracted from HCRD

This chapter gives a summary of the extracted incidents for process leaks fed through process system and utility system (Vent, drain and flare) and leaks from well systems. The detailed number of recorded leaks, as well as the exposure data is given in Appendix B. The total number of recorded process leaks and leaks from well system extracted from HCRD is given in Figure 2.16, while the fraction of leaks fed through process system, vent, drain and flare system and well system is given in Figure 2.17. Figure 2.18 and Figure 2.19 give the equipment type distribution for Significant and Marginal leaks for the period Q3 1992 – Q1 2015 and Q1 2001 – Q1 2015. All process leaks and leaks from wells are included. Figure 2.20 and Figure 2.21 give also the equipment type distribution for the period Q3 1992 – Q1 2015 and Q1 2001 – Q1 2015, but the figures also include the equipment size distribution where only incidents recorded with initial leak rate >0.1 kg/s are included. This corresponds to how leaks are logged on NCS (see TN-2).

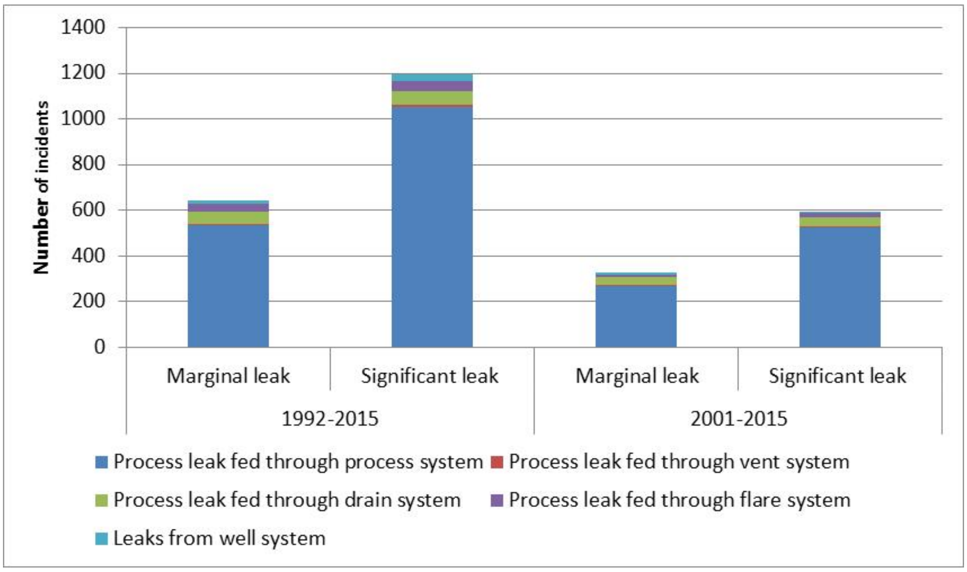

Figure 2.16 - Total number of extracted process leaks from HCRD. The leaks are categorized into Marginal and Significant leaks. Only hole sizes > 1mm (or N/A) are included

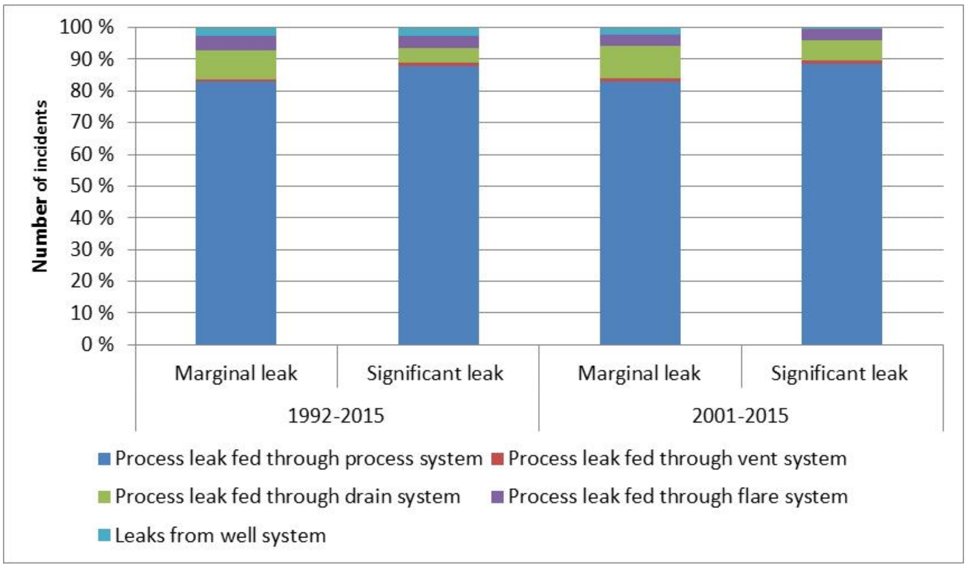

Figure 2.17 - Relative contribution from the same scenarios and incidents as included in Figure 2.16

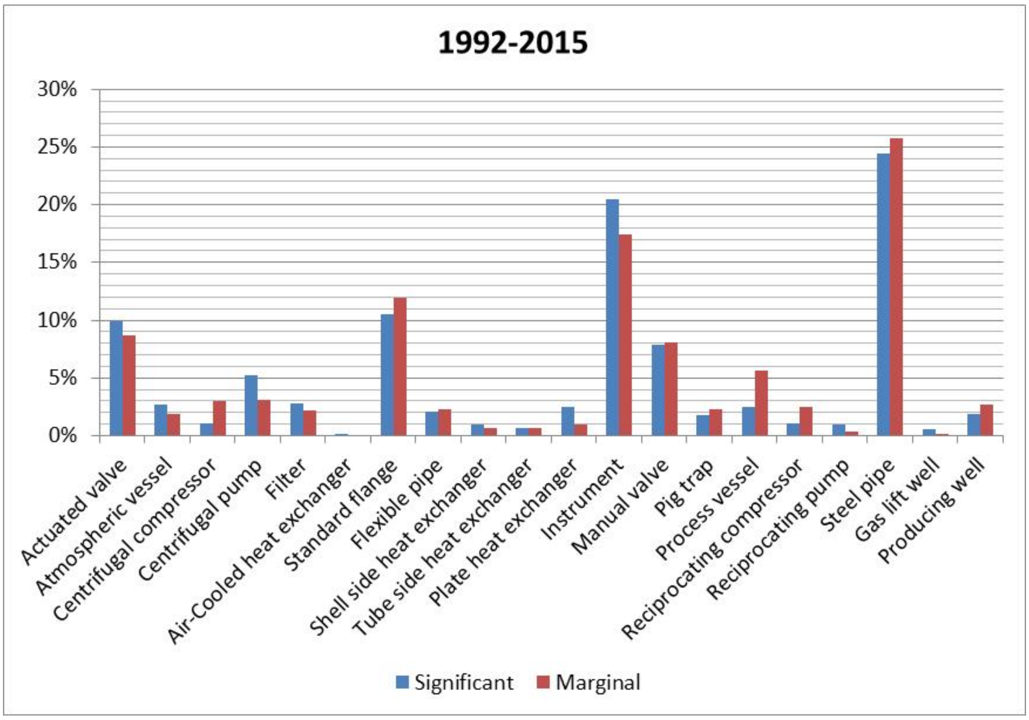

Figure 2.18 - Equipment type distribution for Significant and Marginal leaks for the period Q3 1992 – Q1 2015. All process leaks and leaks from well system are included. Only hole sizes >1 mm (or N/A) are included

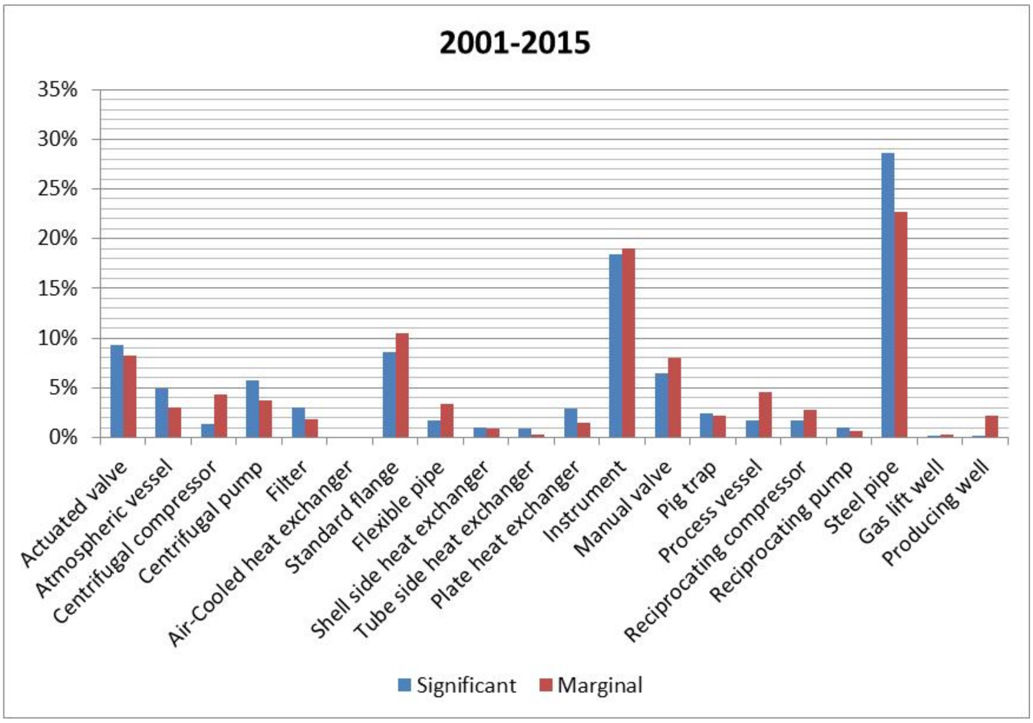

Figure 2.19 - Equipment type distribution for Significant and Marginal leaks for the period Q1 2001 – Q1 2015. All process leaks and leaks from well system are included. Only hole sizes >1 mm (or N/A) are included

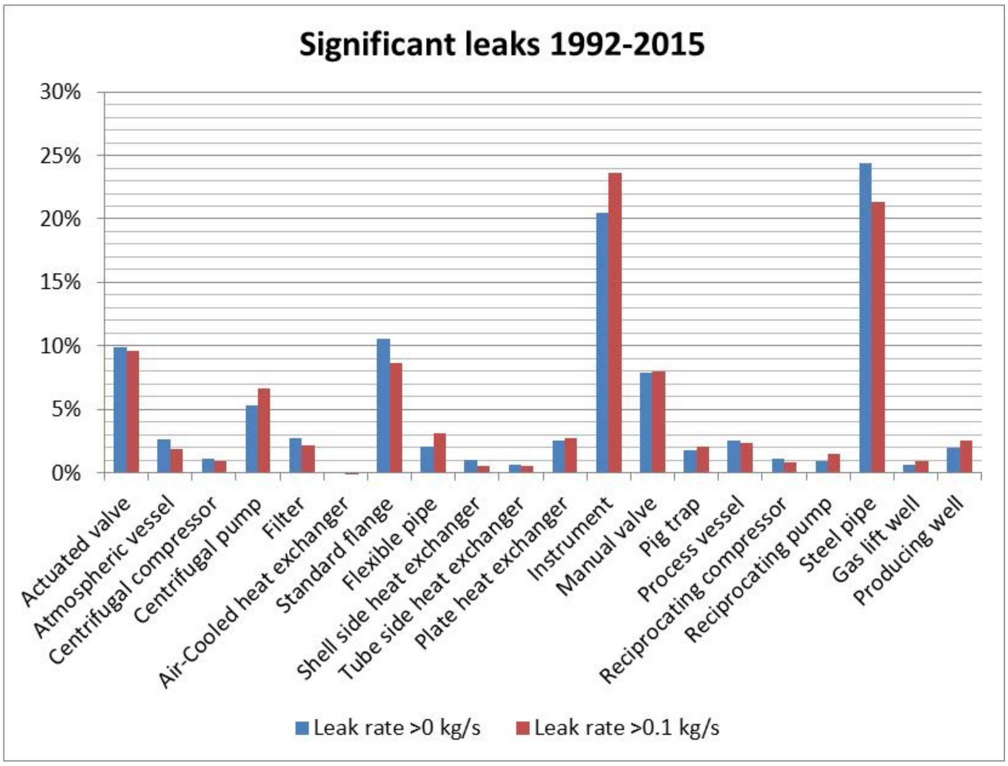

Figure 2.20 - Equipment type distribution for the period Q3 1992 – Q1 2015. All process leaks and leaks from well system are included. The blue columns corresponds to the blue columns in Figure 2.18, while the red columns only includes incidents with initial leak rate >0.1 kg/s. This corresponds to the leaks logged on NCS. Only hole sizes >1 mm (or N/A) are included

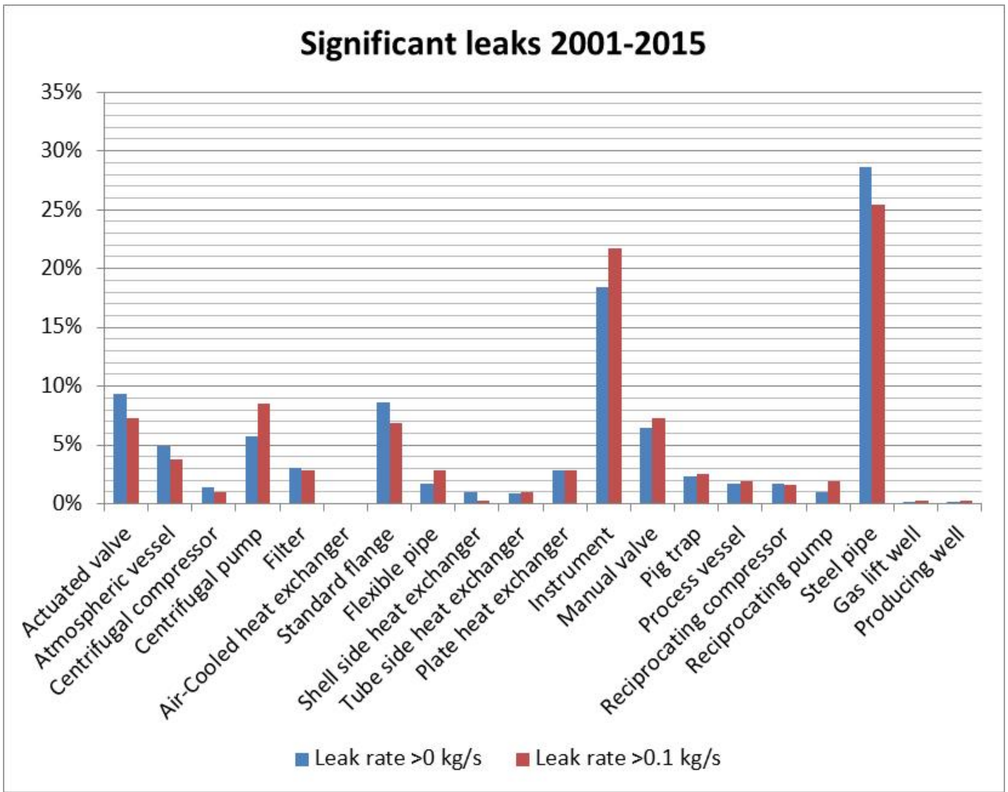

Figure 2.21 - Equipment type distribution for the period Q1 2001 – Q1 2015. All process leaks and leaks from well system are included. The blue columns corresponds to the blue columns in Figure 2.19, while the red columns only includes incidents with initial leak rate >0.1 kg/s. This corresponds to the leaks logged on NCS. Only hole sizes >1 mm (or N/A) are included

3 Exposure database

Chapter 3.1 and 3.2 presents the population data extracted from HCRD for process equipment and wellheads, respectively. Chapter 3.3 presents known issues generating uncertainty related to the exposure data in HCRD.

3.1 Process equipment

The exposure data (population data) for relevant process equipment types extracted from HCRD is given in detail in Appendix B. Figure 3.1 gives the exposure data for relevant equipment types. Note that the scale of the y-axis is logarithmic. The population data are used for estimating leak frequencies per equipment per year as described in Chapter 4.

HCRD defines one flange face as one flange. In the suggested counting guideline (TN-5 Appendix A) which is in accordance with population data extracted from QRAs for installations on the NCS, two flange faces are counted as one flanged joint. In order to adjust for this difference, the exposure data extracted from HCRD for flanges is divided by a factor 2. This is not entirely correct as some flanges consist of only one flange face (*e.g.* blinded flanges for temporary mounting of equipment). The number of flange years at UKCS will therefore be slightly underestimated using a factor of 2.

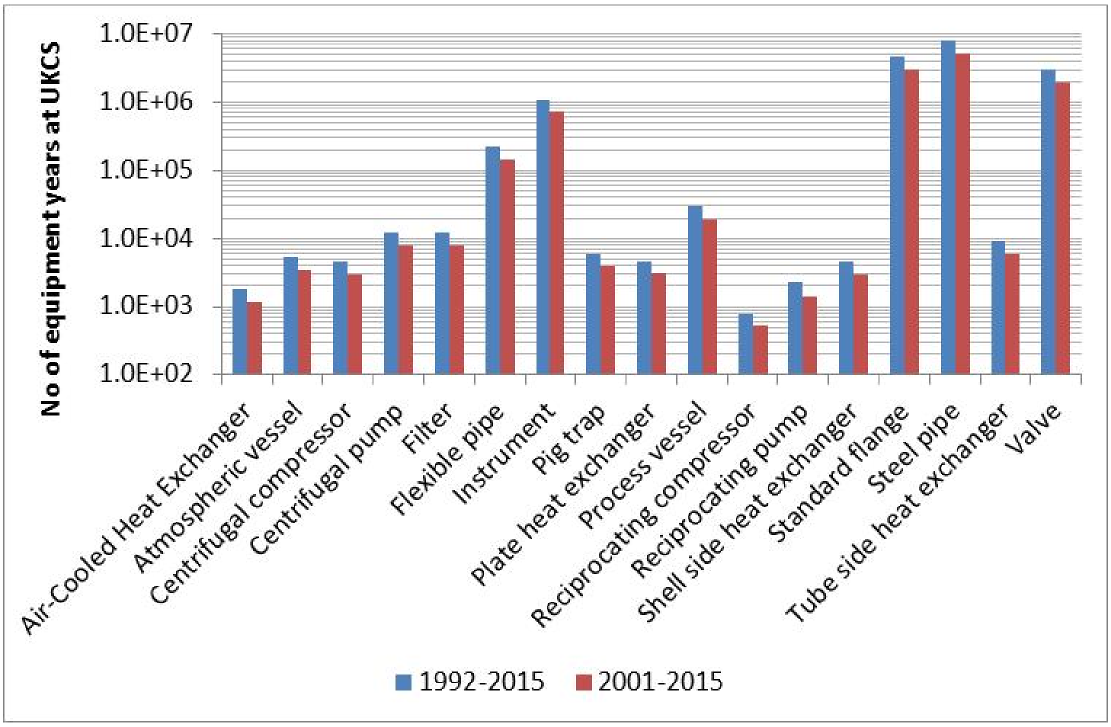

Figure 3.1 - Exposure data for relevant equipment types. For steel pipe and flexible pipe the exposure data is given as the number of equipment year meters. Note that the y-axis has logarithmic scale. Exact values are given in Appendix B

3.2 Well head

The number of wellhead years extracted from HCRD is given in detail in Appendix B for:

- Gas injection wellhead
- Gas producing wellhead
- Oil producing wellhead
- Other wellhead

This is also presented in Figure 2.4. The figure shows the exposure data both for the period Q3 1992- Q1 2001 and the period Q1 2001 – Q1 2015. Table 3.1 and Figure 2.5, gives the estimated exposure data for gas lift well and producing well. The following assumptions are made:

1. All types of wellheads given above are relevant for producing wells
2. The number of gas lifted wells on UKCS is not available. However, an estimate is established based on the SINTEF offshore blowout database, Ref. /1/. For US GOM OCS, the percentage of gas lifted wells is from 20 % to 63 % in the period 1992-2012. 50 % is suggested for UCKCS for the period 2001-2015

Table 3.1 - Exposure data for well heads extracted from HCRD

	Exposure data	
Well head type	**1992-2015**	**2001-2015**
Gas lift well	5953	3515
Producing well	28081	17670

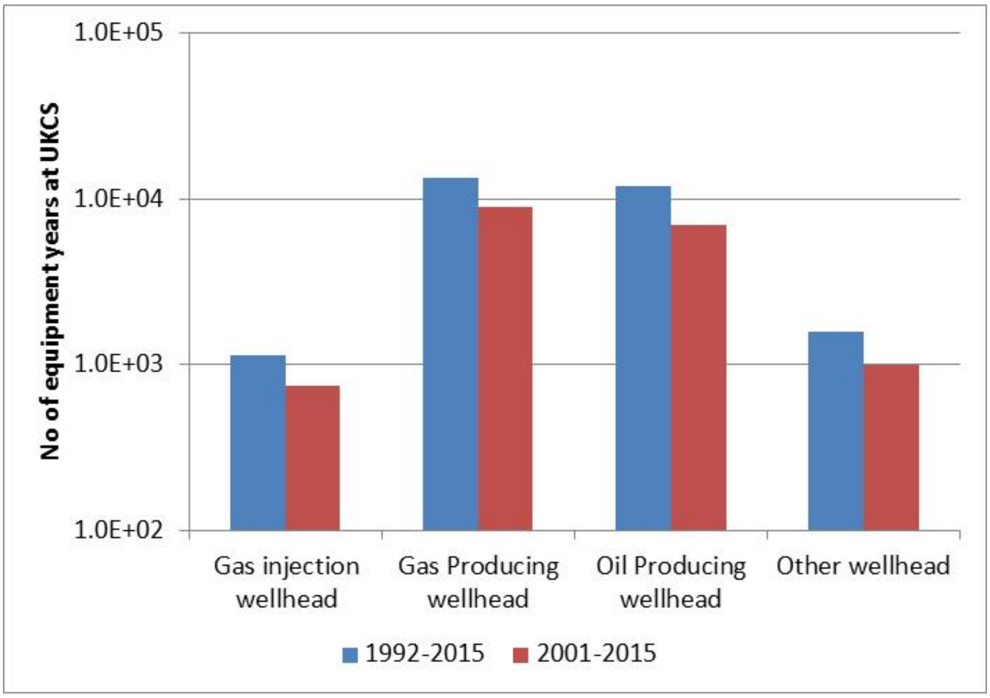

Figure 3.2 - Exposure data for relevant types of wellhead. Note that the y-axis has logarithmic scale

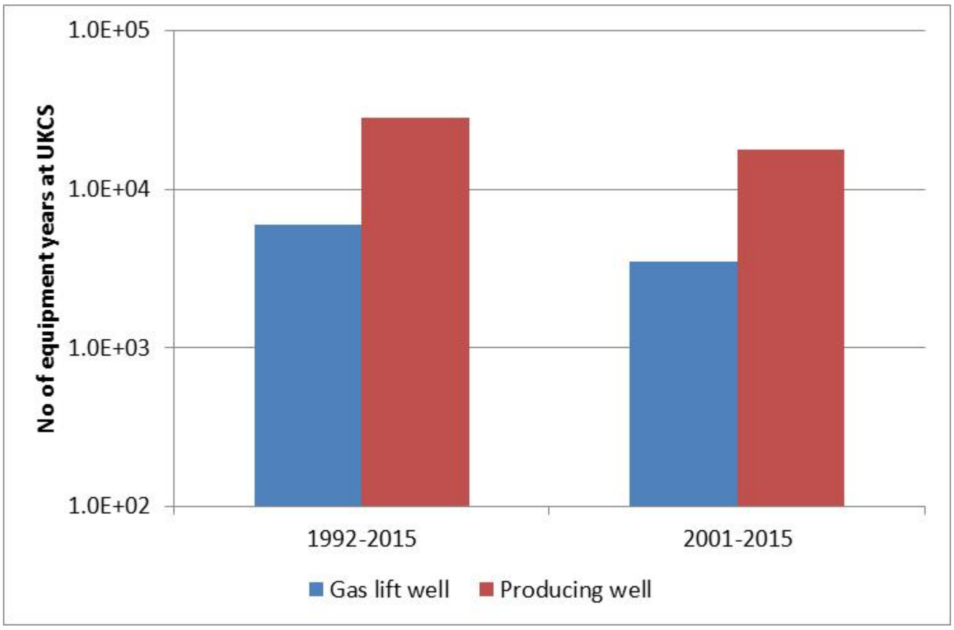

Figure 3.3 - Estimated exposure data for gas lift wells and producing wells

4 Calculation of leak frequencies based on HCR-data and trends in data material for the period 1992-2015

Based on the number of leak incidents for equipment type i, denoted l_i, and the number of equipment years (exposure data) for equipment type i, denoted t_i the leak frequency is calculated as

$$f_i = \frac{l_i}{t_i} \quad (1)$$

The estimated leak frequency per component based on HCR-data are presented in detail in Appendix B. Figure 4.1 and Figure 4.2 give the estimated process leak frequency for hole size >1 mm (or N/A) for Marginal and Significant leaks, respectively. Figure 4.4 shows the ratio obtained when the total leak frequency for all hole sizes is divided by the leak frequency for hole size >1 mm for Significant leaks Figure 4.3 shows the same result for Marginal leaks. This ratio is denoted K_{1mm} in TN-6 when the model is parameterized based on the HCR data.

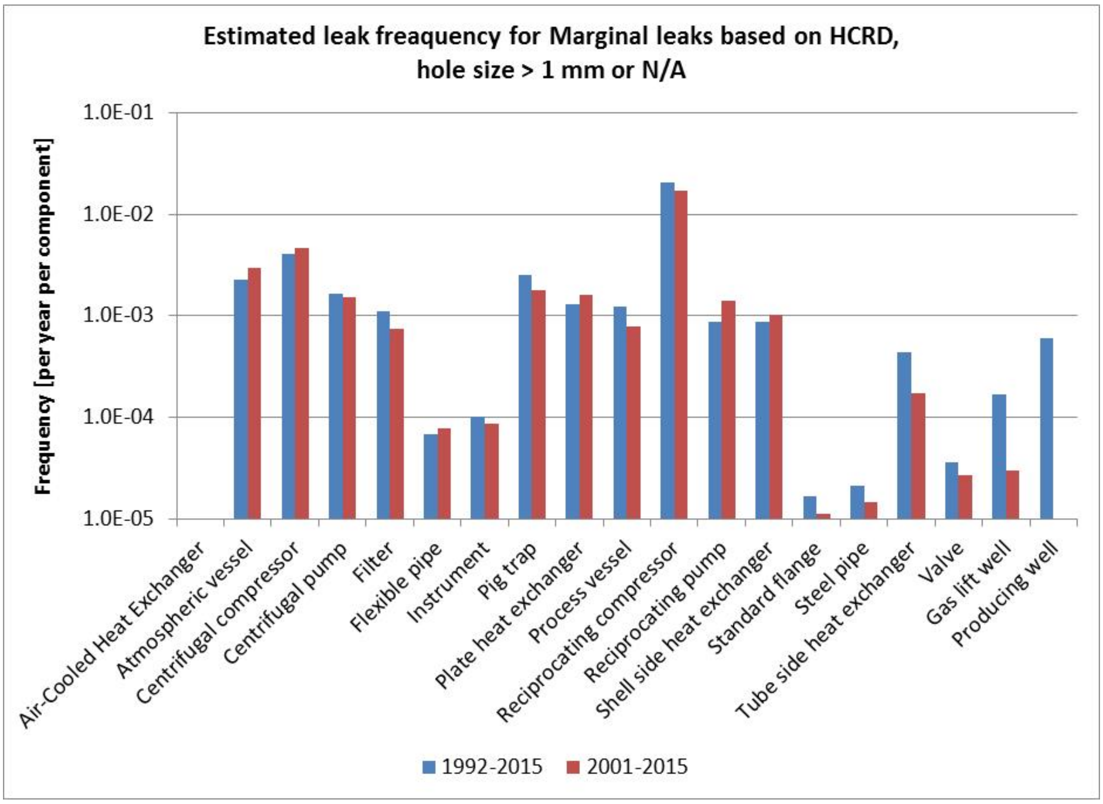

Figure 4.1 - Estimated process leak frequency for Marginal leaks with hole size >1 mm or N/A

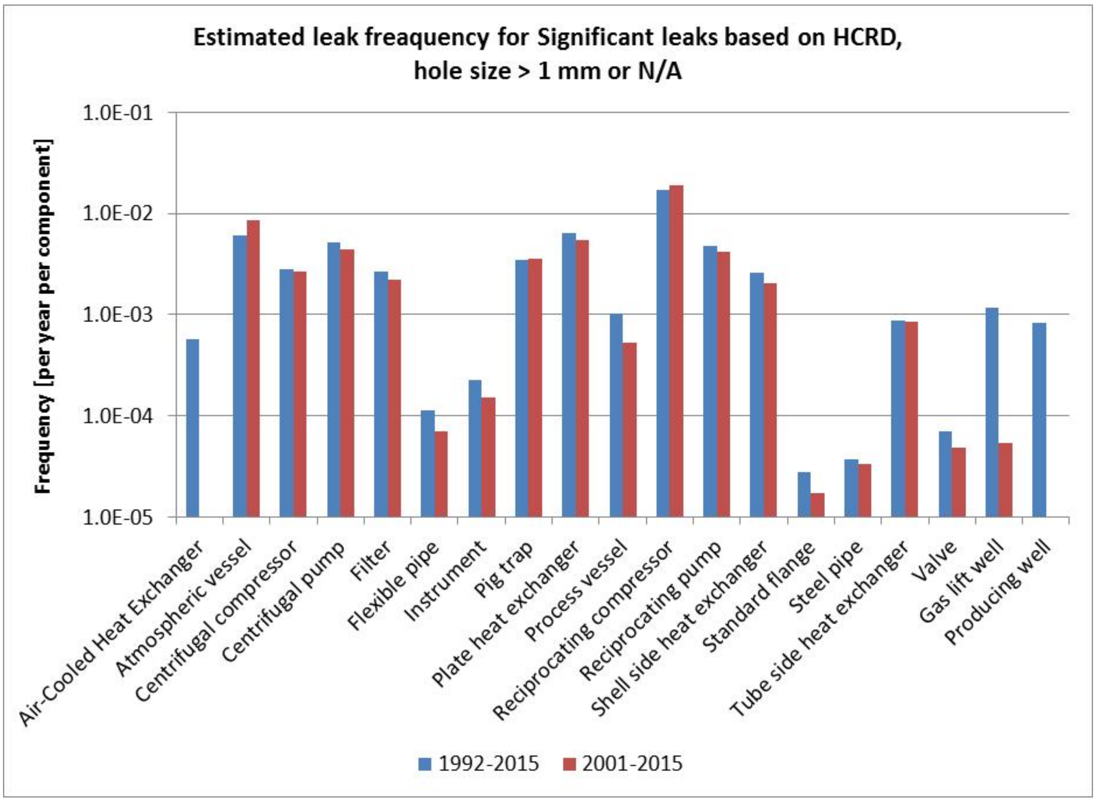

Figure 4.2 - Estimated process leak frequency for Significant leaks with hole size >1 mm or N/A

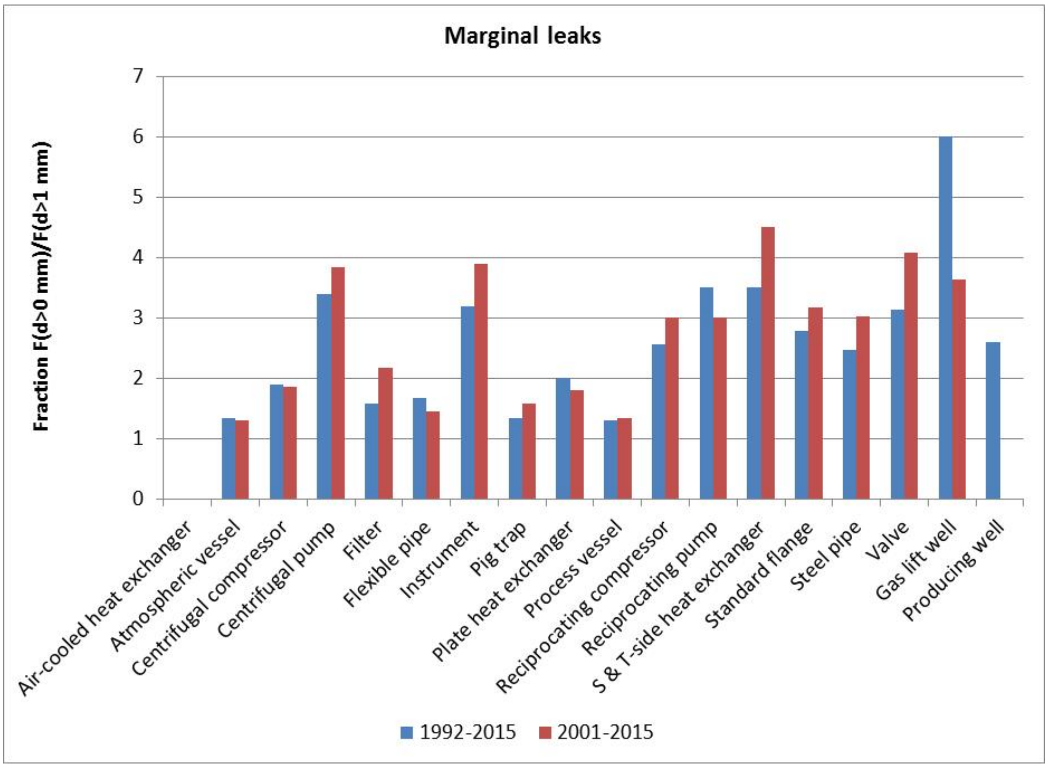

Figure 4.3 - Marginal leaks; Total leak frequency divided by leak frequency for hole size >1 mm

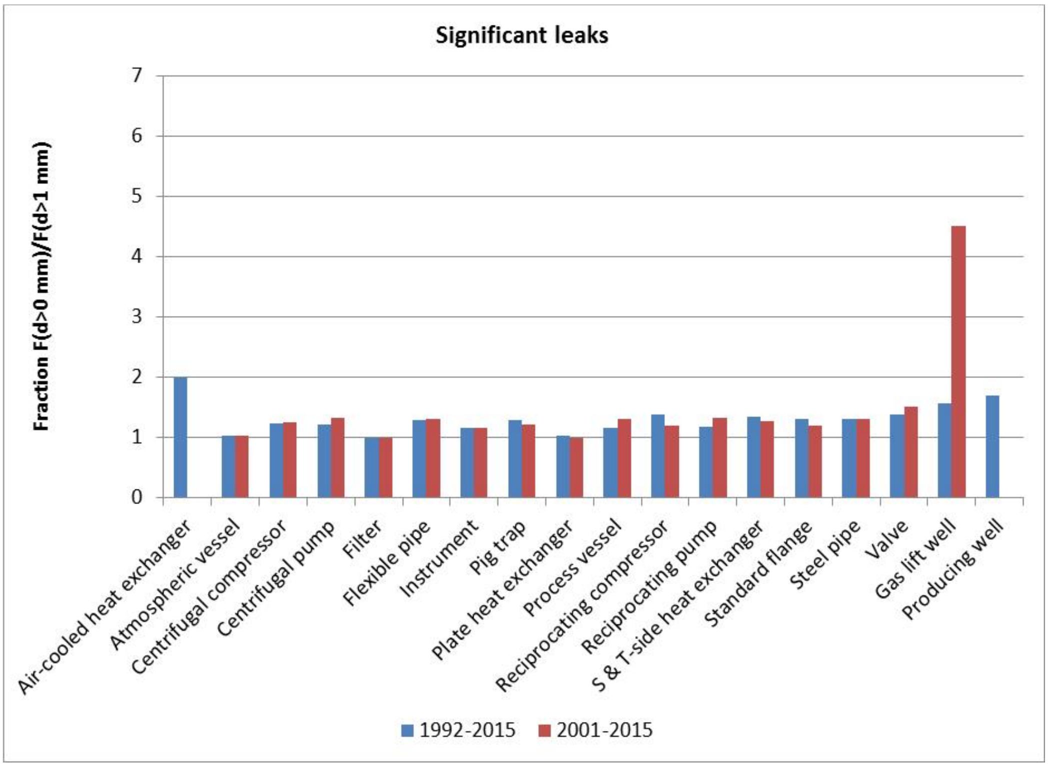

Figure 4.4 - Significant leaks: Total leak frequency divided by leak frequency for hole size >1 mm (ratio denoted K_{1mm} in TN-6)

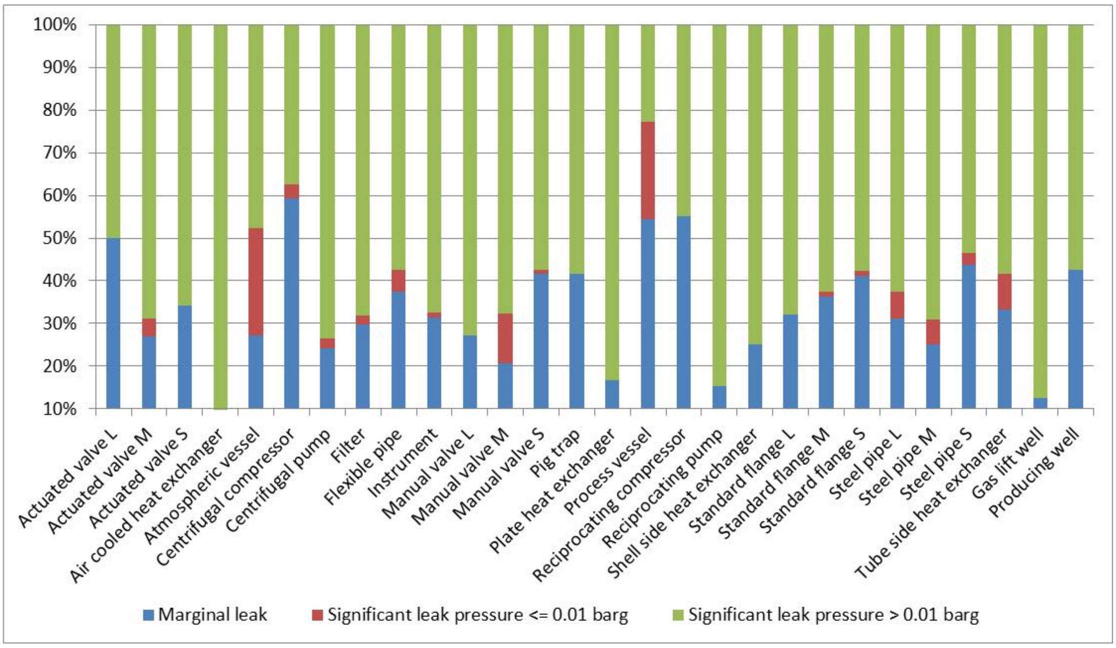

Figure 4.5 - Fraction of the total leak frequency distributed on Marginal leaks and Significant leaks. For significant leaks the contribution in terms of system pressure when leak occurs is presented (above and below 0.01 barg)

5 Complementary cumulative hole size distributions and leak rate distributions based on HCRD

In order to establish hole size distributions based on HCRD, relevant incidents has to be extracted. The filter defined in Figure 2.1, is used as basis, but hole sizes < 1mm or hole sizes recorded as N/A are not included. The hole size distributions will first and foremost be used to estimate the frequency for holes resulting in Significant leaks. Hence, incidents recorded with total released quantity <10 kg and leaks with initial pressure < 0.01 barg are not included in Filter 1, (see Table 5.1 below). This is considered to be the most relevant filter for parameterization of the hole size distributions in the model.

In order to investigate the effect of including other leaks, i.e.

- process leaks fed through utility systems;
- leaks recorded with total released quantity <10 (Marginal leaks) and
- leaks with initial pressure <0.01 barg

alternative filters denoted filter 2 and filter 3 are established. Filters extracting incidents from the period Q3 1992- Q1 2015 are denoted "a", while filters from the period Q1 2001- Q1 2015, are denoted "b". The number of incidents included as basis for the hole size distributions for these two periods are given in Figure 5.1 and Figure 5.2, respectively. Filter 4 is defined to produce initial leak rate distributions based on the same type of incidents as the initial leak rate distributions based on NCS data (i.e. leaks are filtered based on initial leak rate, and not hole size) are based on (see TN-2). The number of incidents included as basis for the initial leak rate distributions for the two periods are given in Figure 5.3 and Figure 5.4. For simplicity the initial leak rate distributions are denoted leak rate distributions.

All complementary cumulative hole size distributions and leak rate distributions based on HCRD are given in Appendix C. An example of a hole size distribution is given in Figure 5.5, where all equipment types are included. In general, filter 3 result in larger fraction large holes compared to filter 2. Filter 2 result in larger fraction large holes compared to filter 1. However, for some equipment types, the situation is the other way around, and for many equipment types the difference between the filters is marginal.

The complementary cumulative hole size distribution for all equipment types based on recorded hole sizes in HCRD is shown in Figure 5.6. Separate leak rate distributions are plotted for gas (gas and 2-phase), liquid (oil and condensate) and gas and liquid altogether (denoted G, L and G&L, respectively). Note that the initial leak rates are calculated by Lilleaker based on hole size and available process conditions in HCRD (using the same formulas as in the validation model presented in TN-6). There is however good reasons to question the quality of the data put as basis for the calculations (see Chapter 6.1).

Table 5.1 - Filters used to extract incidents (hole sizes) as basis for recorded hole size distributions based on HCRD

Filter	Description
Filter 1	All relevant process leak incidents in the HCR-data as defined in Figure 2.1 and well system leaks as defined in Chapter 2.3 are included, except: • Incidents recorded with pressure <0.01 barg • Incidents recorded with total released quantity <10 kg • Incidents recorded with hole size <= 1 mm • Incidents recorded with hole size "N/A" This filter is put as basis for hole size distributions in the model development.
Filter 2	All relevant process leak incidents in the HCR-data as defined in Figure 2.1, relevant leaks fed through utility systems as defined in Chapter 2.2 and relevant well releases as defined in Chapter 2.3 are included, except: • Incidents recorded with pressure <0.01 barg • Incidents recorded with total released quantity <10 kg • Incidents recorded with hole size <= 1 mm • Incidents recorded with hole size "N/A" This filter is defined to analyse the effect of including process leaks fed through utility systems and well systems as basis for hole size distributions.
Filter 3	All relevant process leak incidents in the HCR-data as defined in Figure 2.1, relevant utility leaks as defined in Chapter 2.2 and relevant well releases as defined in Chapter 2.3 are included, except: • Incidents recorded with hole size <= 1 mm • Incidents recorded with hole size "N/A" This filter is defined to also analyse the effect of including incidents recorded with pressure <0.01 barg, and incidents recorded with total released quantity <10 kg.
Filter 4	All relevant process leak incidents in the HCR-data as defined in Figure 2.1, relevant utility leaks as defined in Chapter 2.2 and relevant well releases as defined in Chapter 2.3 are included, except: • Incidents recorded with initial leak rate <0.1 kg/s This filter is defined to establish leak rate distributions based on the same type of incidents as the leak rate distributions based on NCS data are based on.

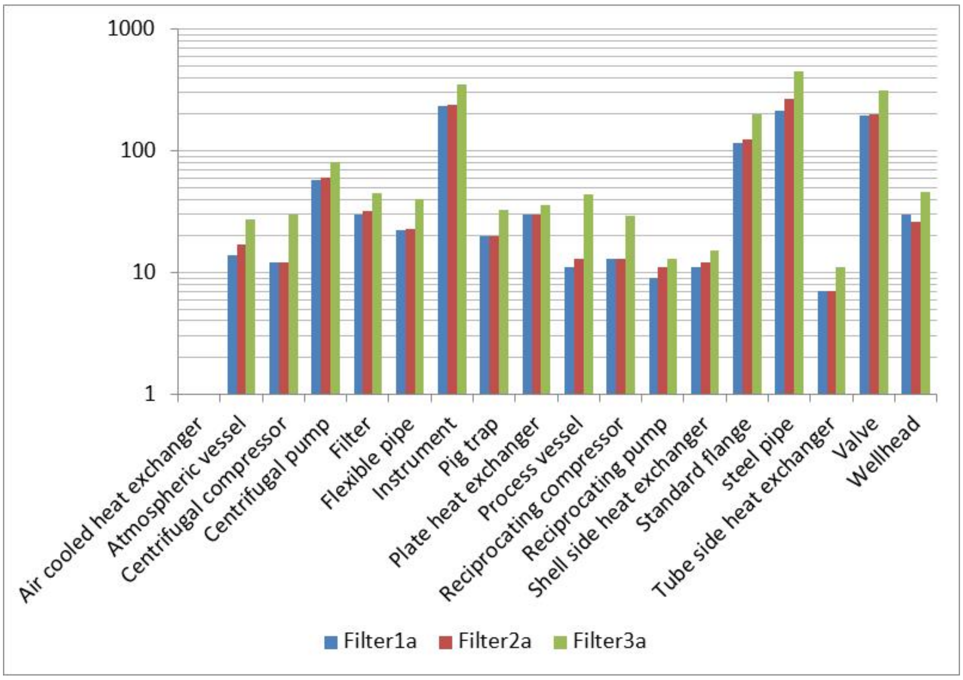

Figure 5.1 - The number of incidents included as basis for the recorded hole size distributions for the period Q3 1992- Q1 2015. Filters extracting incidents from this period are denoted Filter 1a, Filter 2a and Filter 3a. The filters are defined in Table 5.1

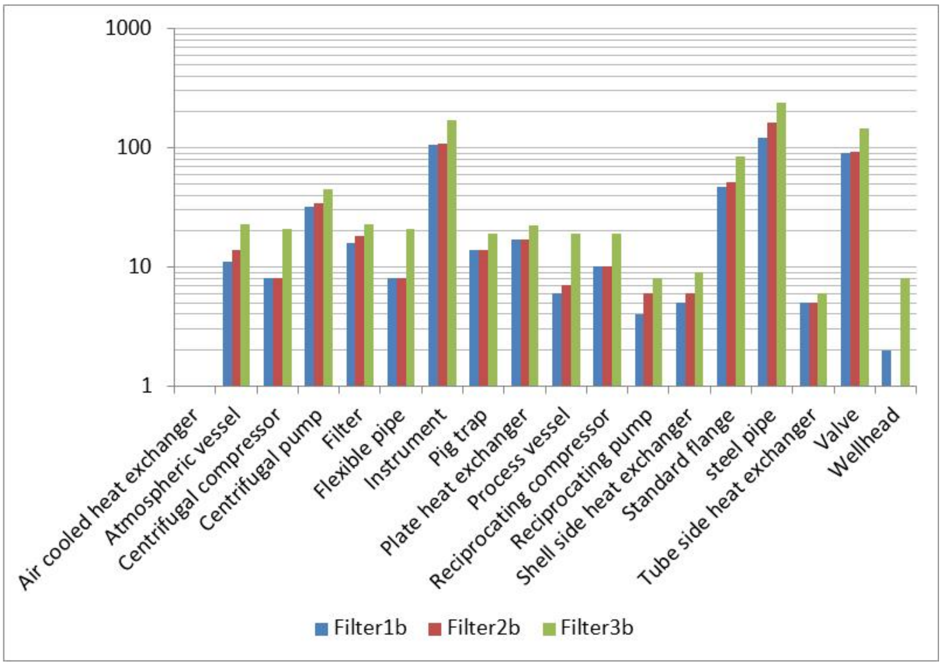

Figure 5.2 - The number of incidents included as basis for the recorded hole size distributions for the period Q1 2001- Q1 2015. Filters extracting incidents from this period are denoted Filter 1b, Filter 2b and Filter 3b. The filters are defined in Table 5.1

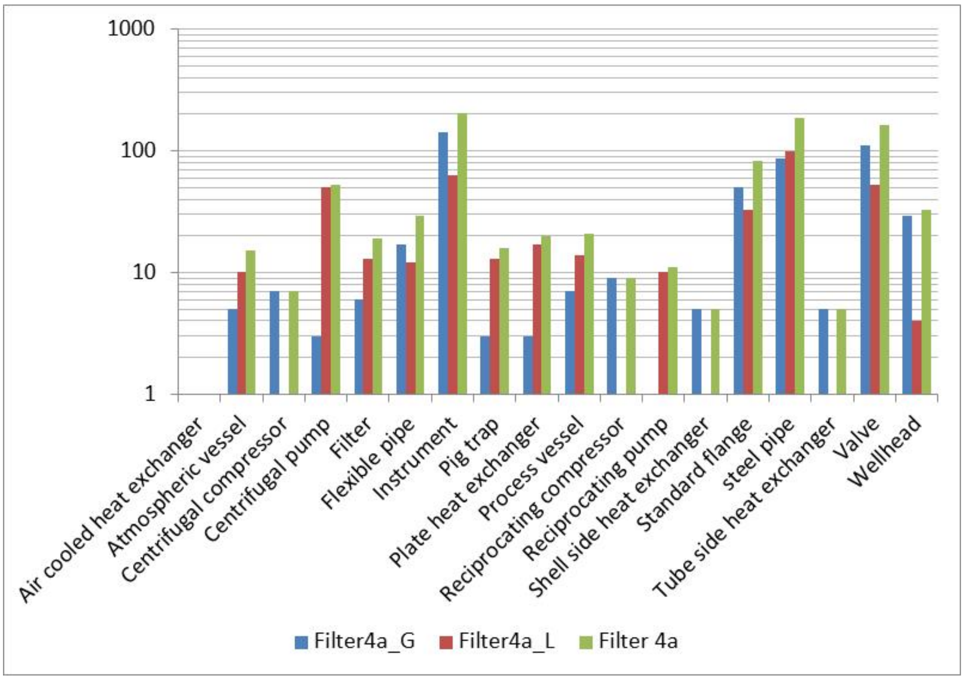

Figure 5.3 - The number of incidents included as basis for the recorded hole size distributions for the period Q3 1992- Q1 2015. Filters extracting incidents from this period are denoted Filter 1a, Filter 2a and Filter 3a. The filters are defined in Table 5.1

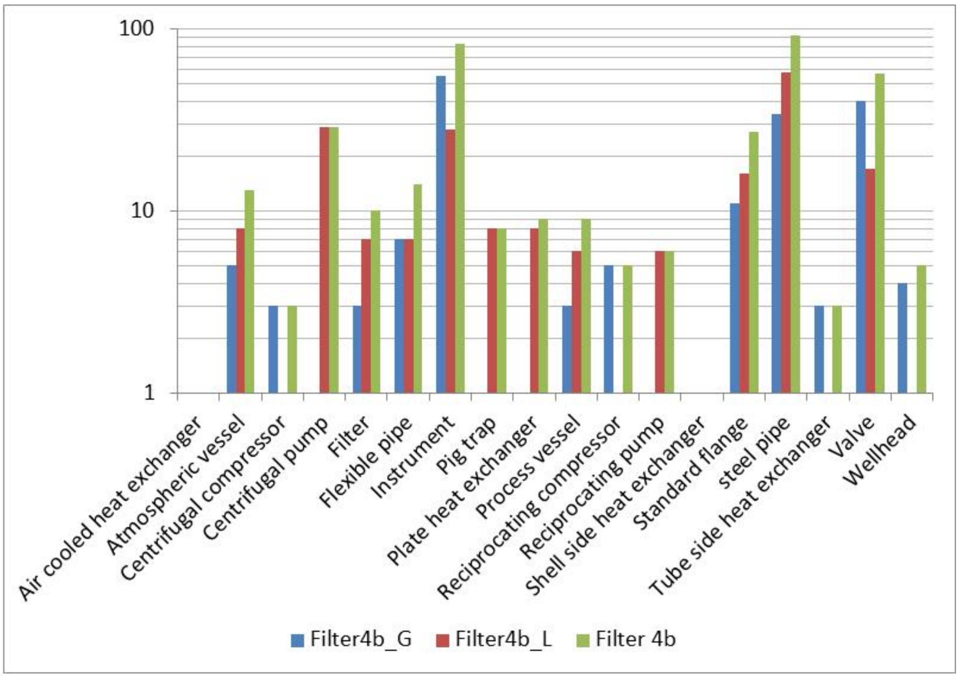

Figure 5.4 - The number of incidents included as basis for the recorded hole size distributions for the period Q1 2001- Q1 2015. Filters extracting incidents from this period are denoted Filter 1b, Filter 2b and Filter 3b. The filters are defined in Table 5.1

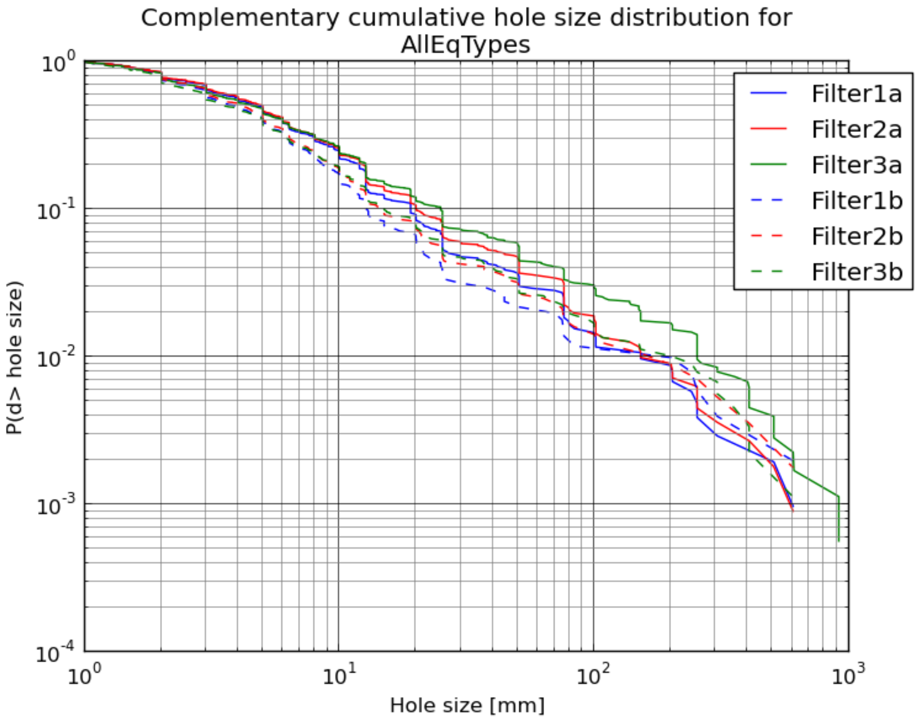

Figure 5.5 - Complementary cumulative hole size distribution for all equipment types, based on recorded hole sizes in HCRD

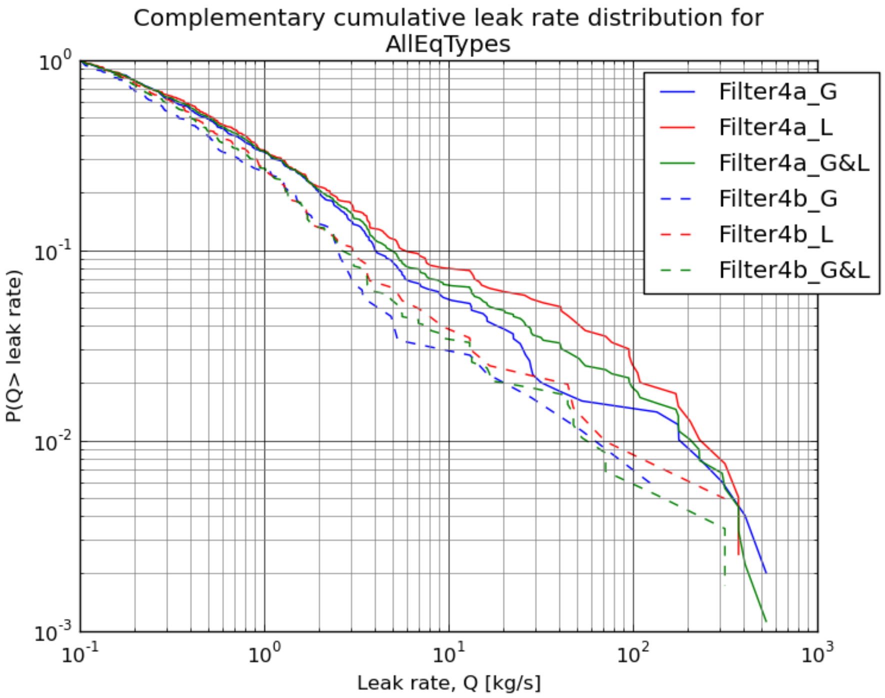

Figure 5.6 - Complementary cumulative leak rate distribution for all equipment types, estimated based on hole sizes and process conditions recorded in HCRD. Separate curves are given for gas (gas and 2-phase), liquid (oil and condensate) and gas & oil, denoted G, L and G&L, respectively

6 Uncertainty and quality of HCR-data

There is uncertainty related to the recorded hole sizes and recorded process conditions in HCRD. There are also known major deficiencies related to the exposure data.

The shortcomings for the data where discussed by HSE at the FABIG meeting June 2016.

6.1 Incident data

The following understanding of the quality of the HCR-database was achieved in the project meeting 04.09.2015, Ref. /2/: The registration of incidents in HCRD is voluntary, but it is expected that the general industry practice is that incidents are registered. Thus, it is reasonable to believe that the database is quite complete in terms of number of incidents. In the initial phase of the project, upgrading the database has discovered some inconsistencies in the raw data and the publicly available HCR-data. This may be due to inadequate procedures for compiling the data. Some issues identified are:

- Data fields were not the same in the two data sets (raw data and the publicly available HCR-data)
- The data sets had two ways of assessing the hole size
    - o Calculated hydraulic hole size diameter.
    - o Measured hydraulic hole size diameter
- Uncertainty which of the two data sets that contains the most correct value

The hole size recorded in HCRD is of particular importance for the model development. The model are based on hole size distributions, and hole sizes are not recorded as part of the registered leaks at installations on the NCS data. Hence HCRD is the only available data source where hole sizes are available. In the HCR-definitions, the data field HOLE_DIAM, which gives the hole diameter used as basis for the model, is defined as follows (see also Appendix A in Appendix A):

"HOLE_DIAM - This is the hydraulic equivalent hole size, deduced from d = 4A/p, in mm. Where d is the diameter of the hydraulic equivalent hole, A is the cross-sectional area of the actual hole in mm2, and p is the wetted perimeter of the actual hole in mm. It is important to note that N/A in this field indicates that hole size is not applicable to the mode of release involved".

Note that the definition does not state whether the diameter is measured or calculated, but the project meeting 04.09 indicates that some are calculated and some are measured. The methodology for calculating the hole sizes are not stated in HCRD. Lilleaker has calculated the initial leak rate based on hole size and process conditions at the onset of the leak (using the same equations as in the validation model presented in TN-6). In Figure 6.1, the ratio between calculated initial leak rate and average leak rate is plotted for all relevant process leaks fed through process systems (2855 incidents, see Figure 2.1). A similar figure is given in Appendix A for all leaks in HCRD. Figure 6.1 shows that ratio for about 2/3 of all incidents is ≤1. This means that the estimated initial leak rate is less than the average leak rate. This demonstrates that some data fields are incorrect. These uncertainties must be accounted for when interpreting the data and using the data to parameterize the leak frequency model.

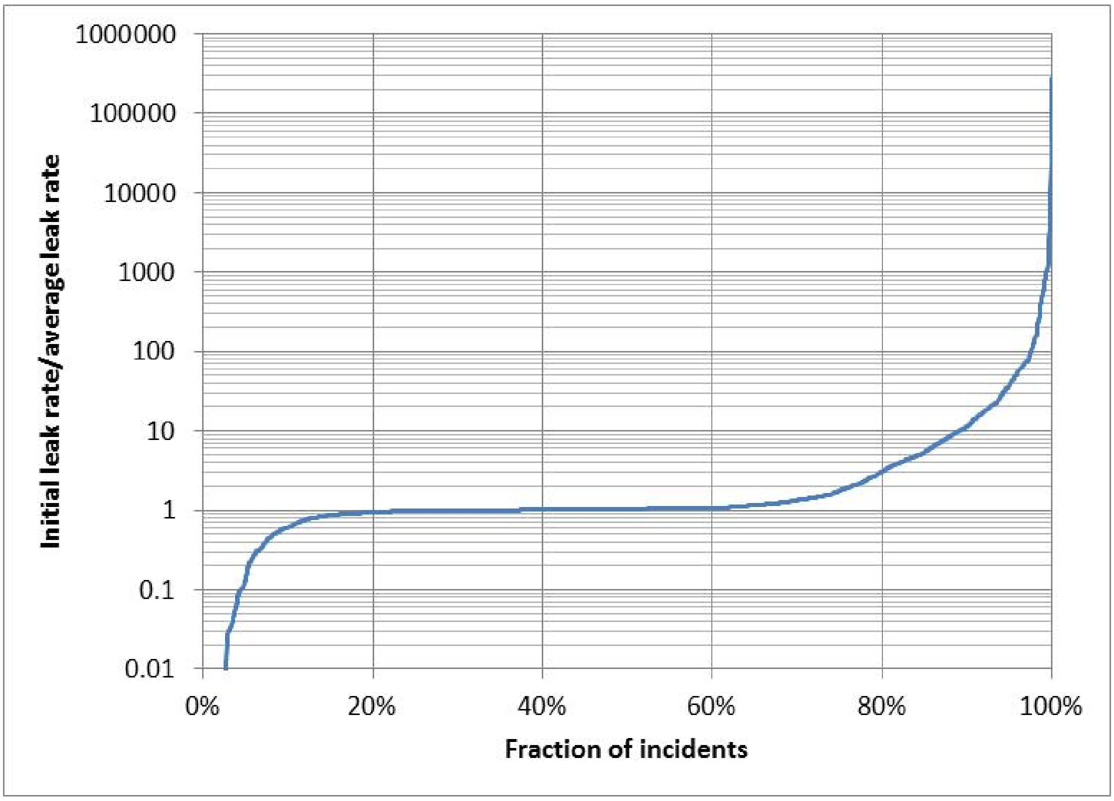

Figure 6.1 - Ratio between calculated initial leak rate and average leak rate. The x-axis gives the fraction of the total number of relevant process leaks fed through process systems (2855 incidents, see Figure 2.1). A similar figure is given in Appendix A for all leaks in HCRD

6.2 Exposure data

The HCRD exposure data has been updated after the first revision of PLOFAM. The following adjustments have been made to the original data;

1) Equipment associated with non-production installations, mobile installations and sub-sea installations have been removed. Consequently, the equipment counted here relates to fixed production installations. The term "fixed" in this context includes floating production installations

2) Systems which did not have equipment counts have been augmented with the average equipment counts for those systems

3) Installation which had no equipment counts were matched with similar installations which did have parts counts and an equipment from those surrogate installations substituted. In some cases a factor was used

4) The commissioning and de-commissioning dates were adjusted where better information was available

The quality of the HCRD exposure data is still not complete, (Ref. /2/). The following aspects must be considered when using the data for estimation of leak frequency per component:

a The procedures for update of population data is unclear in terms for responsibility for maintenance of the data

b There is most likely inconsistency in the way equipment is counted on the various installations (e.g. how instrument connections are counted with regard to flanges and valves associated with instruments)

c The upgraded population data is to a large degree based on assessments, and not specific counts for the installations

6.3 Concluding remark

Based on above, the overall assessment of the HCR-database is that:

- Leak frequencies per component based on HCRD is uncertain due to the uncertainty related to the population data, and
- The hole size distributions derived from HCRD is not completely representative for the underlying hole size distributions. It is not possible to evaluate whether the actual underlying hole size distribution is shifted towards smaller or bigger holes

These aspects must be taken into account when HCR data is compared with NCS data, and when the HCR data is applied for parameterization of any leak frequency model.

Due to the above incompleteness of the UKCS data, it was agreed not to use the UKCS data for parameterisation of the updated PLOFAM model. The UKCS data has only been used for reference and support in terms of certain aspects of the parameterisation process.

7 Application of UKCS for parameterisation of PLOFAM

The UKCS historical data extracted from the HCR database has not been used directly when setting the leak frequency model parameters. The UKCS data, with its uncertainties, nevertheless constitutes an important basis when evaluating certain aspects on a higher level, such as:

- the relative distribution of leaks on the various types of equipment
- the relative distribution of leaks in terms of the initial leak rate, *e.g.* the fraction large vs. small leaks
- the relative distribution of leaks equivalent with the leak scenario modelled in QRA's (sudden leak in a fully pressurized process isolatable segment) and leaks from initially isolated and/or depressurized segments (in PLOFAM denoted 'Significant' and 'Marginal' leaks respectively)
- the time trend of observed leaks at UKCS demonstrating a downward trend from the initial years levelling out around 2010 to around 10 leaks per year (see Figure 7.1)

The UKCS data is also important for our confidence in the performance of the PLOFAM model based on NCS data. The PLOFAM parameters derived based on NCS data generate a good fit to the UKCS data when accounting for the uncertainties in the UKCS data (see TN-6).

Figure 7.3 display the number of leaks (significant + marginal leaks) per equipment year (all types of pipes excluded, see Figure 7.2) per year for NCS and UKCS. The plot show that the leak frequency per equipment year and time trend in the leak frequency at UKCS is similar to the time trend seen on NCS. The average frequency appears to be slightly less at UKCS (about 25% less for the period 2012-2016), but that may for instance be due to uncertainty in the UKCS population data.

The observed deviations (see TN-3 in previous version of PLOFAM, Ref. /3/) are very likely to be explained by the uncertainties in the quality of the UKCS data. This means that the underlying leak frequency at installations located on the UKCS appears to be the same as the underlying frequency at installations on the NCS.

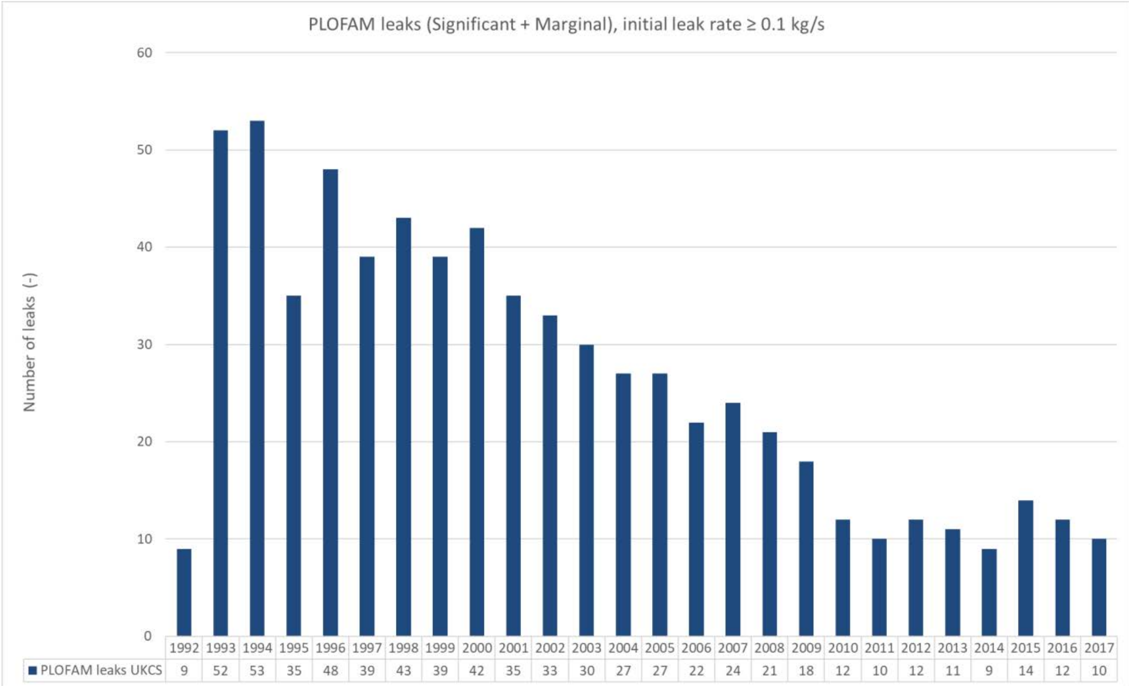

Figure 7.1 - Leak per year at UKCS installations

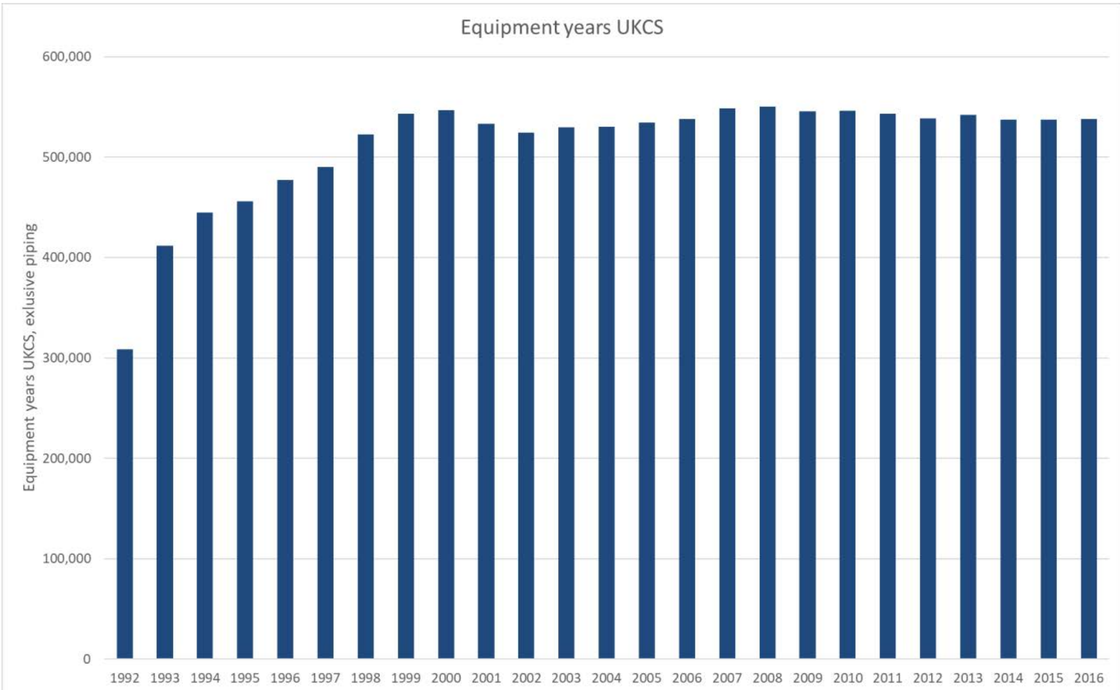

Figure 7.2 Equipment years per year (exclusive steel pipe) extracted from UKCS population data

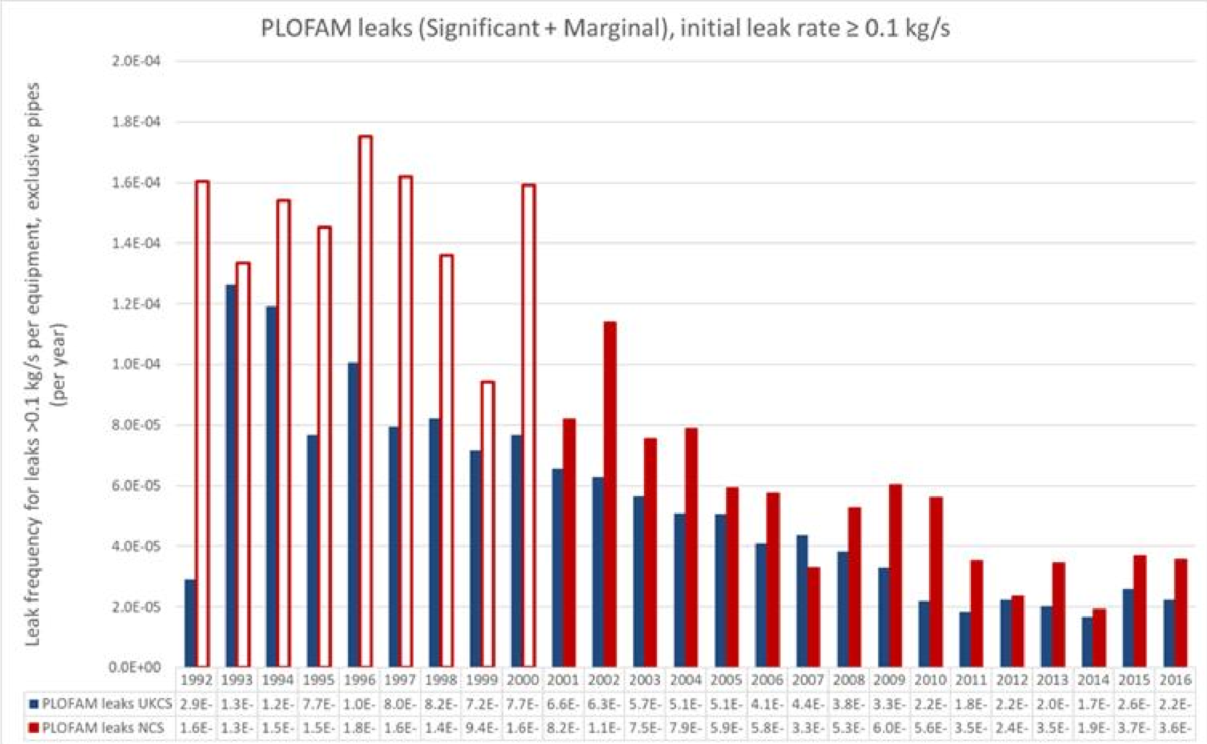

Figure 7.3 – Annual frequency for leaks ≥ 0.1 kg/s per equipment (includes all types of equipment except steel pipe) both for UKCS and NCS. For NCS the columns giving the leak frequency after 2001 are filled to indicate that that there is a shift in the uncertainty related to the data. Note however that the uncertainty related to the overall frequency presented in the figure is regarded low also before 2001. No shift in data quality is known for UKCS data. The correct exponent belonging to the figures in the table must be read from the second axis (the font size is maximized to enhance readability of the figures)

8 References

/1/ Lloyd's Register Consulting, "Blowout and well release frequencies based on SINTEF offshore blowout database 2014", 17 March 2015, Report No: 19101001-8/2015/R3 Rev: Final

/2/ Minutes of meeting from Project meeting 04.09.2015.

/3/ Lloyd's Register Consulting, "Process leak for offshore installations frequency assessment model – PLOFAM", report no: 105586/R1, Rev: Final, Date: 18.03.2016

Appendix A

HCR databasis

Table of contents

Page

1 Introduction

In the project of building the leak frequency model, Lilleaker has built a databasis in excel format with all HCR-data and developed additional data fields (based on the existing data fields), filters and tools for data analysis. This appendix contains Lilleaker's documentation of the HCR-data, documentation of the developed databasis and also general considerations related to the data fields in HCRD.

Lilleakers's report contains one main report and one Appendix. They are both given in the next chapter.

2 Lilleaker's report

Lilleaker Consulting a.s.

HCR data for leak frequency model

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HCR data for leak frequency model

Contract no.:	Document no.:	LA project no.:	No. of Pages:
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Client:	Client contact person:
Lloyd's Register Consulting	Are Sæbø

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DRAFT B	08.05.2015	For workshop	MR/JMN	JW	
DRAFT A	30.04.2015	For internal comments	MR/JMN	JW	

Table of contents:

1 Summary

This report describes the contents of the HCR database [1] with the objective of using the records of hydrocarbon leaks as a basis for making a process leak frequency model for use on NCS.

It is important to have a common understanding of the definition of *a process leak* scenario. Table 1-1 shows some categories in the HCR database that may be relevant for classifying a process leak and evaluations of these.

Further classification of the process leaks based on their severity/potential/relevance for QRA. Table 1-2 shows such fields and evaluation of these.

Each field in the database is described in Appendix A.

Table 1-1 Process leaks categories

HCR field #	HCR data field	HCR Description	Comment
2	CATEGORY	Installation type: FIXED, MOBILE, SUBSEA. The installation may have a subsea satellite (recorded in field 16 subsea)	Fixed installations have equipment population counts.
19	PROCESS	This is the type of Hydrocarbon released, i.e. NON-PROCESS OIL CONDENSATE GAS 2-PHASE	Equipment population does not exist for non-process equipment
28	SYSTEM	This field contains either a full description of the system involved or a Drilling or Well Operation activity description where appropriate.	Some systems are not relevant for process leak scenarios.
32	EQUIPMENT	This gives the full equipment item description. For Drilling/Well Operations activities (see item 28 above) this will be left blank.	Som equipment types are not relevant for process leak scenarios.
43	HAZ_CLASS	This field contains the Hazardous Area Classification for the location of the incident, where 1 and 2 represent areas 1 and 2 respectively, and 3 represents unclassified.	Leaks in unclassified areas may not be relevant for process leak scenarios.

HCR field #	HCR data field	HCR Description	Comment
47	MOD_VOLUME	This contains the volume of the module involved, in m^3, and will show 'NOT KNOWN' where not reported.	Module is not defined in HCRD, however it is stated: "3000m^3 explosive clouds [are] enough to fill an entire module or deck area." Module volumes are sometimes reported to be very small, maybe inside confinements such as separate rooms (e.g. for pumps) or under hood of turbines.
53	INVENTORY	This is the isolatable hydrocarbon inventory contained in the system, in kgs. And will show 'NOT KNOWN' where not reported.	The inventory of a standard isolatable segment should be significant. Many are reported as very small.
58	DETECTION_ OTHER	Leak detected by "other" means	May indicate that the leak was not a process leak. E.g. ROV detection or pressure drop may indicate subsea leak. Subsea leaks are not relevant for process leak scenarios.

Table 1-2 Process leaks severity/potential/relevance for QRA leak frequency model

HCR field #	HCR data field	Description	Comment
21	SEVERITY	This shows the severity of the release as either 'MAJOR', 'SIGNIFICANT', or 'MINOR'.	Leaks with "minor" severity may not be relevant for QRAs.
26	QUANTITY	Amount of Hydrocarbon released in kg	Leaks with small quantities released may not be relevant for QRAs.
27	DURATION	Duration of leak in minutes.	
44	HOLE_DIAM	This is the hydraulic equivalent hole size, deduced from d = 4A/p, in mm. Where d is the diameter of the hydraulic equivalent hole, A is the cross-sectional area of the actual hole in mm^2, and p is the wetted perimeter of the actual hole in mm. It is important to note that N/A in this field indicates that hole size is not applicable to the mode of release involved.	This is in general an unreliable data field. No hole sizes <1mm recorded before 2001.
51	MAX_ PRESSURE	This is the maximum allowable pressure of the system, in barg.	(Actual pressure > max pressure) may be a leak scenario of particular
52	ACT_	The actual (working) pressure at	

HCR field #	HCR data field	Description	Comment
	PRESSURE	time of incident, in barg.	interest (rupture leaks).
53	INVENTORY	This is the isolatable hydrocarbon inventory contained in the system, in kg/s. and will show 'NOT KNOWN' where not reported.	The inventory of a standard isolatable segment should be significant. Many are reported as very small.
60	EQUIP_CAUSE	Leak causes.	
61	OP_CAUSE		Operation cause hard to imagine for some equipment types, such as piping.
62	PRO_CAUSE		
62	OP_MODE	The operational mode in the area at the time of release,	
71	SHUTDOWN	Emergency actions taken because of the leak	No action taken indicates a less serious accident for loss of main safety function
72	BLOWDOWN		
73	DELUGE		
74	CO2_HALON		
75	MUSTER		
76	EMERACT_ OTHER		

2 Introduction

The HCR database [1] includes 4561 leaks from the UK continental shelf from 3rd quarter 1992 to 1st quarter 2015. These data may act as a basis for building a process leak frequency model. Since the model shall model *process leaks*, all leaks in the data basis may not be relevant for this purpose and should be removed from the data basis.

QRAs usually models process leaks as leaks occurring spontaneously from a fully pressurized process segment and is controlled by ESD and blowdown.

This document will discuss the entries in the HCR database and how they may be used as basis for the leak frequency model.

The data in the HCR data base should be used with care. The sections below discuss some findings in the data. Data found in this section is given in a separate excel worksheet [2]. This report is structured to match the filters created in the worksheet.

Note that whenever leak counts are presented in this report, it is either based on the full set of leak in the spreadsheet or an indicative subset called "process leaks". For the final definition of process leaks, see TN-4.

2.1 Abbreviations

Abbreviations used in this report are shown in Table 2-1. For abbreviations used in database fieldnames, see appendix A.

Table 2-1 Abbreviations

Abbreviation.	In full
HCR	Hydrocarbon release
HCRD	Hydrocarbon release database
MISOF	Modelling of ignition sources on offshore oil and gas facilities
ROV	Remote Operated Vehicle
DNV	Det Norske Veritas
N/A	Not Applicable
NCS	Norwegian continental shelf

3 Process leak (leak scenarios)

It is of critical importance that a user knows and understands what leaks are included in the data set. NORSOK Z-013 section 7.4.4 describes process accidents as a specific category to be analyzed in a QRA. Z-013 does however not define a process accident (it refers to the HAZID), and therefore the QRA will define "process accidents" for each specific project or client.

It is not within the scope of this report to establish a common or standard rule set for what to include as a process leak in a QRA context. But since the project proposes leak frequencies for use in QRA, it is important that a user of these frequencies understands what leaks scenarios are included and what leak scenarios are not. This could be on a system level, equipment level or even relate to causes or leak location. For example, are the following process leaks that should be included in the recommended frequencies?

- A leak that occurred outside a process area (non-hazardous area)
- A leak from the flare system
- A leak from the gas lift annulus through the wellhead
- A leak during maintenance with a platform that is shut down
- A leak that resulted from incompliance with procedures

These questions do not have correct yes/no answers, but for a user of generic leak frequencies it is important that these battery limits are well defined and correctly understood.

From the description of incidents in the database, it is not always obvious whether a specific incident should or should not be included in any given category of incidents. Rule sets will be established, but the quality of the data and limitations to what is actually recorded means that the number of incidents in any given leak category would be uncertain.

3.1 Process

This field refers to the fluid released, and "non-process" leaks should identify incidents that are normally not considered process leaks in a QRA context.

3.2 Category

This field indidates installation type: FIXED, MOBILE, SUBSEA. The installation may have a subsea satellite (recorded in field 16 subsea)

To what extent "M" and "S" type installations is part of scope and how these are reflected in the population data is of interest.

3.3 Severity

The leak severity categories are defined in Appendix A. Note that severity is an automatic evaluation based on other data fields. For the total data set considered, leaks are distributed on the three severity categories as follows:

- 207 categorized as “MAJOR” (27 of these with hole size diameter D > 100)
- 2103 categorized as “SIGNIFICANT” (59 of these with hole size diameter D > 100)
- 2251 categorized as “MINOR” (27 of these with hole size diameter D > 100)

3.4 Hazardous area classification

The hazardous area classification for the location of the incident is included as field 43 HAZ_CLASS. Where leak is in unclassified area, the leak point is outside the process area. The relevance of such incidents to process area risk analysis can be discussed. The data set contains 147 process fluid leaks where the area is categorized as unclassified, so this is not a large fraction of the incidents.

The information in this data field may not always reliable. For example, some of the subsea leaks are recorded in zone 2.

3.5 System

All leaks are assigned to a “system”. This field contains either a full description of the system involved or a Drilling or Well Operation activity description where appropriate.

Some systems are obviously relevant when it comes to defining a process leak, such as “separation” or “compression”. Others are less obvious, such as releases from the drain or drilling systems. Which systems are relevant for the process leak frequencies to be established?

Leaks from the open and closed drain system could be hard to interpret. The hydrocarbons have come from process equipment via the drain system. There are 198 leaks from drain or open drain systems of which 112 are minor. For example, there are three leaks from pressure vessels (equipment type) in the open drain system. It is believed that the pressure vessel is part of another system, while the released fluid is from the drain system. (Drain tank should normally not be defined as a pressure vessel).

3.6 Equipment

This field gives the leaking equipment description. Most leaks are assigned to an “equipment type” (some are “N/A”). Note that sometimes equipment type and system type appear to be in conflict.

Equipment that is generally not considered process leaks includes categories such as “riser” and “BOP”.

For Drilling/Well Operations activities this will be left blank.

Piping

There are 1144 leaks from piping. Of these, 188 incidents have equipment cause "NONE". Operational cause is "LEFTOPEN", "OPENED" or "IMPROPOP" for 93 of these. Of these 93, 12 have hole diameter N/A, 17 have hole diameter > 100mm and 17 have diameter sizes in the range 1" to 3". See chapter 4.4 for further discussions.

An important point is that the fraction of large hole diameters is quite different:

- For those 93 leaks with no equipment cause and operational cause as above, 13% have hole diameter > 100mm.
- For the remaining 956 leaks (with equipment cause "NONE"), 0.9% (9 incidents) have hole diameter > 100 mm. For these 9 incidents, duration is anything from very short (5 seconds) to very long (8 days).

It may well be that the operational piping leaks with D > 100 and D = N/A are similar incidents. For the SHLFM [3], "N/A" are discarded (D< 1 mm) while D > 100 certainly contributes to the large leak category. Further, there are likely to be many similar incidents in the 1" – 4" range as well (see chapter 4.4).

Discussion: The "N/A" incidents are likely to be less severe than the > 100 incidents. This should be further addressed in order to justify omission of incidents with hole size "N/A".

3.7 Major units

The definition of «major equipment» (which includes e.g. "Pressure vessels" as separators) in HCRD is as follows (see appendix A):

Each item comprises the item of equipment itself, but excluding all valves, piping, flanges, instruments and fittings beyond the first flange and excluding the first flange itself.

The definition of Instruments in HCRD:
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).

It is Lilleaker's understanding that leaks from instrument connections on major equipment are recorded as leaks from the major equipment:

- The «first flange» does not exist for an instrument connection because this is included in the definition of the instrument it self
- The leak data seem to suggest that this is the case: several recorded hole sizes of 0.5'', 1'' and 2'' may correspond to rupture of instrument connections.

3.8 Blowout

"Blowout" is not a category in the database. 11 leaks with system containing "well" or "drilling" have duration of 24 hours or more. One incident seems to be a blowout (Year 2012, number 125), the remaining are different well leaks scenarios that were not detected by gas detectors (one exception). One is detected as a fire "Flame".

24 UK blowouts and well releases are included in the Sintef offshore blowout database for this period 1992-2015. Of these, 4 are releases are from X-mas tree or wellheads.

Table 2: HCRD incidents x-mas tree or wellhead that are found in the blowout database

HCR ID	Sintef Offshore blowout database ID	Category (Sintef Offshore blowout database)
1994-1995-25	490	Limited surface flow before the secondary barrier was activated
1995-1996-146	497	Limited surface flow before the secondary barrier was activated
1996-1997-99	492	Totally uncontrolled flow, from a deep zone
2011-2012-125	626	Totally uncontrolled flow, from a deep zone

One incident from UKCS for the period 1992-2015 and none from the NCS are included in the estimate for Blowout and Well release frequencies for producing wells for use on NCS, as reported in the annual LR consulting report (Two incidents from the UKCS in 1988 and 1989, respectively, are included.)

Reference is made to the latest annual report: *Blowout and well release frequencies based on SINTEF offshore blowout database 2014 Report no: 19101001-8/2015/R3 Rev: Final, March 17th 201*5 [4], tables 4.1 to 4.4.

The one incident is a well release from 2007 and has ID 596 in the Sintef Offshore blowout database. This is a subsea release and not relevant for the Leak frequency model.

Description of ID596 from the Sintef Offshore blowout database:

Wells Incident -<...>Incident reported by field standby vessel "Putford Artemis". Vessel reportes bubbles coming to surface with a 10m dispersion radius at location of <...>subsea wellhead structure.<...> responded as contractedd operator through a sequence of shut downs to determine the hydrocarbon gas release was from the B1 (B9) well. The well was shut in and the gas release stopped. The well remains shut in and will require inspection of the structure to ascertain the causef cause of the gas release.

In Lilleaker's opinion, no adjustment has to be made for the Process leak frequency model based on events included in the blowout and well release frequencies for producing wells.

3.9 Subsea leak

Subsea leaks should be not included in the data set. It is not straight-forward to identify these leaks from the HCR database. (There are some examples of subsea leaks that have been included in the MISOF data set.)

If one or more of the following is true, the leak should be considered a subsea leak:

- Category = "S"[1]
- System contains "SUBSEA"
- Equipment contains "SUBSEA"
- Detection other = "ROV"

53 leaks are identified this way as subsea leaks. Most likely, there are more subsea leaks in the dataset after this exercise. Note that the fields "ventilation", "no of sides" and "mod volume" are typically set to "NOT KNOWN" for these leaks, while "air changes" seems to be "not known" in every case. So these fields may also be an indicator for a subsea leak.

Another indicator for a subsea leak may be a leak with long duration. 56 different leaks not detected by filters above with "non process" ="" (empty) have a duration of 24 hours or more. Of these leaks were 36 leaks from systems that may be subsea systems.

For subsea leaks, the field "HAZ_CLASS" should be unclassified, but this is not the current practice in the database. It seems like some subsea leaks may have "HAZ_CLASS"=2, which is the case for subsea wells.

[1] See Appendix A for description of the different categories in the HCR database

4 Leak causes

It may be of interest to look into what caused a leak. As we understand, industry practice for process leak analyses has been to consider all causes as relevant. This may not be the case for other parts of the QRA such as collision (way-point at installation) riser leak and blowouts (external causes), and dropped objects (lifting restrictions).

Anyway, it is of interest to look into what caused the incidents that pass a set of other criteria. When a particular type of equipment is analyzed, it is important to know whether the fault is an equipment fault or not. An example here that is further discussed is piping leaks that have no equipment failure. These have mostly operational causes. It may not be a productive to mix these incidents with piping leaks caused by corrosion or mechanical failure.

4.1 Design cause

This field in the database indicate that the failure was related to design.

- Of the total of 4561 leaks, 629 are recorded to have a design cause.
- Of 2758 process leaks, 373 are recorded to have a design cause.

4.2 Procedural cause

This field in the database indicated that the failure was related to procedures (both non-compliance and deficient procedures).

- Of the total of 4561 leaks, 1070 are recorded to have a procedural cause.
- Of 2758 process leaks, 545 are recorded to have a procedural cause.

4.3 Equipment cause

This field in the database indicated that the failure was related to the equipment itself such as corrosion, erosion mechanical fatigue.

- Of the total of 4561 leaks, 2895 are recorded to have an equipment cause.
- Of 2758 process leaks, 1881 are recorded to have an equipment cause.

4.4 Operational cause

704 leaks have operational cause “OPENED” “LEFT OPEN” or “IMPROPOP” while the equipment cause is “NONE”. 58 of these have hole size > 100. This is 50% of the leaks with D > 100. Equipment type varies, but many are piping, flange or valve. Is there any good reason to scale these events with the number of flanges, valves or piping length except that all of these could be good indirect measures of activities that could involve all types of mistakes?

For the leaks with operational causes as listed above, equipment type for most of the incidents is listed as piping, flange or valve. The question to ask is whether this categorization to some extent is arbitrary. Say a valve is opened and gas is released as a consequence. Could it be that in this case the operator has a difficult task to decide if the equipment type is the valve that was opened, the piping the gas was released through, or the flange at the end of the piping? And the hole size, would that be the diameter of the piping (even if other restrictions might exist)? Or would some operators perhaps record N/A for the hole size for the very same event. Physically, piping cannot be "opened" to cause a leak, since piping is a simply a physical barrier. A valve may be opened, and a flange could be opened as well. This could be important for several reasons. If a pipe is routed through an area and there are no flanges or connections of any kind, what is the leak frequency? "Opened" is not really an option. The relatively large number of leaks (with large hole diameters) due to operational causes would not be applicable in this case.

Assigning the leaks caused by operational mistakes to equipment type (such as piping) could potentially be misleading and lead to incorrect focus and decisions when it comes to risk assessments or mitigation means. This does not mean that the population of valves and flanges cannot be a reasonably good indicator for the leak frequency also for operational leaks.

5 Leak details

Leak details include the quantity and duration and inventory of the leaks. Actual pressure and maximum pressure are included here as well, in addition to the recorded hole size. Finally, operational mode is included. This is relevant information for describing the consequence of a leak. The following data fields are relevant in this context.

- Hole size
- Actual pressure
- Max pressure
- Quantity
- Duration
- Inventory
- Operational mode
- Hazardous class
- Severity

The rules for which leaks are reportable are very strict: Leaks with rate > 1 kg per hour (gas) or 5 kg per day (liquid) are reportable. Many small leaks may not be of interest for QRAs. The flowchart for deciding whether a leak is reportable or not is shown in Figure 5-1.

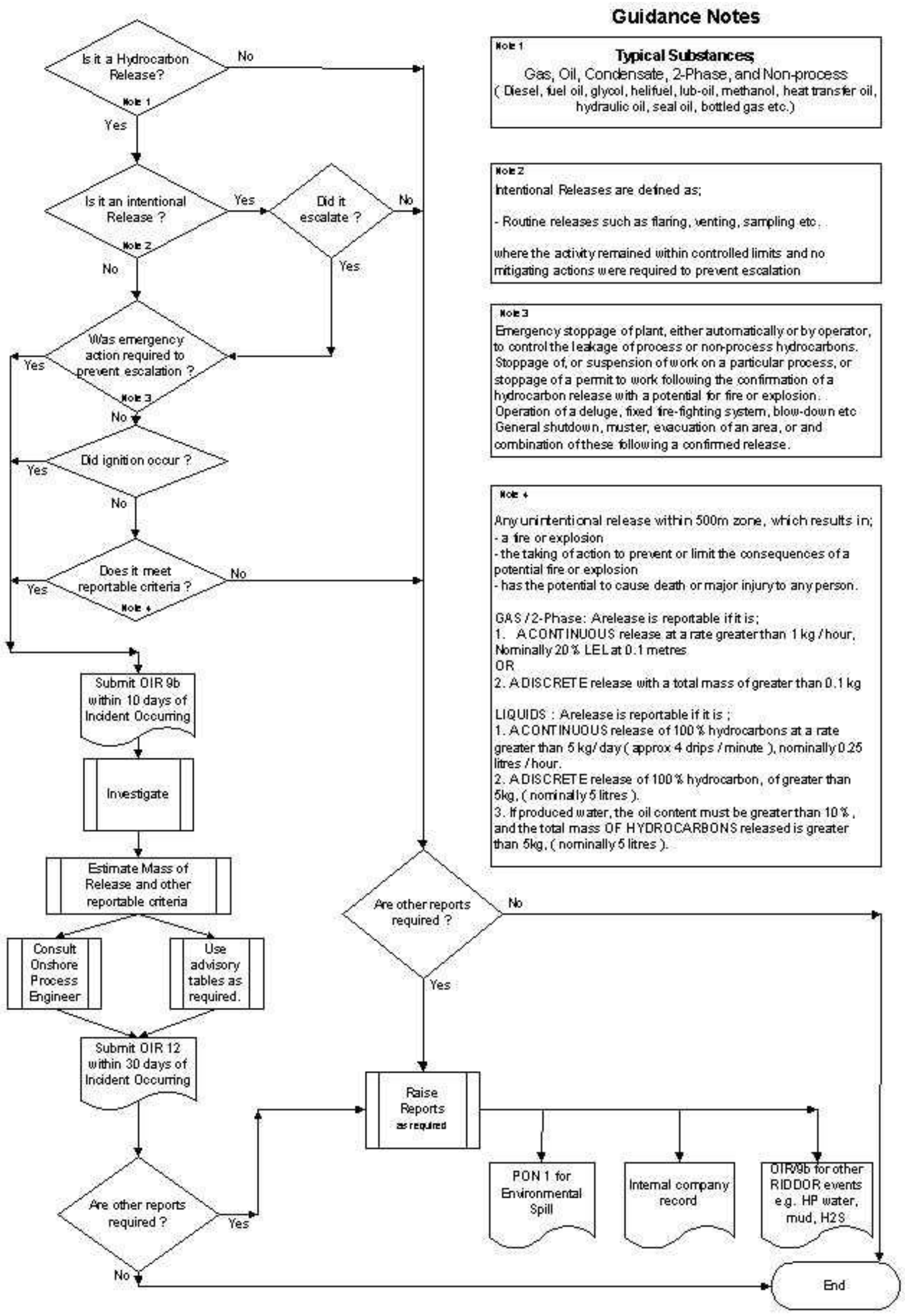

Figure 5-1 Ratio between Flowchart on Reportability of Hydrocarbon Releases

5.1 Hole size

In HCR, Hole sizes are the hydraulic equivalent hole size, deduced from d = 4A/p, in mm. Where d is the diameter of the hydraulic equivalent hole, A is the cross-sectional area of the actual hole in mm^2, and p is the wetted perimeter of the actual hole in mm.

It is important to note, that those releases with a hole size labelled N/A are special cases where the release rate is not applicable to the mode of release (e.g. open topped vessels such as shale shakers, or where carry-over of hydrocarbons from one system to another was involved). All such releases were classified by inspection of the amount released only. Hole sizes less than 1 mm are set to 1 before 2001. It is also debatable how easy it is to be consistent when measuring the hole diameter. The hole may be everything from a full rupture, to a small fracture or a poor fitted flange coupling.

In all, there are 160 leaks with hole size N/A. 111 of these have equipment cause “NONE”. 4 of these have severity “MAJOR”.

There are 113 leaks with hole size > 100. 83 of the latter have operational cause “NONE”. 17 of these have severity “MAJOR”.

5.2 Initial leak rate

Leak rate is not reported in the HCRD. The graph in Figure 5-2 shows the ratio between calculated initial rate and average rate. For almost 3000 leaks, the initial rate is between 75% and 200% of the average leak rate. For about 500 incidents, the initial rate is between 2 times and 10 times the average rate. For the remaining 500 incidents, the initial leak rate is more than a factor 10 higher than the average rate.

For about 500 leaks, the calculated initial rate is significantly less than the average rate. Except if the leak rate was increasing over time, the calculated initial rate is too low for these leaks. Most of these incidents are categorized as “Zero pressure leaks” in [3]. For 287 leaks with average rate ten times or more higher than the calculated initial rate, 38 have initial rate exceeding 1 kg/s.

For a few leaks, the two values are very different, indicating that something is incorrect. The initial leak rate is calculated with the method used in *Standardised Hydrocarbon Leak Frequencies* [3].

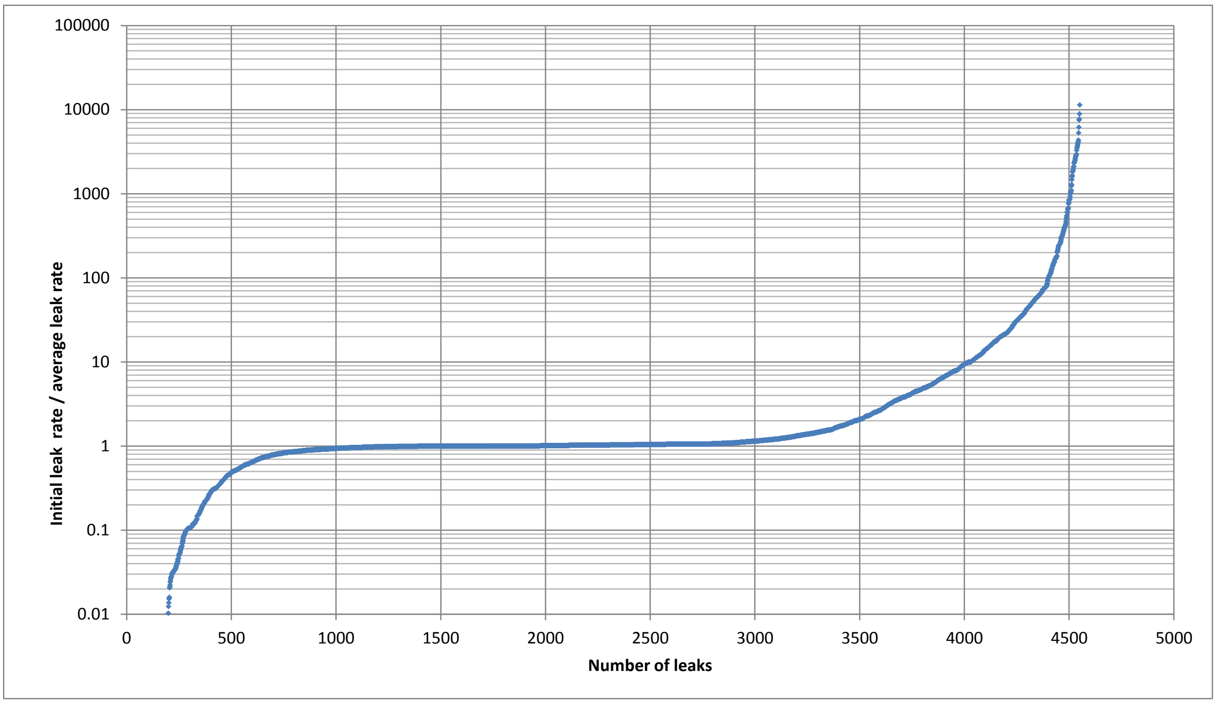

Figure 5-2 Ratio between calculated initial rate and average rate

In Figure 5-2, leak rates for hole sizes > 100 mm are calculated based on a hole diameter of 110mm. An alternative calculation with 220 mm hole size was performed. The resulting graph is virtually identical with the one shown.

5.3 Duration

Normally, process leaks will have durations of more than 1 minute and less than one hour due to the size of isolatable segments of the process plant and safety systems such as blowdown. Most leaks in the HCR database are within this category.

Leaks with very short duration would normally be leaks from a very limited inventory. It seems that leaks with very long duration are in many cases not really process leaks but may for instance be subsea leaks.

- 55 leaks have duration less than 5 seconds
- 151 leaks have duration 15 seconds or less
- 714 leaks have duration 1 minute or less
- 3147 leaks have duration between 1 minute and 60 minutes
- 700 leaks have duration 1 hour or more
- 81 leaks have duration 24 hours or more
- 16 leaks have duration 1 week or more

5.4 Actual pressure

Actual pressure is a very central data field for the current leak frequency model. The pressure is used for calculating initial leak rates and for classification of the leaks.

For all but one leak, an actual pressure is recorded. For two leaks, the actual pressure is slightly less than zero. For 334 leaks, the actual pressure is less than or equal to 0.01 barg.

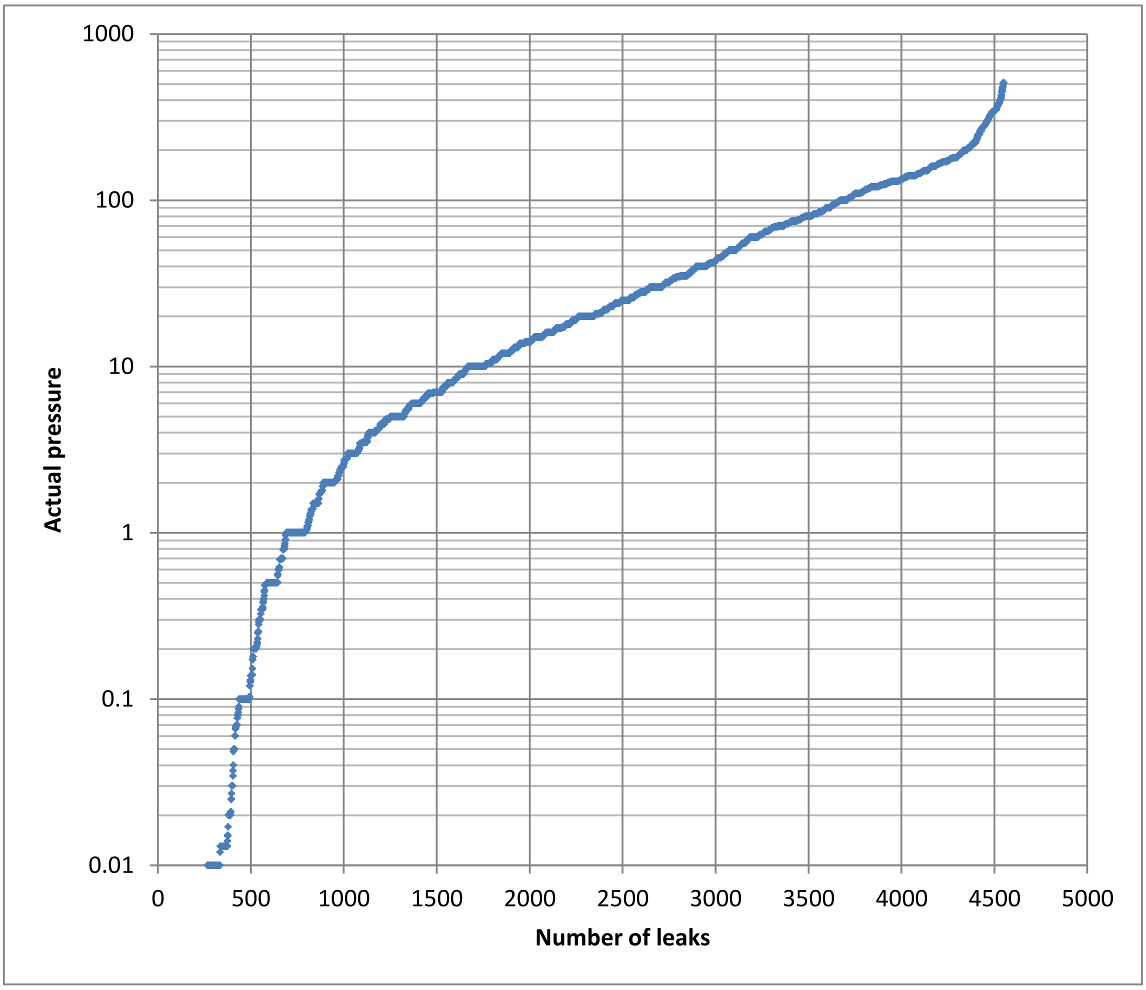

Figure 5-3: Distribution for actual pressure

5.5 Quantity

Leaks are registered with the amount of hydrocarbon released; this field is called Quantity in the database.

For about 50% of the leaks in the HCR database, the released quantity is less than 10 kg. The relevance of these leaks should be debated. Below the number of leaks is shown for different quantity categories. The total number of leaks is 4561.

Quantity < 1 kg: 1095 leak
Quantity < 10 kg: 2358 leaks
Quantity < 100 kg: 3628 leaks
Quantity > 10 000 kg: 42 leaks
Quantity> 50 000 kg: 13 leaks
Quantity > 100 000 kg: 7 leaks

(Of these 7 leaks, 1 is apparently a blowout, 1 flaring, 1 storage tank, 1 pipeline, 1 subsea, 1 manifold -with duration 6 days , 1 with duration 73 days-export oil, piping, mech. ventilated area of unknown volume.)

5.6 Inventory

Of the total 4561 leaks

- 1092 are reported with inventory < 100 kg
- 808 with inventory 100-1000 kg
- 540 with inventory 1000-4000 kg
- 272 with inventory 4000-10000 kg
- 426 with inventory > 10000 kg
- 1417 with inventory "NOT KNOWN"

Of 2758 process leaks

- 636 are reported with inventory < 100 kg
- 580 with inventory 100-1000 kg
- 379 with inventory 1000-4000 kg
- 194 with inventory 4000-10000 kg
- 287 with inventory > 10000 kg
- 682 with inventory "NOT KNOWN"

Incidents with inventory not known seem to include all types of systems, and not restricted to systems with inventory that is hard to define such as wells.

For 69 leaks, inventory is reported to zero and in 233 cases less than 1 kg. Again, these leaks are from all kinds of systems. In some cases, inventory might have been set to zero rather than "not known". For some leaks, the system might have been empty when intrusive maintenance is initiated. The gas or oil might then come from faulty isolation from a neighboring segment.

5.7 Operational mode

11 different operational modes are recorded.

- Of 4561 leaks, 2495 are recorded during normal operation.
- Of 2758 process leaks, 1692 are during normal operation.

5.8 Gas detection

This shows whether a GAS detector was activated.

- Of the total of 4561 leaks, 1712 are recorded with gas detection
- Of 2758 process leaks, 1111 are recorded with gas detection.

5.9 Other detection means

20 leaks are detected by use of ROV. Not all of these are easily identified as subsea leaks. There are also 32 leaks detected by pressure change. Some of these appear to be subsea leaks as well.

6 Emergency reactions

Emergency reactions include actions such as shutdown and blowdown, but also deluge, and muster. These may give useful additional information on the incident. For example if no shutdown or blowdown was initiated this is an incident that has a development deviating from what is commonly modelled in a QRA.

6.1 Shutdown

This field signifies that shutdown took place, either automatically or manually initiated.

- Of the total of 4561 leaks, 3020 are recorded to have been shut down (manual or automatic)
- Of 2758 process leaks, 1938 are recorded to have been shut down (manual or automatic)

6.2 Blowdown

This field signifies that blowdown took place, either automatically or manually initiated

- Of the total of 4561 leaks, 1563 are recorded with blowdown initiated (manual or automatic).
- Of 2758 process leaks, 1182 are recorded with blowdown initiated (manual or automatic).

6.3 Deluge

This field signifies that deluge took place, either automatically or manually initiated

- Of the total of 4561 leaks, 122 are recorded with deluge initiated (manual or automatic).
- Of 2758 process leaks, 72 are recorded with deluge initiated

6.4 Muster

This field signifies that a muster took place at stations or at the lifeboats.

- Of the total of 4561 leaks, 1225 are recorded with mustering initiated (at life boats or at stations).
- Of 2758 process leaks, 713 are recorded with mustering initiated (at life boats or at stations).

6.5 Other

If any other emergency action was taken during the incident, but was not adequately covered by any of the previous fields, it is recorded in this field.

- Of the total of 4561 leaks, 1225 are recorded with other emergency reaction initiated.
- Of 2758 process leaks, 713 are recorded with mustering initiated

7 Population Data

The population data should be used with care in this study. Not all systems with recorded leaks have population data. It is for instance recorded leaks in the flare systems, but the population data (on equipment) does not contain any data for this system. The population has also been more or less constant since 2006, indicating update problems. The population data does not contain the same amount of information as the leak data. Therefore, it is difficult to use the same filters for the population data as for the leak data.

3164 leaks are registered with population data (equipment type). This means that 31 % of the leaks are in systems that does not contain population data. The table below shows the percentage of leaks registered in each severity category. The leaks with population data seem to have similar distribution among the severity categories.

Table 7-1 leaks in different severity categories, all leaks and leaks with population data

Severity	Percentage of all leaks	Percentage of leaks registered with population data
Major	5 %	5 %
Significant	46 %	48 %
Minor	49 %	47 %

8 Conclusion

This project's intention is to use the HCR database for establishing generic frequencies for process leaks. To do this, process leaks that match the purpose for these generic frequencies must be identified. Many data fields in the HCR database [1] can be used for categorization of incidents as a process leak scenario or not.

Leak scenarios recorded in HCR may, however, differ from what is usually modelled in QRAs. The frequency assigned to the scenarios usually modelled in QRAs must be based on carefully selected subset of the database.

9 References

[1] *Hydrocarbon Releases System*, https://www.hse.gov.uk/hcr3/index.asp.

[2] HCR, *data, Excel Workbook.*

[3] *Offshore QRA - Standardised Hydrocarbon Leak Frequencies*, Report No 2008-1768/1241Y35-14, Rev. 1 2009.

[4] LR Consulting, *Blowout and well release frequencies based on SINTEF offshore blowout database 2014 Report no: 19101001-8/2015/R3 Rev: Final, March 17th 2015*,, 2015.

Appendix B

Extracted data from HCRD and estimated leak frequencies

Table of contents

Page

1 Introduction

This Appendix contains detailed data extracted from HCRD. The data is used as basis for estimating leak frequencies (per equipment year) for the defined leak types covered by the model. Calculated leak frequencies based on HCR-data are given in detail in this appendix.

2 Relevant process leaks fed through process system

2.1 Q3 1992 – Q1 2015

Table 2.1 - Relevant process incidents fed through process systems for the period Q3 1992 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Process leaks fed through process systems														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg				
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Actuated valve L	15	0	6	0	0	0	**21**	8	0	6	0	0	0	**14**	**35**
Actuated valve M	55	0	17	0	0	1	**73**	19	0	48	0	1	2	**70**	**143**
Actuated valve S	77	2	24	0	0	1	**104**	16	1	56	0	0	0	**73**	**177**
Air cooled heat exchanger	4	0	0	0	0	0	**4**	1	0	1	0	0	0	**2**	**6**
Atmospheric vessel	4	2	5	0	2	0	**13**	1	4	14	0	6	3	**28**	**41**
Centrifugal compressor	17	1	16	0	0	2	**36**	3	0	12	0	1	0	**16**	**52**
Centrifugal pump	44	0	13	1	0	3	**61**	13	0	58	0	0	1	**72**	**133**
Filter	8	0	11	0	1	0	**20**	0	0	30	0	0	1	**31**	**51**
Flexible pipe	8	0	12	0	0	1	**21**	6	0	22	0	0	2	**30**	**51**
Instrument	238	1	98	2	1	8	**348**	40	2	234	0	1	2	**279**	**627**
Manual valve L	14	0	2	0	0	0	**16**	7	0	8	0	0	0	**15**	**31**
Manual valve M	24	0	6	0	0	0	**30**	13	0	22	0	0	3	**38**	**68**
Manual valve S	42	0	36	1	0	0	**79**	16	0	55	0	0	1	**72**	**151**
Pig trap	5	0	8	0	2	5	**20**	6	1	20	0	0	0	**27**	**47**
Plate heat exchanger	6	0	6	0	0	0	**12**	1	0	30	0	0	0	**31**	**43**
Process vessel	9	7	16	1	4	6	**43**	5	2	11	0	4	6	**28**	**71**
Reciprocating compressor	25	0	16	0	0	0	**41**	5	0	13	0	0	0	**18**	**59**
Reciprocating pump	5	0	2	0	0	0	**7**	2	0	9	0	0	0	**11**	**18**
Shell side heat exchanger	9	0	3	0	1	0	**13**	2	0	11	0	0	0	**13**	**26**
Standard flange L	12	0	4	0	1	2	**19**	7	0	15	0	0	0	**22**	**41**
Standard flange M	65	0	22	0	1	1	**89**	17	0	53	0	0	1	**71**	**160**
Standard flange S	56	0	28	1	0	3	**88**	13	0	48	0	0	1	**62**	**150**
Steel pipe L	16	1	7	1	0	5	**30**	11	0	21	1	0	1	**34**	**64**
Steel pipe M	66	0	25	1	1	3	**96**	35	0	74	0	0	5	**114**	**210**
Steel pipe S	136	1	69	2	0	8	**216**	34	1	117	0	0	4	**156**	**372**
Tube side heat exchanger	11	0	3	0	0	1	**15**	5	0	7	0	1	0	**13**	**28**
Total	**971**	**15**	**455**	**10**	**14**	**50**	**1515**	**286**	**11**	**995**	**1**	**14**	**33**	**1340**	**2855**

Table 2.2 - Relevant process incidents fed through process systems for the period Q3 1992 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Process leaks fed through process system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Actuated valve L	6	6	**12**	15	8	**23**	**35**
Actuated valve M	18	51	**69**	55	19	**74**	**143**
Actuated valve S	27	57	**84**	77	16	**93**	**177**
Air cooled heat exchanger	0	1	**1**	4	1	**5**	**6**
Atmospheric vessel	9	27	**36**	4	1	**5**	**41**
Centrifugal compressor	19	13	**32**	17	3	**20**	**52**
Centrifugal pump	16	59	**75**	45	13	**58**	**133**
Filter	12	31	**43**	8	0	**8**	**51**
Flexible pipe	13	24	**37**	8	6	**14**	**51**
Instrument	108	239	**347**	240	40	**280**	**627**
Manual valve L	2	8	**10**	14	7	**21**	**31**
Manual valve M	6	25	**31**	24	13	**37**	**68**
Manual valve S	36	56	**92**	43	16	**59**	**151**
Pig trap	15	21	**36**	5	6	**11**	**47**
Plate heat exchanger	6	30	**36**	6	1	**7**	**43**
Process vessel	33	23	**56**	10	5	**15**	**71**
Reciprocating compressor	16	13	**29**	25	5	**30**	**59**
Reciprocating pump	2	9	**11**	5	2	**7**	**18**
Shell side heat exchanger	4	11	**15**	9	2	**11**	**26**
Standard flange L	7	15	**22**	12	7	**19**	**41**
Standard flange M	24	54	**78**	65	17	**82**	**160**
Standard flange S	31	49	**80**	57	13	**70**	**150**
Steel pipe L	13	22	**35**	17	12	**29**	**64**
Steel pipe M	29	79	**108**	67	35	**102**	**210**
Steel pipe S	78	122	**200**	138	34	**172**	**372**
Tube side heat exchanger	4	8	**12**	11	5	**16**	**28**
Total	**534**	**1053**	**1587**	**981**	**287**	**1268**	**2855**

Table 2.3 - Relevant process incidents fed through process systems for the period Q3 1992 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A. All equipment size categories of actuated and manual valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Process leaks fed through process system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Air-cooled heat exchanger	0	1	**1**	4	1	**5**	**6**
Atmospheric vessel	9	27	**36**	4	1	**5**	**41**
Centrifugal compressor	19	13	**32**	17	3	**20**	**52**
Centrifugal pump	16	59	**75**	45	13	**58**	**133**
Filter	12	31	**43**	8	0	**8**	**51**
Flexible pipe	13	24	**37**	8	6	**14**	**51**
Instrument	108	239	**347**	240	40	**280**	**627**
Pig trap	15	21	**36**	5	6	**11**	**47**
Plate heat exchanger	6	30	**36**	6	1	**7**	**43**
Process vessel	33	23	**56**	10	5	**15**	**71**
Reciprocating compressor	16	13	**29**	25	5	**30**	**59**
Reciprocating pump	2	9	**11**	5	2	**7**	**18**
S & T-side heat exchanger	8	19	**27**	20	7	**27**	**54**
Standard flange	62	118	**180**	134	37	**171**	**351**
Steel pipe	120	223	**343**	222	81	**303**	**646**
Valve	95	203	**298**	228	79	**307**	**605**
Total	534	1053	**1587**	981	287	**1268**	**2855**

2.2 Q1 2001 – Q1 2015

Table 2.4 - Relevant process incidents fed through process systems for the period Q1 2001 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Process leaks fed through process systems														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							Total
	pressure >0.01 barg			pressure <=0.01 barg			Total	pressure >0.01 barg			pressure <=0.01 barg			Total	
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Actuated valve L	13	0	4	0	0	0	**17**	3	0	4	0	0	0	**7**	**24**
Actuated valve M	36	0	11	0	0	0	**47**	9	0	21	0	0	0	**30**	**77**
Actuated valve S	60	0	10	0	0	0	**70**	9	0	28	0	0	0	**37**	**107**
Air cooled heat exchanger	4	0	0	0	0	0	**4**	0	0	0	0	0	0	**0**	**4**
Atmospheric vessel	3	1	4	0	2	0	**10**	1	4	11	0	6	3	**25**	**35**
Centrifugal compressor	12	1	13	0	0	0	**26**	2	0	8	0	0	0	**10**	**36**
Centrifugal pump	33	0	8	0	0	1	**42**	11	0	32	0	0	0	**43**	**85**
Filter	7	0	4	0	0	0	**11**	0	0	16	0	0	0	**16**	**27**
Flexible pipe	3	0	8	0	0	1	**12**	2	0	8	0	0	2	**12**	**24**
Instrument	174	0	57	1	0	3	**235**	16	1	106	0	0	1	**124**	**359**
Manual valve L	9	0	1	0	0	0	**10**	3	0	4	0	0	0	**7**	**17**
Manual valve M	14	0	3	0	0	0	**17**	8	0	4	0	0	0	**12**	**29**
Manual valve S	27	0	18	1	0	0	**46**	15	0	29	0	0	0	**44**	**90**
Pig trap	4	0	5	0	2	0	**11**	3	0	14	0	0	0	**17**	**28**
Plate heat exchanger	4	0	5	0	0	0	**9**	0	0	17	0	0	0	**17**	**26**
Process vessel	5	2	9	0	1	1	**18**	3	1	6	0	0	2	**12**	**30**
Reciprocating compressor	18	0	9	0	0	0	**27**	2	0	10	0	0	0	**12**	**39**
Reciprocating pump	4	0	2	0	0	0	**6**	2	0	4	0	0	0	**6**	**12**
Shell side heat exchanger	7	0	3	0	0	0	**10**	0	0	5	0	0	0	**5**	**15**
Standard flange L	9	0	1	0	0	1	**11**	2	0	4	0	0	0	**6**	**17**
Standard flange M	37	0	13	0	0	1	**51**	4	0	25	0	0	0	**29**	**80**
Standard flange S	27	0	11	0	0	2	**40**	4	0	18	0	0	0	**22**	**62**
Steel pipe L	10	0	3	0	0	2	**15**	9	0	14	1	0	0	**24**	**39**
Steel pipe M	41	0	15	0	0	0	**56**	18	0	42	0	0	2	**62**	**118**
Steel pipe S	84	1	27	0	0	2	**114**	20	0	66	0	0	1	**87**	**201**
Tube side heat exchanger	7	0	1	0	0	0	**8**	3	0	5	0	0	0	**8**	**16**
Total	**652**	**5**	**245**	**2**	**5**	**14**	**923**	**149**	**6**	**501**	**1**	**6**	**11**	**674**	**1597**

Table 2.5 - Relevant process incidents fed through process systems for the period Q1 2001 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Process leaks fed through process system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Actuated valve L	4	4	**8**	13	3	**16**	**24**
Actuated valve M	11	21	**32**	36	9	**45**	**77**
Actuated valve S	10	28	**38**	60	9	**69**	**107**
Air cooled heat exchanger	0	0	**0**	4	0	**4**	**4**
Atmospheric vessel	7	24	**31**	3	1	**4**	**35**
Centrifugal compressor	14	8	**22**	12	2	**14**	**36**
Centrifugal pump	9	32	**41**	33	11	**44**	**85**
Filter	4	16	**20**	7	0	**7**	**27**
Flexible pipe	9	10	**19**	3	2	**5**	**24**
Instrument	60	108	**168**	175	16	**191**	**359**
Manual valve L	1	4	**5**	9	3	**12**	**17**
Manual valve M	3	4	**7**	14	8	**22**	**29**
Manual valve S	18	29	**47**	28	15	**43**	**90**
Pig trap	7	14	**21**	4	3	**7**	**28**
Plate heat exchanger	5	17	**22**	4	0	**4**	**26**
Process vessel	13	9	**22**	5	3	**8**	**30**
Reciprocating compressor	9	10	**19**	18	2	**20**	**39**
Reciprocating pump	2	4	**6**	4	2	**6**	**12**
Shell side heat exchanger	3	5	**8**	7	0	**7**	**15**
Standard flange L	2	4	**6**	9	2	**11**	**17**
Standard flange M	14	25	**39**	37	4	**41**	**80**
Standard flange S	13	18	**31**	27	4	**31**	**62**
Steel pipe L	5	14	**19**	10	10	**20**	**39**
Steel pipe M	15	44	**59**	41	18	**59**	**118**
Steel pipe S	30	67	**97**	84	20	**104**	**201**
Tube side heat exchanger	1	5	**6**	7	3	**10**	**16**
Total	**269**	**524**	**793**	**654**	**150**	**804**	**1597**

Table 2.6 - Relevant process incidents fed through process systems for the period Q1 2001 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A. All equipment size categories of actuated and manual valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Process leaks fed through process system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significan t leak	Total	Total
Air-cooled heat exchanger	0	0	**0**	4	0	**4**	**4**
Atmospheric vessel	7	24	**31**	3	1	**4**	**35**
Centrifugal compressor	14	8	**22**	12	2	**14**	**36**
Centrifugal pump	9	32	**41**	33	11	**44**	**85**
Filter	4	16	**20**	7	0	**7**	**27**
Flexible pipe	9	10	**19**	3	2	**5**	**24**
Instrument	60	108	**168**	175	16	**191**	**359**
Pig trap	7	14	**21**	4	3	**7**	**28**
Plate heat exchanger	5	17	**22**	4	0	**4**	**26**
Process vessel	13	9	**22**	5	3	**8**	**30**
Reciprocating compressor	9	10	**19**	18	2	**20**	**39**
Reciprocating pump	2	4	**6**	4	2	**6**	**12**
S & T-side heat exchanger	4	10	**14**	14	3	**17**	**31**
Standard flange	29	47	**76**	73	10	**83**	**159**
Steel pipe	50	125	**175**	135	48	**183**	**358**
Valve	47	90	**137**	160	47	**207**	**344**
Total	269	524	**793**	654	150	**804**	**1597**

3 Relevant process leaks fed through utility system

3.1 Q3 1992 – Q1 2015

Table 3.1 - Relevant process incidents fed through utility systems for the period Q3 1992 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Process leaks fed through utility systems														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg				
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Actuated valve L	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Actuated valve M	1	0	2	0	0	0	**3**	0	0	3	0	0	0	**3**	**6**
Actuated valve S	0	0	2	0	0	1	**3**	0	1	0	0	0	0	**1**	**4**
Air cooled heat exchanger	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Atmospheric vessel	0	1	2	0	0	0	**3**	0	0	3	0	2	0	**5**	**8**
Centrifugal compressor	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Centrifugal pump	3	1	2	0	0	1	**7**	0	1	2	0	0	1	**4**	**11**
Filter	0	1	1	0	0	0	**2**	0	0	2	0	0	0	**2**	**4**
Flexible pipe	2	0	2	0	0	0	**4**	1	0	1	0	0	0	**2**	**6**
Instrument	5	0	4	0	0	0	**9**	1	0	5	0	0	1	**7**	**16**
Manual valve L	0	0	0	0	0	1	**1**	0	0	0	0	0	0	**0**	**1**
Manual valve M	1	0	1	0	0	0	**2**	0	1	0	0	0	1	**2**	**4**
Manual valve S	1	0	4	0	0	2	**7**	0	0	3	0	0	0	**3**	**10**
Pig trap	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Plate heat exchanger	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Process vessel	0	1	0	1	1	1	**4**	0	0	2	0	1	4	**7**	**11**
Reciprocating compressor	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Reciprocating pump	0	0	0	0	0	0	**0**	0	0	2	0	0	0	**2**	**2**
Shell side heat exchanger	0	0	0	0	0	0	**0**	0	0	1	0	0	0	**1**	**1**
Standard flange L	0	0	1	0	0	0	**1**	0	0	2	0	0	0	**2**	**3**
Standard flange M	2	0	8	1	0	0	**11**	0	0	2	0	0	0	**2**	**13**
Standard flange S	0	0	2	0	0	4	**6**	1	0	4	0	0	0	**5**	**11**
Steel pipe L	2	0	2	1	0	0	**5**	0	2	7	0	0	2	**11**	**16**
Steel pipe M	6	0	5	0	0	4	**15**	2	4	27	0	2	2	**37**	**52**
Steel pipe S	11	0	31	1	0	4	**47**	4	0	20	0	0	3	**27**	**74**
Tube side heat exchanger	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Total	**34**	**4**	**69**	**4**	**1**	**18**	**130**	**9**	**9**	**86**	**0**	**5**	**14**	**123**	**253**

Table 3.2 - Relevant process incidents fed through utility systems for the period Q3 1992 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Process leaks fed through utility systems						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Actuated valve L	0	0	**0**	0	0	**0**	**0**
Actuated valve M	2	3	**5**	1	0	**1**	**6**
Actuated valve S	3	1	**4**	0	0	**0**	**4**
Air cooled heat exchanger	0	0	**0**	0	0	**0**	**0**
Atmospheric vessel	3	5	**8**	0	0	**0**	**8**
Centrifugal compressor	0	0	**0**	0	0	**0**	**0**
Centrifugal pump	4	4	**8**	3	0	**3**	**11**
Filter	2	2	**4**	0	0	**0**	**4**
Flexible pipe	2	1	**3**	2	1	**3**	**6**
Instrument	4	6	**10**	5	1	**6**	**16**
Manual valve L	1	0	**1**	0	0	**0**	**1**
Manual valve M	1	2	**3**	1	0	**1**	**4**
Manual valve S	6	3	**9**	1	0	**1**	**10**
Pig trap	0	0	**0**	0	0	**0**	**0**
Plate heat exchanger	0	0	**0**	0	0	**0**	**0**
Process vessel	3	7	**10**	1	0	**1**	**11**
Reciprocating compressor	0	0	**0**	0	0	**0**	**0**
Reciprocating pump	0	2	**2**	0	0	**0**	**2**
Shell side heat exchanger	0	1	**1**	0	0	**0**	**1**
Standard flange L	1	2	**3**	0	0	**0**	**3**
Standard flange M	8	2	**10**	3	0	**3**	**13**
Standard flange S	6	4	**10**	0	1	**1**	**11**
Steel pipe L	2	11	**13**	3	0	**3**	**16**
Steel pipe M	9	35	**44**	6	2	**8**	**52**
Steel pipe S	35	23	**58**	12	4	**16**	**74**
Tube side heat exchanger	0	0	**0**	0	0	**0**	**0**
Total	**92**	**114**	**206**	**38**	**9**	**47**	**253**

Table 3.3 - Relevant process incidents fed through utility systems for the period Q3 1992 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A. All equipment size categories of actuated and manual valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Process leaks fed through utility system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			Total
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	
Air-cooled heat exchanger	0	0	**0**	0	0	**0**	**0**
Atmospheric vessel	3	5	**8**	0	0	**0**	**8**
Centrifugal compressor	0	0	**0**	0	0	**0**	**0**
Centrifugal pump	4	4	**8**	3	0	**3**	**11**
Filter	2	2	**4**	0	0	**0**	**4**
Flexible pipe	2	1	**3**	2	1	**3**	**6**
Instrument	4	6	**10**	5	1	**6**	**16**
Pig trap	0	0	**0**	0	0	**0**	**0**
Plate heat exchanger	0	0	**0**	0	0	**0**	**0**
Process vessel	3	7	**10**	1	0	**1**	**11**
Reciprocating compressor	0	0	**0**	0	0	**0**	**0**
Reciprocating pump	0	2	**2**	0	0	**0**	**2**
S & T-side heat exchanger	0	1	**1**	0	0	**0**	**1**
Standard flange	15	8	**23**	3	1	**4**	**27**
Steel pipe	46	69	**115**	21	6	**27**	**142**
Valve	13	9	**22**	3	0	**3**	**25**
Total	92	114	**206**	38	9	**47**	**253**

3.2 Q1 2001 – Q1 2015

Table 3.4 - Relevant process incidents fed through utility systems for the period Q1 2001 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Process leaks fed through utility systems														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg				
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Actuated valve L	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Actuated valve M	1	0	1	0	0	0	**2**	0	0	2	0	0	0	**2**	**4**
Actuated valve S	0	0	1	0	0	0	**1**	0	0	0	0	0	0	**0**	**1**
Air cooled heat exchanger	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Atmospheric vessel	0	1	2	0	0	0	**3**	0	0	3	0	2	0	**5**	**8**
Centrifugal compressor	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Centrifugal pump	1	1	1	0	0	1	**4**	0	0	2	0	0	0	**2**	**6**
Filter	0	1	1	0	0	0	**2**	0	0	2	0	0	0	**2**	**4**
Flexible pipe	2	0	2	0	0	0	**4**	1	0	0	0	0	0	**1**	**5**
Instrument	4	0	2	0	0	0	**6**	1	0	1	0	0	0	**2**	**8**
Manual valve L	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Manual valve M	1	0	1	0	0	0	**2**	0	0	0	0	0	0	**0**	**2**
Manual valve S	1	0	1	0	0	2	**4**	0	0	1	0	0	0	**1**	**5**
Pig trap	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Plate heat exchanger	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Process vessel	0	1	0	0	1	0	**2**	0	0	1	0	0	0	**1**	**3**
Reciprocating compressor	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Reciprocating pump	0	0	0	0	0	0	**0**	0	0	2	0	0	0	**2**	**2**
Shell side heat exchanger	0	0	0	0	0	0	**0**	0	0	1	0	0	0	**1**	**1**
Standard flange L	0	0	0	0	0	0	**0**	0	0	2	0	0	0	**2**	**2**
Standard flange M	1	0	4	0	0	0	**5**	0	0	1	0	0	0	**1**	**6**
Standard flange S	0	0	1	0	0	0	**1**	0	0	1	0	0	0	**1**	**2**
Steel pipe L	2	0	0	0	0	0	**2**	0	0	7	0	0	0	**7**	**9**
Steel pipe M	4	0	3	0	0	2	**9**	2	1	19	0	0	0	**22**	**31**
Steel pipe S	7	0	17	1	0	2	**27**	2	0	14	0	0	3	**19**	**46**
Tube side heat exchanger	0	0	0	0	0	0	**0**	0	0	0	0	0	0	**0**	**0**
Total	**24**	**4**	**37**	**1**	**1**	**7**	**74**	**6**	**1**	**59**	**0**	**2**	**3**	**71**	**145**

Table 3.5 - Relevant process incidents fed through utility systems for the period Q1 2001 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Process leaks fed through utility systems						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Actuated valve L	0	0	**0**	0	0	**0**	**0**
Actuated valve M	1	2	**3**	1	0	**1**	**4**
Actuated valve S	1	0	**1**	0	0	**0**	**1**
Air cooled heat exchanger	0	0	**0**	0	0	**0**	**0**
Atmospheric vessel	3	5	**8**	0	0	**0**	**8**
Centrifugal compressor	0	0	**0**	0	0	**0**	**0**
Centrifugal pump	3	2	**5**	1	0	**1**	**6**
Filter	2	2	**4**	0	0	**0**	**4**
Flexible pipe	2	0	**2**	2	1	**3**	**5**
Instrument	2	1	**3**	4	1	**5**	**8**
Manual valve L	0	0	**0**	0	0	**0**	**0**
Manual valve M	1	0	**1**	1	0	**1**	**2**
Manual valve S	3	1	**4**	1	0	**1**	**5**
Pig trap	0	0	**0**	0	0	**0**	**0**
Plate heat exchanger	0	0	**0**	0	0	**0**	**0**
Process vessel	2	1	**3**	0	0	**0**	**3**
Reciprocating compressor	0	0	**0**	0	0	**0**	**0**
Reciprocating pump	0	2	**2**	0	0	**0**	**2**
Shell side heat exchanger	0	1	**1**	0	0	**0**	**1**
Standard flange L	0	2	**2**	0	0	**0**	**2**
Standard flange M	4	1	**5**	1	0	**1**	**6**
Standard flange S	1	1	**2**	0	0	**0**	**2**
Steel pipe L	0	7	**7**	2	0	**2**	**9**
Steel pipe M	5	20	**25**	4	2	**6**	**31**
Steel pipe S	19	17	**36**	8	2	**10**	**46**
Tube side heat exchanger	0	0	**0**	0	0	**0**	**0**
Total	**49**	**65**	**114**	**25**	**6**	**31**	**145**

Table 3.6 - Relevant process incidents fed through utility systems for the period Q1 2001 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A. All equipment size categories of actuated and manual valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Process leaks fed through utility system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Air-cooled heat exchanger	0	0	**0**	0	0	**0**	**0**
Atmospheric vessel	3	5	**8**	0	0	**0**	**8**
Centrifugal compressor	0	0	**0**	0	0	**0**	**0**
Centrifugal pump	3	2	**5**	1	0	**1**	**6**
Filter	2	2	**4**	0	0	**0**	**4**
Flexible pipe	2	0	**2**	2	1	**3**	**5**
Instrument	2	1	**3**	4	1	**5**	**8**
Pig trap	0	0	**0**	0	0	**0**	**0**
Plate heat exchanger	0	0	**0**	0	0	**0**	**0**
Process vessel	2	1	**3**	0	0	**0**	**3**
Reciprocating compressor	0	0	**0**	0	0	**0**	**0**
Reciprocating pump	0	2	**2**	0	0	**0**	**2**
S & T-side heat exchanger	0	1	**1**	0	0	**0**	**1**
Standard flange	5	4	**9**	1	0	**1**	**10**
Steel pipe	24	44	**68**	14	4	**18**	**86**
Valve	6	3	**9**	3	0	**3**	**12**
Total	49	65	**114**	25	6	**31**	**145**

4 Relevant process leaks fed through process system or utility system

4.1 Q3 1992 – Q1 2015

Table 4.1 - Relevant process incidents fed through process or utility systems for the period Q3 1992 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Process leaks fed through process systems															
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg								
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg					
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Actuated valve L	15	0	6	0	0	0	**21**	8	0	6	0	0	0	**14**	**35**
Actuated valve M	56	0	19	0	0	1	**76**	19	0	51	0	1	2	**73**	**149**
Actuated valve S	77	2	26	0	0	2	**107**	16	2	56	0	0	0	**74**	**181**
Air cooled heat exchanger	4	0	0	0	0	0	**4**	1	0	1	0	0	0	**2**	**6**
Atmospheric vessel	4	3	7	0	2	0	**16**	1	4	17	0	8	3	**33**	**49**
Centrifugal compressor	17	1	16	0	0	2	**36**	3	0	12	0	1	0	**16**	**52**
Centrifugal pump	47	1	15	1	0	4	**68**	13	1	60	0	0	2	**76**	**144**
Filter	8	1	12	0	1	0	**22**	0	0	32	0	0	1	**33**	**55**
Flexible pipe	10	0	14	0	0	1	**25**	7	0	23	0	0	2	**32**	**57**
Instrument	243	1	102	2	1	8	**357**	41	2	239	0	1	3	**286**	**643**
Manual valve L	14	0	2	0	0	1	**17**	7	0	8	0	0	0	**15**	**32**
Manual valve M	25	0	7	0	0	0	**32**	13	1	22	0	0	4	**40**	**72**
Manual valve S	43	0	40	1	0	2	**86**	16	0	58	0	0	1	**75**	**161**
Pig trap	5	0	8	0	2	5	**20**	6	1	20	0	0	0	**27**	**47**
Plate heat exchanger	6	0	6	0	0	0	**12**	1	0	30	0	0	0	**31**	**43**
Process vessel	9	8	16	2	5	7	**47**	5	2	13	0	5	10	**35**	**82**
Reciprocating compressor	25	0	16	0	0	0	**41**	5	0	13	0	0	0	**18**	**59**
Reciprocating pump	5	0	2	0	0	0	**7**	2	0	11	0	0	0	**13**	**20**
Shell side heat exchanger	9	0	3	0	1	0	**13**	2	0	12	0	0	0	**14**	**27**
Standard flange L	12	0	5	0	1	2	**20**	7	0	17	0	0	0	**24**	**44**
Standard flange M	67	0	30	1	1	1	**100**	17	0	55	0	0	1	**73**	**173**
Standard flange S	56	0	30	1	0	7	**94**	14	0	52	0	0	1	**67**	**161**
Steel pipe L	18	1	9	2	0	5	**35**	11	2	28	1	0	3	**45**	**80**
Steel pipe M	72	0	30	1	1	7	**111**	37	4	101	0	2	7	**151**	**262**
Steel pipe S	147	1	100	3	0	12	**263**	38	1	137	0	0	7	**183**	**446**
Tube side heat exchanger	11	0	3	0	0	1	**15**	5	0	7	0	1	0	**13**	**28**
Total	**1005**	**19**	**524**	**14**	**15**	**68**	**1645**	**295**	**20**	**1081**	**1**	**19**	**47**	**1463**	**3108**

Table 4.2 - Relevant process incidents fed through process or utility systems for the period Q3 1992 - Q1 2015. The frequencies are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Process leaks						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Actuated valve L	6	6	**12**	15	8	**23**	**35**
Actuated valve M	20	54	**74**	56	19	**75**	**149**
Actuated valve S	30	58	**88**	77	16	**93**	**181**
Air cooled heat exchanger	0	1	**1**	4	1	**5**	**6**
Atmospheric vessel	12	32	**44**	4	1	**5**	**49**
Centrifugal compressor	19	13	**32**	17	3	**20**	**52**
Centrifugal pump	20	63	**83**	48	13	**61**	**144**
Filter	14	33	**47**	8	0	**8**	**55**
Flexible pipe	15	25	**40**	10	7	**17**	**57**
Instrument	112	245	**357**	245	41	**286**	**643**
Manual valve L	3	8	**11**	14	7	**21**	**32**
Manual valve M	7	27	**34**	25	13	**38**	**72**
Manual valve S	42	59	**101**	44	16	**60**	**161**
Pig trap	15	21	**36**	5	6	**11**	**47**
Plate heat exchanger	6	30	**36**	6	1	**7**	**43**
Process vessel	36	30	**66**	11	5	**16**	**82**
Reciprocating compressor	16	13	**29**	25	5	**30**	**59**
Reciprocating pump	2	11	**13**	5	2	**7**	**20**
Shell side heat exchanger	4	12	**16**	9	2	**11**	**27**
Standard flange L	8	17	**25**	12	7	**19**	**44**
Standard flange M	32	56	**88**	68	17	**85**	**173**
Standard flange S	37	53	**90**	57	14	**71**	**161**
Steel pipe L	15	33	**48**	20	12	**32**	**80**
Steel pipe M	38	114	**152**	73	37	**110**	**262**
Steel pipe S	113	145	**258**	150	38	**188**	**446**
Tube side heat exchanger	4	8	**12**	11	5	**16**	**28**
Total	**626**	**1167**	**1793**	**1019**	**296**	**1315**	**3108**

Table 4.3 - Relevant process incidents fed through process or utility systems for the period Q3 1992 - Q1 2015. The frequencies are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A. All equipment size categories of valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Process leaks fed through process system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Air-cooled heat exchanger	0	1	**1**	4	1	**5**	**6**
Atmospheric vessel	12	32	**44**	4	1	**5**	**49**
Centrifugal compressor	19	13	**32**	17	3	**20**	**52**
Centrifugal pump	20	63	**83**	48	13	**61**	**144**
Filter	14	33	**47**	8	0	**8**	**55**
Flexible pipe	15	25	**40**	10	7	**17**	**57**
Instrument	112	245	**357**	245	41	**286**	**643**
Pig trap	15	21	**36**	5	6	**11**	**47**
Plate heat exchanger	6	30	**36**	6	1	**7**	**43**
Process vessel	36	30	**66**	11	5	**16**	**82**
Reciprocating compressor	16	13	**29**	25	5	**30**	**59**
Reciprocating pump	2	11	**13**	5	2	**7**	**20**
S & T-side heat exchanger	8	20	**28**	20	7	**27**	**55**
Standard flange	77	126	**203**	137	38	**175**	**378**
Steel pipe	166	292	**458**	243	87	**330**	**788**
Valve	108	212	**320**	231	79	**310**	**630**
Total	626	1167	**1793**	1019	296	**1315**	**3108**

4.2 Q1 2001 – Q1 2015

Table 4.4 - Relevant process incidents fed through process or utility systems for the period Q1 2001 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Process leaks fed through process systems														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg				
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Actuated valve L	13	0	4	0	0	0	**17**	3	0	4	0	0	0	**7**	**24**
Actuated valve M	37	0	12	0	0	0	**49**	9	0	23	0	0	0	**32**	**81**
Actuated valve S	60	0	11	0	0	0	**71**	9	0	28	0	0	0	**37**	**108**
Air cooled heat exchanger	4	0	0	0	0	0	**4**	0	0	0	0	0	0	**0**	**4**
Atmospheric vessel	3	2	6	0	2	0	**13**	1	4	14	0	8	3	**30**	**43**
Centrifugal compressor	12	1	13	0	0	0	**26**	2	0	8	0	0	0	**10**	**36**
Centrifugal pump	34	1	9	0	0	2	**46**	11	0	34	0	0	0	**45**	**91**
Filter	7	1	5	0	0	0	**13**	0	0	18	0	0	0	**18**	**31**
Flexible pipe	5	0	10	0	0	1	**16**	3	0	8	0	0	2	**13**	**29**
Instrument	178	0	59	1	0	3	**241**	17	1	107	0	0	1	**126**	**367**
Manual valve L	9	0	1	0	0	0	**10**	3	0	4	0	0	0	**7**	**17**
Manual valve M	15	0	4	0	0	0	**19**	8	0	4	0	0	0	**12**	**31**
Manual valve S	28	0	19	1	0	2	**50**	15	0	30	0	0	0	**45**	**95**
Pig trap	4	0	5	0	2	0	**11**	3	0	14	0	0	0	**17**	**28**
Plate heat exchanger	4	0	5	0	0	0	**9**	0	0	17	0	0	0	**17**	**26**
Process vessel	5	3	9	0	2	1	**20**	3	1	7	0	0	2	**13**	**33**
Reciprocating compressor	18	0	9	0	0	0	**27**	2	0	10	0	0	0	**12**	**39**
Reciprocating pump	4	0	2	0	0	0	**6**	2	0	6	0	0	0	**8**	**14**
Shell side heat exchanger	7	0	3	0	0	0	**10**	0	0	6	0	0	0	**6**	**16**
Standard flange L	9	0	1	0	0	1	**11**	2	0	6	0	0	0	**8**	**19**
Standard flange M	38	0	17	0	0	1	**56**	4	0	26	0	0	0	**30**	**86**
Standard flange S	27	0	12	0	0	2	**41**	4	0	19	0	0	0	**23**	**64**
Steel pipe L	12	0	3	0	0	2	**17**	9	0	21	1	0	0	**31**	**48**
Steel pipe M	45	0	18	0	0	2	**65**	20	1	61	0	0	2	**84**	**149**
Steel pipe S	91	1	44	1	0	4	**141**	22	0	80	0	0	4	**106**	**247**
Tube side heat exchanger	7	0	1	0	0	0	**8**	3	0	5	0	0	0	**8**	**16**
Total	**676**	**9**	**282**	**3**	**6**	**21**	**997**	**155**	**7**	**560**	**1**	**8**	**14**	**745**	**1742**

Table 4.5 - Relevant process incidents fed through process or utility systems for the period Q1 2001 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Process leaks						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Actuated valve L	4	4	**8**	13	3	**16**	**24**
Actuated valve M	12	23	**35**	37	9	**46**	**81**
Actuated valve S	11	28	**39**	60	9	**69**	**108**
Air cooled heat exchanger	0	0	**0**	4	0	**4**	**4**
Atmospheric vessel	10	29	**39**	3	1	**4**	**43**
Centrifugal compressor	14	8	**22**	12	2	**14**	**36**
Centrifugal pump	12	34	**46**	34	11	**45**	**91**
Filter	6	18	**24**	7	0	**7**	**31**
Flexible pipe	11	10	**21**	5	3	**8**	**29**
Instrument	62	109	**171**	179	17	**196**	**367**
Manual valve L	1	4	**5**	9	3	**12**	**17**
Manual valve M	4	4	**8**	15	8	**23**	**31**
Manual valve S	21	30	**51**	29	15	**44**	**95**
Pig trap	7	14	**21**	4	3	**7**	**28**
Plate heat exchanger	5	17	**22**	4	0	**4**	**26**
Process vessel	15	10	**25**	5	3	**8**	**33**
Reciprocating compressor	9	10	**19**	18	2	**20**	**39**
Reciprocating pump	2	6	**8**	4	2	**6**	**14**
Shell side heat exchanger	3	6	**9**	7	0	**7**	**16**
Standard flange L	2	6	**8**	9	2	**11**	**19**
Standard flange M	18	26	**44**	38	4	**42**	**86**
Standard flange S	14	19	**33**	27	4	**31**	**64**
Steel pipe L	5	21	**26**	12	10	**22**	**48**
Steel pipe M	20	64	**84**	45	20	**65**	**149**
Steel pipe S	49	84	**133**	92	22	**114**	**247**
Tube side heat exchanger	1	5	**6**	7	3	**10**	**16**
Total	**318**	**589**	**907**	**679**	**156**	**835**	**1742**

Table 4.6 - Relevant process incidents fed through process or utility systems for the period Q1 2001 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A. All equipment size categories of actuated valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Process leaks fed through process system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			Total
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	
Air-cooled heat exchanger	0	0	**0**	4	0	**4**	**4**
Atmospheric vessel	10	29	**39**	3	1	**4**	**43**
Centrifugal compressor	14	8	**22**	12	2	**14**	**36**
Centrifugal pump	12	34	**46**	34	11	**45**	**91**
Filter	6	18	**24**	7	0	**7**	**31**
Flexible pipe	11	10	**21**	5	3	**8**	**29**
Instrument	62	109	**171**	179	17	**196**	**367**
Pig trap	7	14	**21**	4	3	**7**	**28**
Plate heat exchanger	5	17	**22**	4	0	**4**	**26**
Process vessel	15	10	**25**	5	3	**8**	**33**
Reciprocating compressor	9	10	**19**	18	2	**20**	**39**
Reciprocating pump	2	6	**8**	4	2	**6**	**14**
S & T-side heat exchanger	4	11	**15**	14	3	**17**	**32**
Standard flange	34	51	**85**	74	10	**84**	**169**
Steel pipe	74	169	**243**	149	52	**201**	**444**
Valve	53	93	**146**	163	47	**210**	**356**
Total	318	589	**907**	679	156	**835**	**1742**

5 Relevant leaks from well system

5.1 Q3 1992 – Q1 2015

Table 5.1 - Relevant incidents from well systems for the period Q3 1992 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Leaks from well system														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg				
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Gas lift well	5	0	1	0	0	0	**6**	4	0	7	0	0	0	**11**	**17**
Producing well	27	1	13	0	0	3	**44**	16	0	23	0	0	0	**39**	**83**
Total	**32**	**1**	**14**	**0**	**0**	**3**	**50**	**20**	**0**	**30**	**0**	**0**	**0**	**50**	**100**

Table 5.2 - Relevant process from well systems for the period Q3 1992 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Leaks from well system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Gas lift well	1	7	**8**	5	4	**9**	**17**
Producing well	17	23	**40**	27	16	**43**	**83**
Total	18	30	**48**	32	20	**52**	**100**

5.2 Q1 2001 – Q1 2015

Table 5.3 - Relevant incidents from well systems for the period Q1 2001 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Leaks from well system														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg				
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Gas lift well	4	0	1	0	0	0	**5**	3	0	1	0	0	0	**4**	**9**
Producing well	17	1	6	0	0	0	**24**	4	0	1	0	0	0	**5**	**29**
Total	**21**	**1**	**7**	**0**	**0**	**0**	**29**	**7**	**0**	**2**	**0**	**0**	**0**	**9**	**38**

Table 5.4 - Relevant process from well systems for the period Q1 2001 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Leaks from well system						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Gas lift well	1	1	**2**	4	3	**7**	**9**
Producing well	7	1	**8**	17	4	**21**	**29**
Total	8	2	**10**	21	7	**28**	**38**

6 Exposure data

6.1 Process equipment

Table 6.1 - Exposure data for process equipment as part of process systems

Equipment	Exposure time 1992-2015	Exposure time 2001-2015
Actuated valve L	35817	23422
Actuated valve M	204544	131946
Actuated valve S	220135	141045
Air cooled heat exchanger	1765	1155
Atmospheric vessel	5330	3389
Centrifugal compressor	4612	3010
Centrifugal pump	12132	7763
Filter	12531	8043
Flexible pipe	218821	141369
Instrument	1095233	712228
Manual valve L	60481	39286
Manual valve M	527685	339613
Manual valve S	1945651	1269408
Pig trap	5959	3875
Plate heat exchanger	4658	3133
Process vessel	29335	18898
Reciprocating compressor	767	524
Reciprocating pump	2273	1422
Shell side heat exchanger	4633	2921
Standard flange L	262895	171462
Standard flange M	1542416	995898
Standard flange S	2794860	1824460
Steel pipe L	1294334	838355
Steel pipe M	3848915	2462765
Steel pipe S	2748817	1767201
Tube side heat exchanger	9059	5834
Total	**16893657**	**10918425**

Table 6.2 - Exposure data for process equipment as part of process systems. All equipment size categories of actuated and manual valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Exposure time	
Equipment	1992-2015	2001-2015
Air-cooled heat exchanger	1765	1155
Atmospheric vessel	5330	3389
Centrifugal compressor	4612	3010
Centrifugal pump	12132	7763
Filter	12531	8043
Flexible pipe	218821	141369
Instrument	1095233	712228
Pig trap	5959	3875
Plate heat exchanger	4658	3133
Process vessel	29335	18898
Reciprocating compressor	767	524
Reciprocating pump	2273	1422
S & T-side heat exchanger	13692	8755
Standard flange	4600170	2991820
Steel pipe	7892066	5068321
Valve	2994313	1944720
Total	**16893657**	**10918425**

6.2 Well head

Table 6.3 - Exposure data for well heads

	Exposure time	
Equipment	1992-2015	2001-2015
Gas injection wellhead	1146	750
Gas production wellhead	13432	8887
Oil production wellhead	11906	7030
Other wellhead	1597	1003

7 Estimated leak frequencies based on HCRD

7.1 Q3 1992 – Q1 2015

Table 7.1 - Estimated process leak frequency based on HCRD for the period Q3 1992 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Process leaks														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg				
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Actuated valve L	4.2E-04	0.0E+00	1.7E-04	0.0E+00	0.0E+00	0.0E+00	**5.9E-04**	2.2E-04	0.0E+00	1.7E-04	0.0E+00	0.0E+00	0.0E+00	**3.9E-04**	**9.8E-04**
Actuated valve M	2.7E-04	0.0E+00	9.3E-05	0.0E+00	0.0E+00	4.9E-06	**3.7E-04**	9.3E-05	0.0E+00	2.5E-04	0.0E+00	4.9E-06	9.8E-06	**3.6E-04**	**7.3E-04**
Actuated valve S	3.5E-04	9.1E-06	1.2E-04	0.0E+00	0.0E+00	9.1E-06	**4.9E-04**	7.3E-05	9.1E-06	2.5E-04	0.0E+00	0.0E+00	0.0E+00	**3.4E-04**	**8.2E-04**
Air cooled heat exchanger	2.3E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**2.3E-03**	5.7E-04	0.0E+00	5.7E-04	0.0E+00	0.0E+00	0.0E+00	**1.1E-03**	**3.4E-03**
Atmospheric vessel	7.5E-04	5.6E-04	1.3E-03	0.0E+00	3.8E-04	0.0E+00	**3.0E-03**	1.9E-04	7.5E-04	3.2E-03	0.0E+00	1.5E-03	5.6E-04	**6.2E-03**	**9.2E-03**
Centrifugal compressor	3.7E-03	2.2E-04	3.5E-03	0.0E+00	0.0E+00	4.3E-04	**7.8E-03**	6.5E-04	0.0E+00	2.6E-03	0.0E+00	2.2E-04	0.0E+00	**3.5E-03**	**1.1E-02**
Centrifugal pump	3.9E-03	8.2E-05	1.2E-03	8.2E-05	0.0E+00	3.3E-04	**5.6E-03**	1.1E-03	8.2E-05	4.9E-03	0.0E+00	0.0E+00	1.6E-04	**6.3E-03**	**1.2E-02**
Filter	6.4E-04	8.0E-05	9.6E-04	0.0E+00	8.0E-05	0.0E+00	**1.8E-03**	0.0E+00	0.0E+00	2.6E-03	0.0E+00	0.0E+00	8.0E-05	**2.6E-03**	**4.4E-03**
Flexible pipe	4.6E-05	0.0E+00	6.4E-05	0.0E+00	0.0E+00	4.6E-06	**1.1E-04**	3.2E-05	0.0E+00	1.1E-04	0.0E+00	0.0E+00	9.1E-06	**1.5E-04**	**2.6E-04**
Instrument	2.2E-04	9.1E-07	9.3E-05	1.8E-06	9.1E-07	7.3E-06	**3.3E-04**	3.7E-05	1.8E-06	2.2E-04	0.0E+00	9.1E-07	2.7E-06	**2.6E-04**	**5.9E-04**
Manual valve L	2.3E-04	0.0E+00	3.3E-05	0.0E+00	0.0E+00	1.7E-05	**2.8E-04**	1.2E-04	0.0E+00	1.3E-04	0.0E+00	0.0E+00	0.0E+00	**2.5E-04**	**5.3E-04**
Manual valve M	4.7E-05	0.0E+00	1.3E-05	0.0E+00	0.0E+00	0.0E+00	**6.1E-05**	2.5E-05	1.9E-06	4.2E-05	0.0E+00	0.0E+00	7.6E-06	**7.6E-05**	**1.4E-04**
Manual valve S	2.2E-05	0.0E+00	2.1E-05	5.1E-07	0.0E+00	1.0E-06	**4.4E-05**	8.2E-06	0.0E+00	3.0E-05	0.0E+00	0.0E+00	5.1E-07	**3.9E-05**	**8.3E-05**
Pig trap	8.4E-04	0.0E+00	1.3E-03	0.0E+00	3.4E-04	8.4E-04	**3.4E-03**	1.0E-03	1.7E-04	3.4E-03	0.0E+00	0.0E+00	0.0E+00	**4.5E-03**	**7.9E-03**
Plate heat exchanger	1.3E-03	0.0E+00	1.3E-03	0.0E+00	0.0E+00	0.0E+00	**2.6E-03**	2.1E-04	0.0E+00	6.4E-03	0.0E+00	0.0E+00	0.0E+00	**6.7E-03**	**9.2E-03**
Process vessel	3.1E-04	2.7E-04	5.5E-04	6.8E-05	1.7E-04	2.4E-04	**1.6E-03**	1.7E-04	6.8E-05	4.4E-04	0.0E+00	1.7E-04	3.4E-04	**1.2E-03**	**2.8E-03**
Reciprocating compressor	3.3E-02	0.0E+00	2.1E-02	0.0E+00	0.0E+00	0.0E+00	**5.3E-02**	6.5E-03	0.0E+00	1.7E-02	0.0E+00	0.0E+00	0.0E+00	**2.3E-02**	**7.7E-02**
Reciprocating pump	2.2E-03	0.0E+00	8.8E-04	0.0E+00	0.0E+00	0.0E+00	**3.1E-03**	8.8E-04	0.0E+00	4.8E-03	0.0E+00	0.0E+00	0.0E+00	**5.7E-03**	**8.8E-03**
Shell side heat exchanger	1.9E-03	0.0E+00	6.5E-04	0.0E+00	2.2E-04	0.0E+00	**2.8E-03**	4.3E-04	0.0E+00	2.6E-03	0.0E+00	0.0E+00	0.0E+00	**3.0E-03**	**5.8E-03**
Standard flange L	4.6E-05	0.0E+00	1.9E-05	0.0E+00	3.8E-06	7.6E-06	**7.6E-05**	2.7E-05	0.0E+00	6.5E-05	0.0E+00	0.0E+00	0.0E+00	**9.1E-05**	**1.7E-04**
Standard flange M	4.3E-05	0.0E+00	1.9E-05	6.5E-07	6.5E-07	6.5E-07	**6.5E-05**	1.1E-05	0.0E+00	3.6E-05	0.0E+00	0.0E+00	6.5E-07	**4.7E-05**	**1.1E-04**
Standard flange S	2.0E-05	0.0E+00	1.1E-05	3.6E-07	0.0E+00	2.5E-06	**3.4E-05**	5.0E-06	0.0E+00	1.9E-05	0.0E+00	0.0E+00	3.6E-07	**2.4E-05**	**5.8E-05**
Steel pipe L	1.4E-05	7.7E-07	7.0E-06	1.5E-06	0.0E+00	3.9E-06	**2.7E-05**	8.5E-06	1.5E-06	2.2E-05	7.7E-07	0.0E+00	2.3E-06	**3.5E-05**	**6.2E-05**
Steel pipe M	1.9E-05	0.0E+00	7.8E-06	2.6E-07	2.6E-07	1.8E-06	**2.9E-05**	9.6E-06	1.0E-06	2.6E-05	0.0E+00	5.2E-07	1.8E-06	**3.9E-05**	**6.8E-05**
Steel pipe S	5.3E-05	3.6E-07	3.6E-05	1.1E-06	0.0E+00	4.4E-06	**9.6E-05**	1.4E-05	3.6E-07	5.0E-05	0.0E+00	0.0E+00	2.5E-06	**6.7E-05**	**1.6E-04**
Tube side heat exchanger	1.2E-03	0.0E+00	3.3E-04	0.0E+00	0.0E+00	1.1E-04	**1.7E-03**	5.5E-04	0.0E+00	7.7E-04	0.0E+00	1.1E-04	0.0E+00	**1.4E-03**	**3.1E-03**
Gas lift well	8.4E-04	0.0E+00	1.7E-04	0.0E+00	0.0E+00	0.0E+00	**1.0E-03**	6.7E-04	0.0E+00	1.2E-03	0.0E+00	0.0E+00	0.0E+00	**1.8E-03**	**2.9E-03**
Producing well	9.6E-04	3.6E-05	4.6E-04	0.0E+00	0.0E+00	1.1E-04	**1.6E-03**	5.7E-04	0.0E+00	8.2E-04	0.0E+00	0.0E+00	0.0E+00	**1.4E-03**	**3.0E-03**
Total	**5.5E-02**	**1.3E-03**	**3.4E-02**	**1.6E-04**	**1.2E-03**	**2.1E-03**	**9.4E-02**	**1.4E-02**	**1.1E-03**	**5.3E-02**	**7.7E-07**	**2.0E-03**	**1.2E-03**	**7.1E-02**	**1.7E-01**

Table 7.2 - Estimated process leak frequency based on HCRD for the period Q3 1992 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Leak frequency estimated based in HCRD						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Actuated valve L	1.7E-04	1.7E-04	**3.4E-04**	4.2E-04	2.2E-04	**6.4E-04**	**9.8E-04**
Actuated valve M	9.8E-05	2.6E-04	**3.6E-04**	2.7E-04	9.3E-05	**3.7E-04**	**7.3E-04**
Actuated valve S	1.4E-04	2.6E-04	**4.0E-04**	3.5E-04	7.3E-05	**4.2E-04**	**8.2E-04**
Air cooled heat exchanger	0.0E+00	5.7E-04	**5.7E-04**	2.3E-03	5.7E-04	**2.8E-03**	**3.4E-03**
Atmospheric vessel	2.3E-03	6.0E-03	**8.3E-03**	7.5E-04	1.9E-04	**9.4E-04**	**9.2E-03**
Centrifugal compressor	4.1E-03	2.8E-03	**6.9E-03**	3.7E-03	6.5E-04	**4.3E-03**	**1.1E-02**
Centrifugal pump	1.6E-03	5.2E-03	**6.8E-03**	4.0E-03	1.1E-03	**5.0E-03**	**1.2E-02**
Filter	1.1E-03	2.6E-03	**3.8E-03**	6.4E-04	0.0E+00	**6.4E-04**	**4.4E-03**
Flexible pipe	6.9E-05	1.1E-04	**1.8E-04**	4.6E-05	3.2E-05	**7.8E-05**	**2.6E-04**
Instrument	1.0E-04	2.2E-04	**3.3E-04**	2.2E-04	3.7E-05	**2.6E-04**	**5.9E-04**
Manual valve L	5.0E-05	1.3E-04	**1.8E-04**	2.3E-04	1.2E-04	**3.5E-04**	**5.3E-04**
Manual valve M	1.3E-05	5.1E-05	**6.4E-05**	4.7E-05	2.5E-05	**7.2E-05**	**1.4E-04**
Manual valve S	2.2E-05	3.0E-05	**5.2E-05**	2.3E-05	8.2E-06	**3.1E-05**	**8.3E-05**
Pig trap	2.5E-03	3.5E-03	**6.0E-03**	8.4E-04	1.0E-03	**1.8E-03**	**7.9E-03**
Plate heat exchanger	1.3E-03	6.4E-03	**7.7E-03**	1.3E-03	2.1E-04	**1.5E-03**	**9.2E-03**
Process vessel	1.2E-03	1.0E-03	**2.2E-03**	3.7E-04	1.7E-04	**5.5E-04**	**2.8E-03**
Reciprocating compressor	2.1E-02	1.7E-02	**3.8E-02**	3.3E-02	6.5E-03	**3.9E-02**	**7.7E-02**
Reciprocating pump	8.8E-04	4.8E-03	**5.7E-03**	2.2E-03	8.8E-04	**3.1E-03**	**8.8E-03**
Shell side heat exchanger	8.6E-04	2.6E-03	**3.5E-03**	1.9E-03	4.3E-04	**2.4E-03**	**5.8E-03**
Standard flange L	3.0E-05	6.5E-05	**9.5E-05**	4.6E-05	2.7E-05	**7.2E-05**	**1.7E-04**
Standard flange M	2.1E-05	3.6E-05	**5.7E-05**	4.4E-05	1.1E-05	**5.5E-05**	**1.1E-04**
Standard flange S	1.3E-05	1.9E-05	**3.2E-05**	2.0E-05	5.0E-06	**2.5E-05**	**5.8E-05**
Steel pipe L	1.2E-05	2.5E-05	**3.7E-05**	1.5E-05	9.3E-06	**2.5E-05**	**6.2E-05**
Steel pipe M	9.9E-06	3.0E-05	**3.9E-05**	1.9E-05	9.6E-06	**2.9E-05**	**6.8E-05**
Steel pipe S	4.1E-05	5.3E-05	**9.4E-05**	5.5E-05	1.4E-05	**6.8E-05**	**1.6E-04**
Tube side heat exchanger	4.4E-04	8.8E-04	**1.3E-03**	1.2E-03	5.5E-04	**1.8E-03**	**3.1E-03**
Gas lift well	1.7E-04	1.2E-03	**1.3E-03**	8.4E-04	6.7E-04	**1.5E-03**	**2.9E-03**
Producing well	6.1E-04	8.2E-04	**1.4E-03**	9.6E-04	5.7E-04	**1.5E-03**	**3.0E-03**
Total	**3.9E-02**	**5.7E-02**	**9.6E-02**	**5.5E-02**	**1.4E-02**	**7.0E-02**	**1.7E-01**

Table 7.3 - Estimated process leak frequency based on HCRD for the period Q3 1992 - Q1 2015. The frequencies are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A. All equipment size categories of actuated and manual valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Leak frequency estimated based in HCRD						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Air-cooled heat exchanger	0.0E+00	5.7E-04	**5.7E-04**	2.3E-03	5.7E-04	**2.8E-03**	**3.4E-03**
Atmospheric vessel	2.3E-03	6.0E-03	**8.3E-03**	7.5E-04	1.9E-04	**9.4E-04**	**9.2E-03**
Centrifugal compressor	4.1E-03	2.8E-03	**6.9E-03**	3.7E-03	6.5E-04	**4.3E-03**	**1.1E-02**
Centrifugal pump	1.6E-03	5.2E-03	**6.8E-03**	4.0E-03	1.1E-03	**5.0E-03**	**1.2E-02**
Filter	1.1E-03	2.6E-03	**3.8E-03**	6.4E-04	0.0E+00	**6.4E-04**	**4.4E-03**
Flexible pipe	6.9E-05	1.1E-04	**1.8E-04**	4.6E-05	3.2E-05	**7.8E-05**	**2.6E-04**
Instrument	1.0E-04	2.2E-04	**3.3E-04**	2.2E-04	3.7E-05	**2.6E-04**	**5.9E-04**
Pig trap	2.5E-03	3.5E-03	**6.0E-03**	8.4E-04	1.0E-03	**1.8E-03**	**7.9E-03**
Plate heat exchanger	1.3E-03	6.4E-03	**7.7E-03**	1.3E-03	2.1E-04	**1.5E-03**	**9.2E-03**
Process vessel	1.2E-03	1.0E-03	**2.2E-03**	3.7E-04	1.7E-04	**5.5E-04**	**2.8E-03**
Reciprocating compressor	2.1E-02	1.7E-02	**3.8E-02**	3.3E-02	6.5E-03	**3.9E-02**	**7.7E-02**
Reciprocating pump	8.8E-04	4.8E-03	**5.7E-03**	2.2E-03	8.8E-04	**3.1E-03**	**8.8E-03**
S & T-side heat exchanger	5.8E-04	1.5E-03	**2.0E-03**	1.5E-03	5.1E-04	**2.0E-03**	**4.0E-03**
Standard flange	1.7E-05	2.7E-05	**4.4E-05**	3.0E-05	8.3E-06	**3.8E-05**	**8.2E-05**
Steel pipe	2.1E-05	3.7E-05	**5.8E-05**	3.1E-05	1.1E-05	**4.2E-05**	**1.0E-04**
Valve	3.6E-05	7.1E-05	**1.1E-04**	7.7E-05	2.6E-05	**1.0E-04**	**2.1E-04**
Gas lift well	1.7E-04	1.2E-03	**1.3E-03**	8.4E-04	6.7E-04	**1.5E-03**	**2.9E-03**
Producing well	6.1E-04	8.2E-04	**1.4E-03**	9.6E-04	5.7E-04	**1.5E-03**	**3.0E-03**
Total	**3.8E-05**	**7.1E-05**	**1.1E-04**	**6.2E-05**	**1.9E-05**	**8.1E-05**	**1.9E-04**

7.2 Q1 2001 – Q1 2015

Table 7.4 - Estimated process leak frequency based on HCRD for the period Q1 2001 - Q1 2015. It is distinguished on leaked quantity, initial pressure, and on hole sizes ≤1 mm, >1 mm and hole sizes recorded as N/A

	Leak frequency estimated based in HCRD														
	Total leaked quantity <= 10 kg							Total leaked quantity > 10 kg							
	pressure >0.01 barg			pressure <=0.01 barg				pressure >0.01 barg			pressure <=0.01 barg				
Equipment	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Hole size <=1 mm	Hole size N/A	Hole size > 1mm	Total	Total
Actuated valve L	5.6E-04	0.0E+00	1.7E-04	0.0E+00	0.0E+00	0.0E+00	**7.3E-04**	1.3E-04	0.0E+00	1.7E-04	0.0E+00	0.0E+00	0.0E+00	**3.0E-04**	**1.0E-03**
Actuated valve M	2.8E-04	0.0E+00	9.1E-05	0.0E+00	0.0E+00	0.0E+00	**3.7E-04**	6.8E-05	0.0E+00	1.7E-04	0.0E+00	0.0E+00	0.0E+00	**2.4E-04**	**6.1E-04**
Actuated valve S	4.3E-04	0.0E+00	7.8E-05	0.0E+00	0.0E+00	0.0E+00	**5.0E-04**	6.4E-05	0.0E+00	2.0E-04	0.0E+00	0.0E+00	0.0E+00	**2.6E-04**	**7.7E-04**
Air cooled heat exchanger	3.5E-03	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**3.5E-03**	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**0.0E+00**	**3.5E-03**
Atmospheric vessel	8.9E-04	5.9E-04	1.8E-03	0.0E+00	5.9E-04	0.0E+00	**3.8E-03**	3.0E-04	1.2E-03	4.1E-03	0.0E+00	2.4E-03	8.9E-04	**8.9E-03**	**1.3E-02**
Centrifugal compressor	4.0E-03	3.3E-04	4.3E-03	0.0E+00	0.0E+00	0.0E+00	**8.6E-03**	6.6E-04	0.0E+00	2.7E-03	0.0E+00	0.0E+00	0.0E+00	**3.3E-03**	**1.2E-02**
Centrifugal pump	4.4E-03	1.3E-04	1.2E-03	0.0E+00	0.0E+00	2.6E-04	**5.9E-03**	1.4E-03	0.0E+00	4.4E-03	0.0E+00	0.0E+00	0.0E+00	**5.8E-03**	**1.2E-02**
Filter	8.7E-04	1.2E-04	6.2E-04	0.0E+00	0.0E+00	0.0E+00	**1.6E-03**	0.0E+00	0.0E+00	2.2E-03	0.0E+00	0.0E+00	0.0E+00	**2.2E-03**	**3.9E-03**
Flexible pipe	3.5E-05	0.0E+00	7.1E-05	0.0E+00	0.0E+00	7.1E-06	**1.1E-04**	2.1E-05	0.0E+00	5.7E-05	0.0E+00	0.0E+00	1.4E-05	**9.2E-05**	**2.1E-04**
Instrument	2.5E-04	0.0E+00	8.3E-05	1.4E-06	0.0E+00	4.2E-06	**3.4E-04**	2.4E-05	1.4E-06	1.5E-04	0.0E+00	0.0E+00	1.4E-06	**1.8E-04**	**5.2E-04**
Manual valve L	2.3E-04	0.0E+00	2.5E-05	0.0E+00	0.0E+00	0.0E+00	**2.5E-04**	7.6E-05	0.0E+00	1.0E-04	0.0E+00	0.0E+00	0.0E+00	**1.8E-04**	**4.3E-04**
Manual valve M	4.4E-05	0.0E+00	1.2E-05	0.0E+00	0.0E+00	0.0E+00	**5.6E-05**	2.4E-05	0.0E+00	1.2E-05	0.0E+00	0.0E+00	0.0E+00	**3.5E-05**	**9.1E-05**
Manual valve S	2.2E-05	0.0E+00	1.5E-05	7.9E-07	0.0E+00	1.6E-06	**3.9E-05**	1.2E-05	0.0E+00	2.4E-05	0.0E+00	0.0E+00	0.0E+00	**3.5E-05**	**7.5E-05**
Pig trap	1.0E-03	0.0E+00	1.3E-03	0.0E+00	5.2E-04	0.0E+00	**2.8E-03**	7.7E-04	0.0E+00	3.6E-03	0.0E+00	0.0E+00	0.0E+00	**4.4E-03**	**7.2E-03**
Plate heat exchanger	1.3E-03	0.0E+00	1.6E-03	0.0E+00	0.0E+00	0.0E+00	**2.9E-03**	0.0E+00	0.0E+00	5.4E-03	0.0E+00	0.0E+00	0.0E+00	**5.4E-03**	**8.3E-03**
Process vessel	2.6E-04	1.6E-04	4.8E-04	0.0E+00	1.1E-04	5.3E-05	**1.1E-03**	1.6E-04	5.3E-05	3.7E-04	0.0E+00	0.0E+00	1.1E-04	**6.9E-04**	**1.7E-03**
Reciprocating compressor	3.4E-02	0.0E+00	1.7E-02	0.0E+00	0.0E+00	0.0E+00	**5.2E-02**	3.8E-03	0.0E+00	1.9E-02	0.0E+00	0.0E+00	0.0E+00	**2.3E-02**	**7.4E-02**
Reciprocating pump	2.8E-03	0.0E+00	1.4E-03	0.0E+00	0.0E+00	0.0E+00	**4.2E-03**	1.4E-03	0.0E+00	4.2E-03	0.0E+00	0.0E+00	0.0E+00	**5.6E-03**	**9.8E-03**
Shell side heat exchanger	2.4E-03	0.0E+00	1.0E-03	0.0E+00	0.0E+00	0.0E+00	**3.4E-03**	0.0E+00	0.0E+00	2.1E-03	0.0E+00	0.0E+00	0.0E+00	**2.1E-03**	**5.5E-03**
Standard flange L	5.2E-05	0.0E+00	5.8E-06	0.0E+00	0.0E+00	5.8E-06	**6.4E-05**	1.2E-05	0.0E+00	3.5E-05	0.0E+00	0.0E+00	0.0E+00	**4.7E-05**	**1.1E-04**
Standard flange M	3.8E-05	0.0E+00	1.7E-05	0.0E+00	0.0E+00	1.0E-06	**5.6E-05**	4.0E-06	0.0E+00	2.6E-05	0.0E+00	0.0E+00	0.0E+00	**3.0E-05**	**8.6E-05**
Standard flange S	1.5E-05	0.0E+00	6.6E-06	0.0E+00	0.0E+00	1.1E-06	**2.2E-05**	2.2E-06	0.0E+00	1.0E-05	0.0E+00	0.0E+00	0.0E+00	**1.3E-05**	**3.5E-05**
Steel pipe L	1.4E-05	0.0E+00	3.6E-06	0.0E+00	0.0E+00	2.4E-06	**2.0E-05**	1.1E-05	1.2E-06	2.4E-05	1.2E-06	0.0E+00	0.0E+00	**3.7E-05**	**5.7E-05**
Steel pipe M	1.8E-05	0.0E+00	7.3E-06	0.0E+00	0.0E+00	8.1E-07	**2.6E-05**	8.1E-06	4.1E-07	2.5E-05	0.0E+00	0.0E+00	8.1E-07	**3.4E-05**	**6.1E-05**
Steel pipe S	5.1E-05	5.7E-07	2.5E-05	5.7E-07	0.0E+00	2.3E-06	**8.0E-05**	1.2E-05	0.0E+00	4.5E-05	0.0E+00	0.0E+00	2.3E-06	**6.0E-05**	**1.4E-04**
Tube side heat exchanger	1.2E-03	0.0E+00	1.7E-04	0.0E+00	0.0E+00	0.0E+00	**1.4E-03**	5.1E-04	0.0E+00	8.6E-04	0.0E+00	0.0E+00	0.0E+00	**1.4E-03**	**2.7E-03**
Gas lift well	6.3E-03	2.8E-04	1.7E-03	0.0E+00	0.0E+00	0.0E+00	**8.3E-03**	2.0E-03	0.0E+00	5.7E-04	0.0E+00	0.0E+00	0.0E+00	**2.6E-03**	**1.1E-02**
Production well	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**0.0E+00**	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	**0.0E+00**	**0.0E+00**
Total	**6.4E-05**	**9.1E-07**	**2.6E-05**	**2.7E-07**	**5.5E-07**	**1.9E-06**	**9.4E-05**	**1.5E-05**	**7.3E-07**	**5.1E-05**	**9.1E-08**	**7.3E-07**	**1.3E-06**	**6.9E-05**	**1.6E-04**

Table 7.5 - Estimated process leak frequency based on HCRD for the period Q1 2001 - Q1 2015. The leaks are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A

	Leak frequency estimated based in HCRD						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Actuated valve L	1.7E-04	1.7E-04	**3.4E-04**	5.6E-04	1.3E-04	**6.8E-04**	**1.0E-03**
Actuated valve M	9.1E-05	1.7E-04	**2.7E-04**	2.8E-04	6.8E-05	**3.5E-04**	**6.1E-04**
Actuated valve S	7.8E-05	2.0E-04	**2.8E-04**	4.3E-04	6.4E-05	**4.9E-04**	**7.7E-04**
Air cooled heat exchanger	0.0E+00	0.0E+00	**0.0E+00**	3.5E-03	0.0E+00	**3.5E-03**	**3.5E-03**
Atmospheric vessel	3.0E-03	8.6E-03	**1.2E-02**	8.9E-04	3.0E-04	**1.2E-03**	**1.3E-02**
Centrifugal compressor	4.7E-03	2.7E-03	**7.3E-03**	4.0E-03	6.6E-04	**4.7E-03**	**1.2E-02**
Centrifugal pump	1.5E-03	4.4E-03	**5.9E-03**	4.4E-03	1.4E-03	**5.8E-03**	**1.2E-02**
Filter	7.5E-04	2.2E-03	**3.0E-03**	8.7E-04	0.0E+00	**8.7E-04**	**3.9E-03**
Flexible pipe	7.8E-05	7.1E-05	**1.5E-04**	3.5E-05	2.1E-05	**5.7E-05**	**2.1E-04**
Instrument	8.7E-05	1.5E-04	**2.4E-04**	2.5E-04	2.4E-05	**2.8E-04**	**5.2E-04**
Manual valve L	2.5E-05	1.0E-04	**1.3E-04**	2.3E-04	7.6E-05	**3.1E-04**	**4.3E-04**
Manual valve M	1.2E-05	1.2E-05	**2.4E-05**	4.4E-05	2.4E-05	**6.8E-05**	**9.1E-05**
Manual valve S	1.7E-05	2.4E-05	**4.0E-05**	2.3E-05	1.2E-05	**3.5E-05**	**7.5E-05**
Pig trap	1.8E-03	3.6E-03	**5.4E-03**	1.0E-03	7.7E-04	**1.8E-03**	**7.2E-03**
Plate heat exchanger	1.6E-03	5.4E-03	**7.0E-03**	1.3E-03	0.0E+00	**1.3E-03**	**8.3E-03**
Process vessel	7.9E-04	5.3E-04	**1.3E-03**	2.6E-04	1.6E-04	**4.2E-04**	**1.7E-03**
Reciprocating compressor	1.7E-02	1.9E-02	**3.6E-02**	3.4E-02	3.8E-03	**3.8E-02**	**7.4E-02**
Reciprocating pump	1.4E-03	4.2E-03	**5.6E-03**	2.8E-03	1.4E-03	**4.2E-03**	**9.8E-03**
Shell side heat exchanger	1.0E-03	2.1E-03	**3.1E-03**	2.4E-03	0.0E+00	**2.4E-03**	**5.5E-03**
Standard flange L	1.2E-05	3.5E-05	**4.7E-05**	5.2E-05	1.2E-05	**6.4E-05**	**1.1E-04**
Standard flange M	1.8E-05	2.6E-05	**4.4E-05**	3.8E-05	4.0E-06	**4.2E-05**	**8.6E-05**
Standard flange S	7.7E-06	1.0E-05	**1.8E-05**	1.5E-05	2.2E-06	**1.7E-05**	**3.5E-05**
Steel pipe L	6.0E-06	2.5E-05	**3.1E-05**	1.4E-05	1.2E-05	**2.6E-05**	**5.7E-05**
Steel pipe M	8.1E-06	2.6E-05	**3.4E-05**	1.8E-05	8.1E-06	**2.6E-05**	**6.1E-05**
Steel pipe S	2.8E-05	4.8E-05	**7.5E-05**	5.2E-05	1.2E-05	**6.5E-05**	**1.4E-04**
Tube side heat exchanger	1.7E-04	8.6E-04	**1.0E-03**	1.2E-03	5.1E-04	**1.7E-03**	**2.7E-03**
Gas lift well	2.0E-03	5.7E-04	**2.6E-03**	6.3E-03	2.0E-03	**8.3E-03**	**1.1E-02**
Production well	0.0E+00	0.0E+00	**0.0E+00**	0.0E+00	0.0E+00	**0.0E+00**	**0.0E+00**
Total	**3.0E-05**	**5.4E-05**	**8.4E-05**	**6.4E-05**	**1.5E-05**	**7.9E-05**	**1.6E-04**

Table 7.6 - Estimated process leak frequency based on HCRD for the period Q1 2001 - Q1 2015. The frequencies are categorized into the defined leak scenarios for the model (see TN-4). It is also distinguished on hole sizes ≤1 mm, >1 mm or N/A. All equipment size categories of actuated and manual valves, standard flange, steel pipe and shell and tube side heat exchangers are grouped together

	Leak frequency estimated based in HCRD						
	Hole size > 1 mm or N/A			Hole size <= 1 mm			
Equipment	Marginal leak	Significant leak	Total	Marginal leak	Significant leak	Total	Total
Air-cooled heat exchanger	0.0E+00	0.0E+00	**0.0E+00**	3.5E-03	0.0E+00	**3.5E-03**	**3.5E-03**
Atmospheric vessel	3.0E-03	8.6E-03	**1.2E-02**	8.9E-04	3.0E-04	**1.2E-03**	**1.3E-02**
Centrifugal compressor	4.7E-03	2.7E-03	**7.3E-03**	4.0E-03	6.6E-04	**4.7E-03**	**1.2E-02**
Centrifugal pump	1.5E-03	4.4E-03	**5.9E-03**	4.4E-03	1.4E-03	**5.8E-03**	**1.2E-02**
Filter	7.5E-04	2.2E-03	**3.0E-03**	8.7E-04	0.0E+00	**8.7E-04**	**3.9E-03**
Flexible pipe	7.8E-05	7.1E-05	**1.5E-04**	3.5E-05	2.1E-05	**5.7E-05**	**2.1E-04**
Instrument	8.7E-05	1.5E-04	**2.4E-04**	2.5E-04	2.4E-05	**2.8E-04**	**5.2E-04**
Pig trap	1.8E-03	3.6E-03	**5.4E-03**	1.0E-03	7.7E-04	**1.8E-03**	**7.2E-03**
Plate heat exchanger	1.6E-03	5.4E-03	**7.0E-03**	1.3E-03	0.0E+00	**1.3E-03**	**8.3E-03**
Process vessel	7.9E-04	5.3E-04	**1.3E-03**	2.6E-04	1.6E-04	**4.2E-04**	**1.7E-03**
Reciprocating compressor	1.7E-02	1.9E-02	**3.6E-02**	3.4E-02	3.8E-03	**3.8E-02**	**7.4E-02**
Reciprocating pump	1.4E-03	4.2E-03	**5.6E-03**	2.8E-03	1.4E-03	**4.2E-03**	**9.8E-03**
S & T-side heat exchanger	4.6E-04	1.3E-03	**1.7E-03**	1.6E-03	3.4E-04	**1.9E-03**	**3.7E-03**
Standard flange	1.1E-05	1.7E-05	**2.8E-05**	2.5E-05	3.3E-06	**2.8E-05**	**5.6E-05**
Steel pipe	1.5E-05	3.3E-05	**4.8E-05**	2.9E-05	1.0E-05	**4.0E-05**	**8.8E-05**
Valve	2.7E-05	4.8E-05	**7.5E-05**	8.4E-05	2.4E-05	**1.1E-04**	**1.8E-04**
Gas lift well	2.3E-03	5.7E-04	**2.8E-03**	6.0E-03	2.0E-03	**8.0E-03**	**1.1E-02**
Producing well	0.0E+00	0.0E+00	**0.0E+00**	0.0E+00	0.0E+00	**0.0E+00**	**0.0E+00**
Total	**3.0E-05**	**5.4E-05**	**8.4E-05**	**6.4E-05**	**1.5E-05**	**7.9E-05**	**1.6E-04**

Appendix C

Complementary cumulative hole size distributions and leak rate distributions based on HCRD

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Page

1 Introduction

This appendix gives complementary cumulative hole size distributions for all equipment types in HCRD. The hole size distributions are plotted in log-log in Chapter 2.1 and linear plots in Chapter 2.2. Correspondingly complementary cumulative leak rate distributions are given in log-log in Chapter 3.1 and linear scale in Chapter 3.2. Filter 1 is used to extract incidents as basis for hole size distributions. Filter 2 and 3 are used to analyse the effect of including process leaks fed through utility systems, and including incidents recorded with total released quantity <10 (Marginal leaks) and leaks with initial pressure <0.01 barg. Filter 4 is defined to produce estimated leak rate distributions based on the same type of incidents as the leak rate distributions based on NCS data are based on (see TN-2). Note that there are uncertainties related to both the hole size distributions and the leak rate distributions (see TN-3). Filters extracting incidents from the period Q3 1992- Q1 2015 are denoted "a", while filters from the period Q1 2001- Q1 2015, are denoted "b". The filters are defined in the table below. See also TN-3.

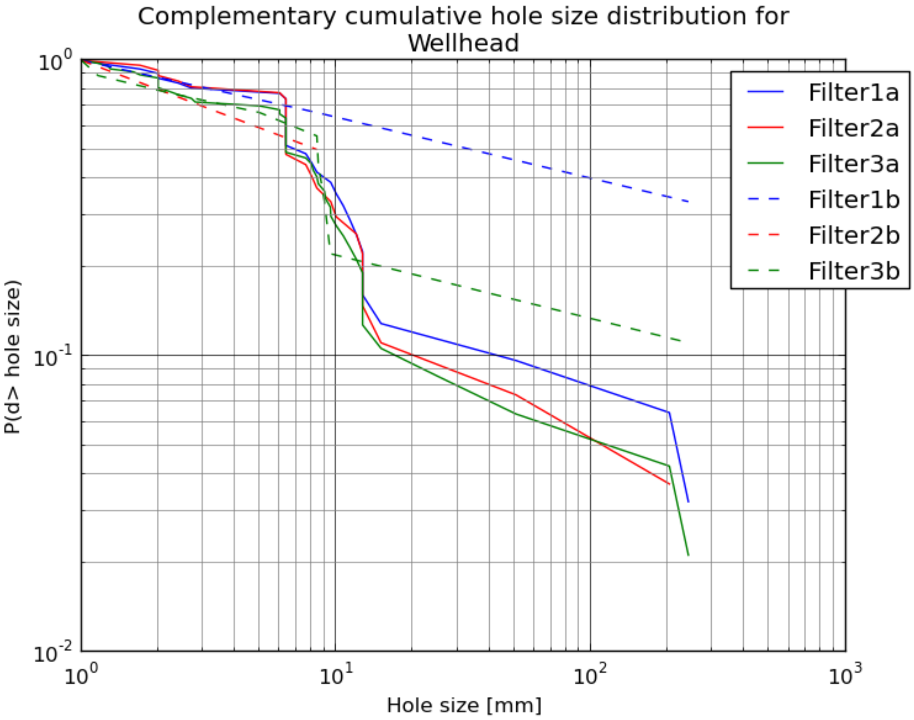
Table 1.1 - Filters used to extract incidents (hole sizes) as basis for recorded hole size distributions and estimated leak rate distributions based on HCRD

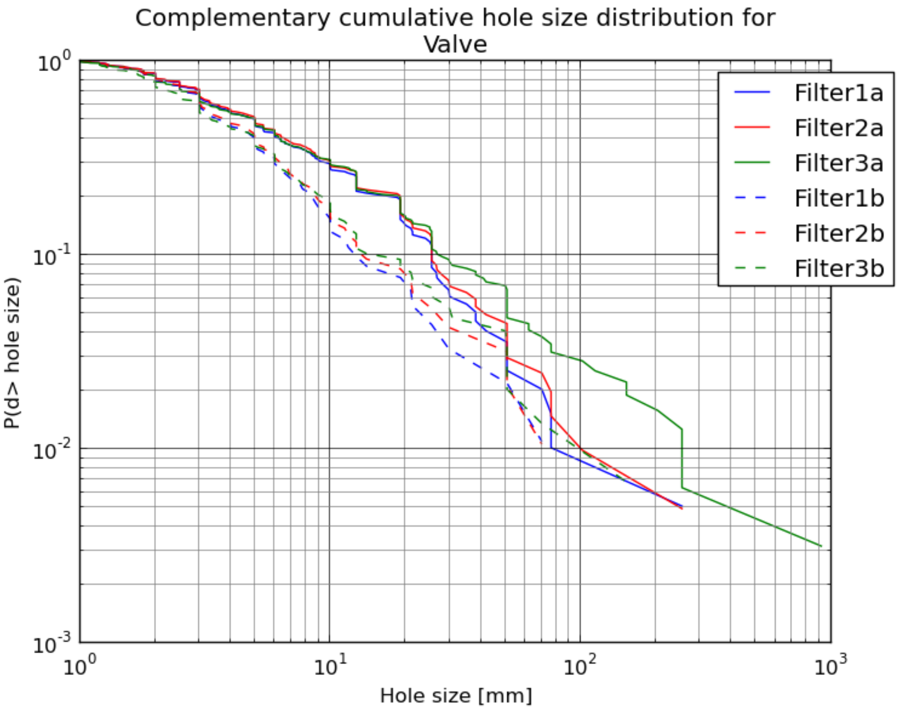
Filter	Description
Filter 1	All relevant process leak and well system leak incidents in the HCR-data as defined in Chapter 2.1 and 2.3 (in TN-3) are included, except: • Incidents recorded with pressure <0.01 barg • Incidents recorded with total released quantity <10 kg • Incidents recorded with hole size <= 1 mm • Incidents recorded with hole size "N/A" This filter is put as basis for hole size distributions in the model development
Filter 2	All relevant process leak incidents in the HCR-data as defined in in Chapter 2.1 (in TN-3), relevant utility leaks as defined in Chapter 2.2 (in TN-3) and relevant well releases as defined in 2.3 (in TN-3) are included, except: • Incidents recorded with pressure <0.01 barg • Incidents recorded with total released quantity <10 kg • Incidents recorded with hole size <= 1 mm • Incidents recorded with hole size "N/A" This filter is defined to analyse the effect of including process leaks fed through utility systems and well systems as basis for hole size distributions.
Filter 3	All relevant process leak incidents in the HCR-data as defined in in Chapter 2.1 (in TN-3), relevant utility leaks as defined in Chapter 2.2 (in TN-3) and relevant well releases as defined in 2.3 (in TN-3) are included, except: • Incidents recorded with hole size <= 1 mm • Incidents recorded with hole size "N/A" This filter is defined to also analyse the effect of including incidents recorded with pressure <0.01 barg, and incidents recorded with total released quantity <10 kg.
Filter 4	All relevant process leak incidents in the HCR-data as defined in Chapter 2.1 (in TN-3), relevant utility leaks as defined in Chapter 2.2 (in TN-3) and relevant well releases as defined in 2.3 (in TN-3) are included, except: • Incidents recorded with initial leak rate <0.1 kg/s This filter is defined to establish leak rate distributions based on the same type of incidents as the leak rate distributions based on NCS data are based on

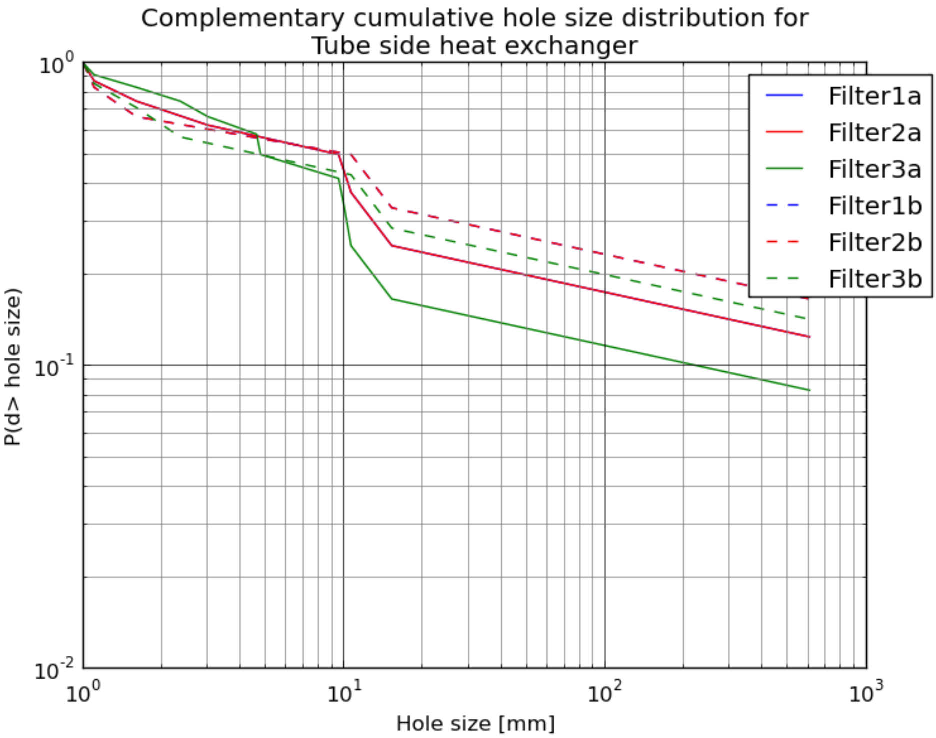
2 Complementary cumulative hole size distributions based on HCRD

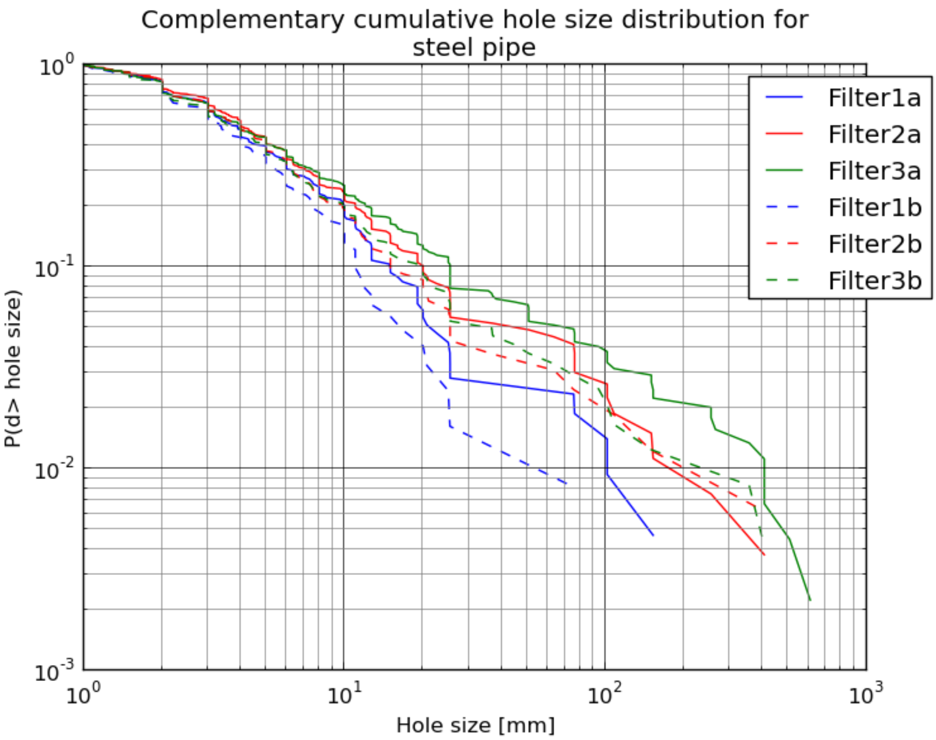
The complementary cumulative hole size distributions are based on recorded hole sizes in HCRD.

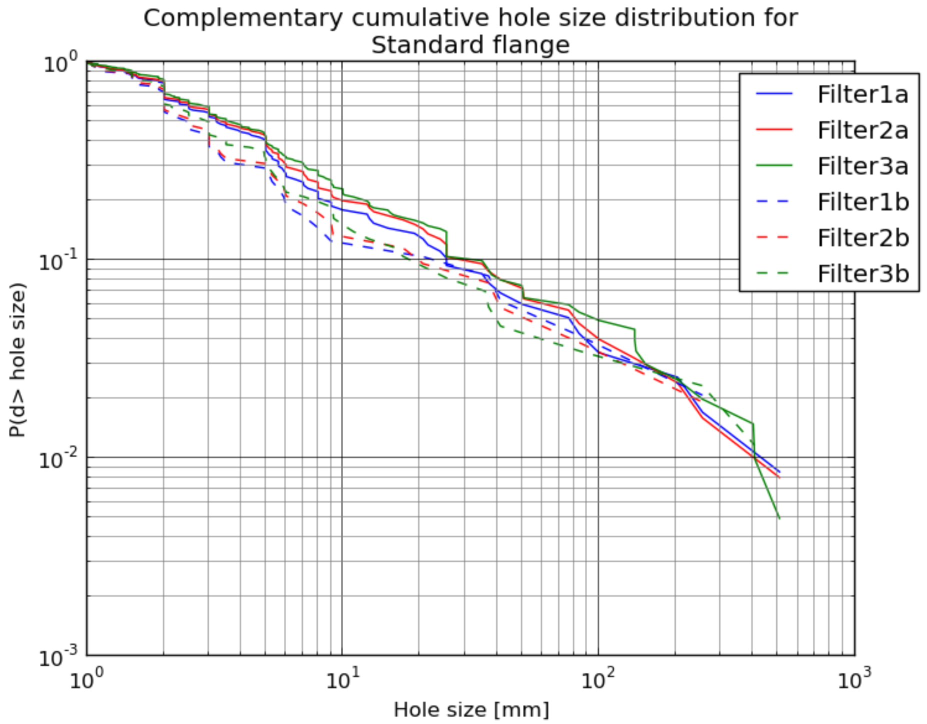
2.1 Log-log plots

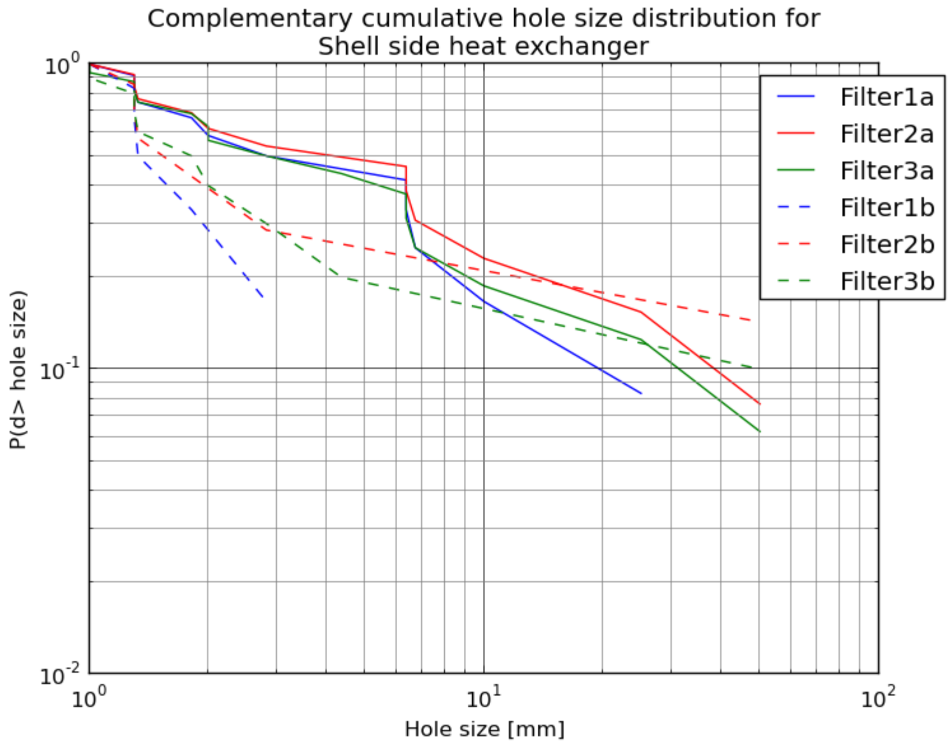


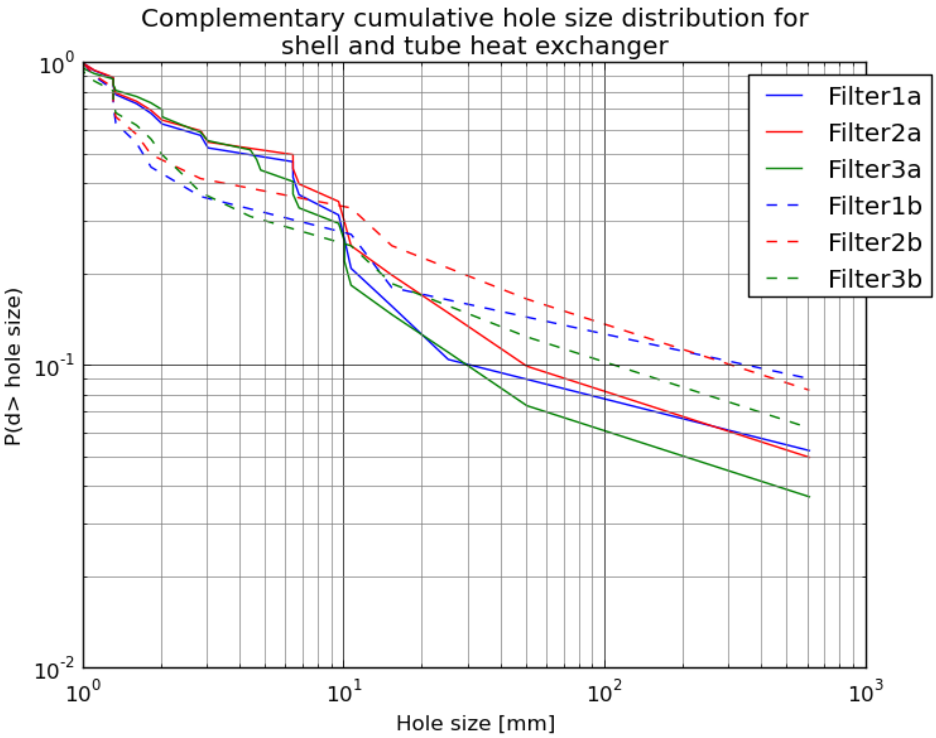


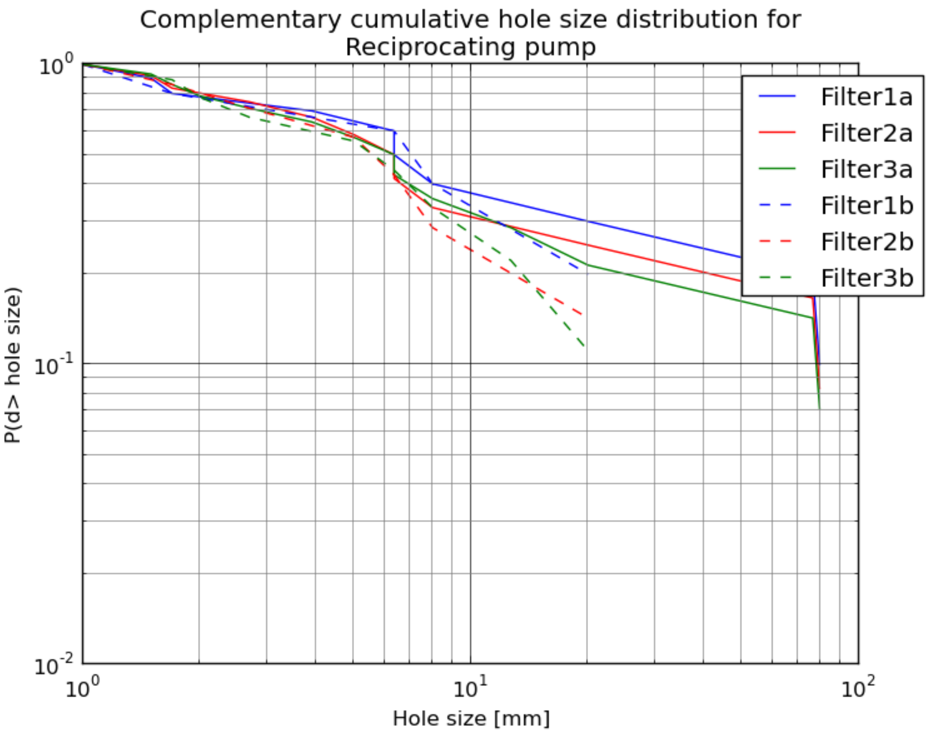

Complementary cumulative hole size distribution for
Tube side heat exchanger
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

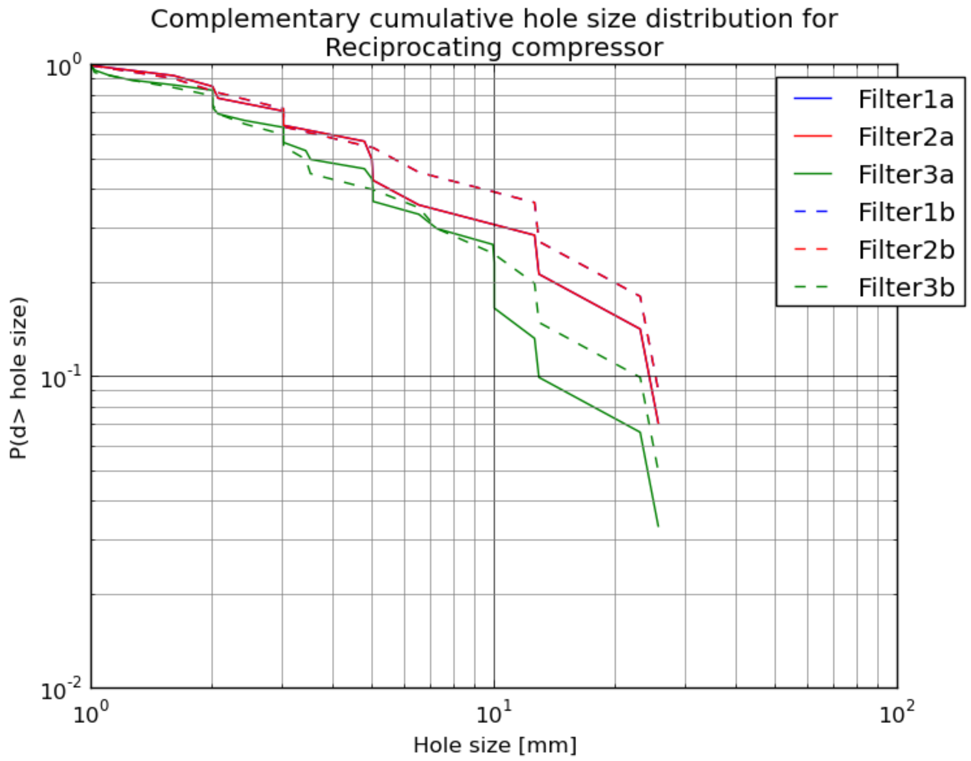

Complementary cumulative hole size distribution for
steel pipe
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

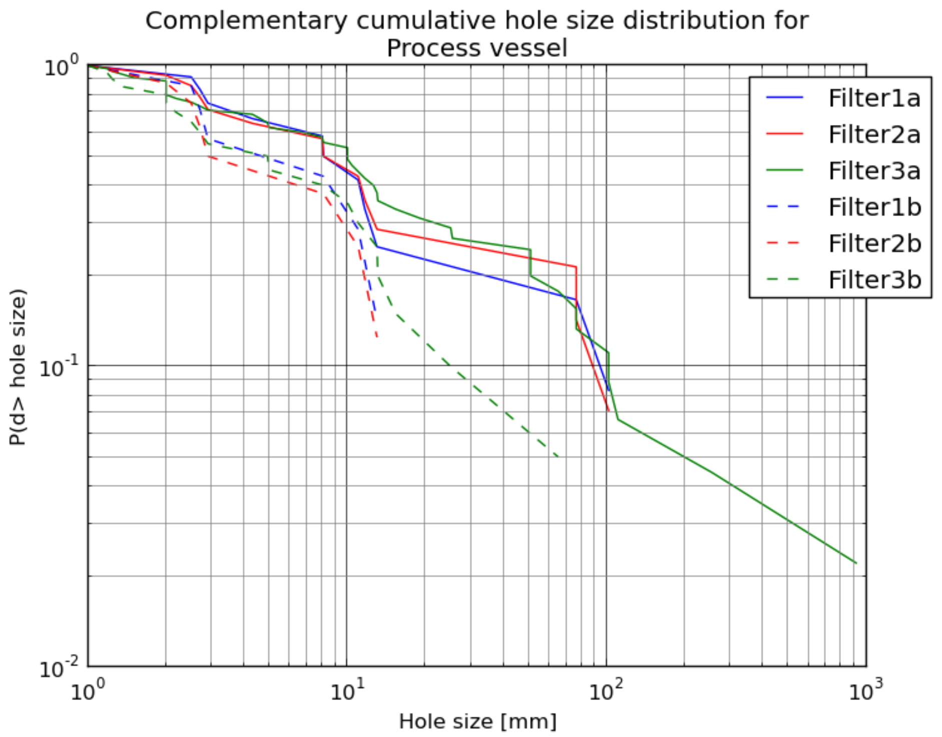

Complementary cumulative hole size distribution for
Standard flange
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

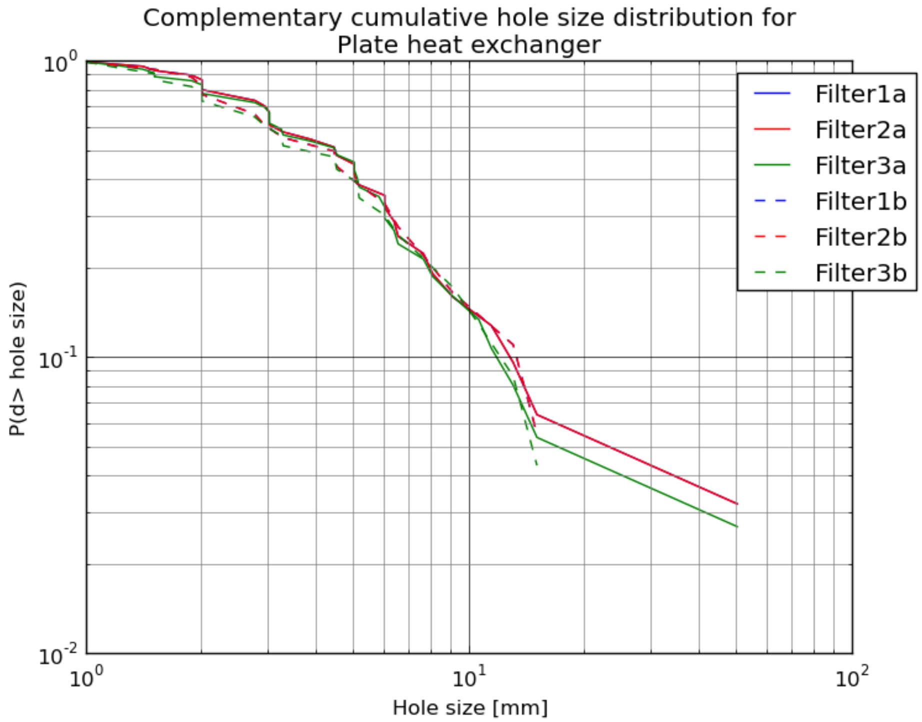

Complementary cumulative hole size distribution for
Shell side heat exchanger
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

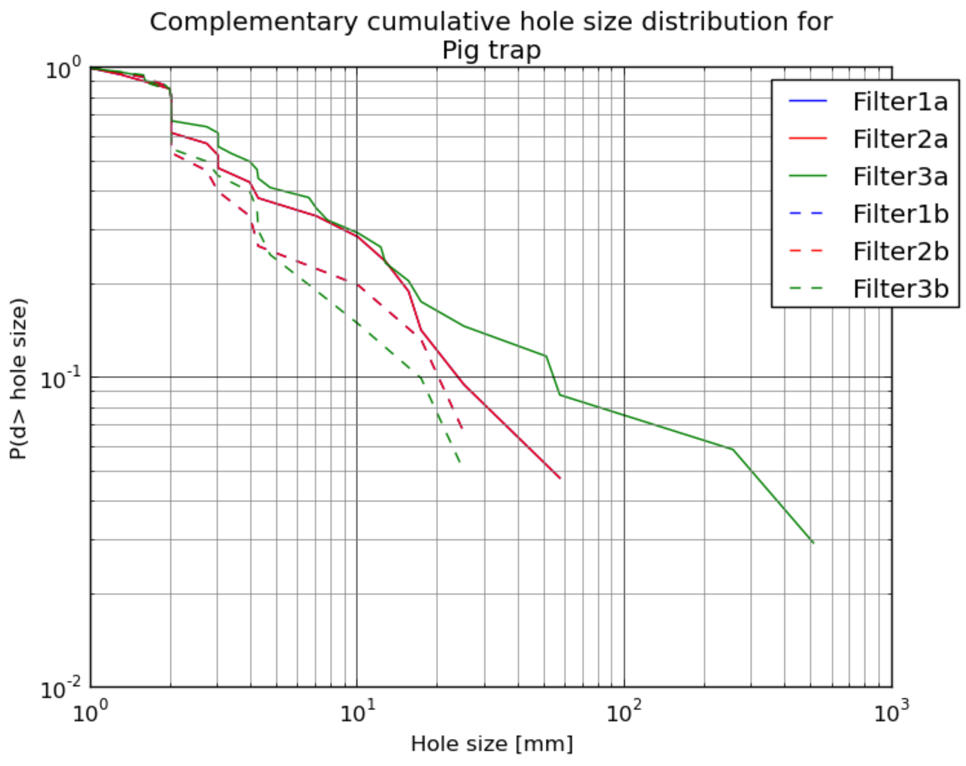

Complementary cumulative hole size distribution for shell and tube heat exchanger
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

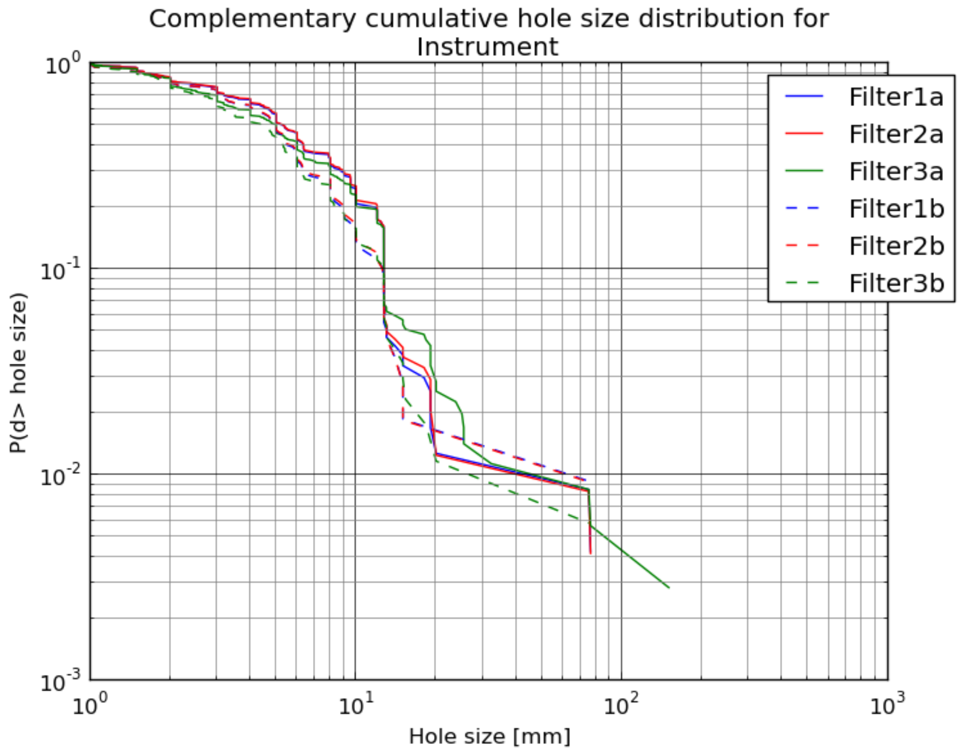

Complementary cumulative hole size distribution for Reciprocating pump
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b


Complementary cumulative hole size distribution for
Reciprocating compressor
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

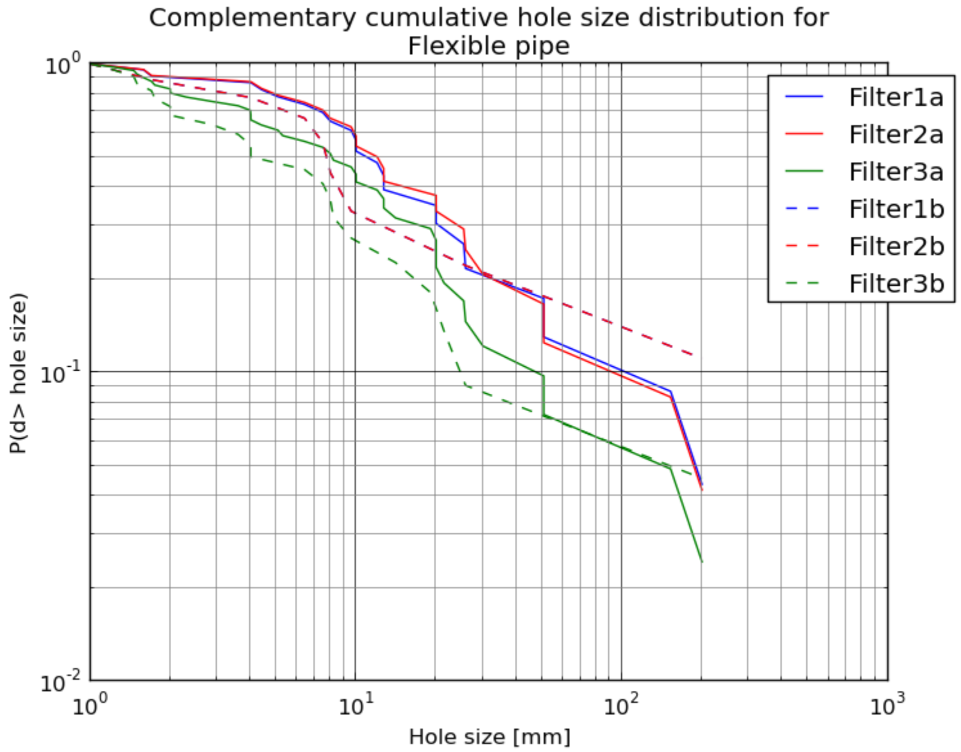

Complementary cumulative hole size distribution for
Process vessel
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b


Complementary cumulative hole size distribution for
Plate heat exchanger
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

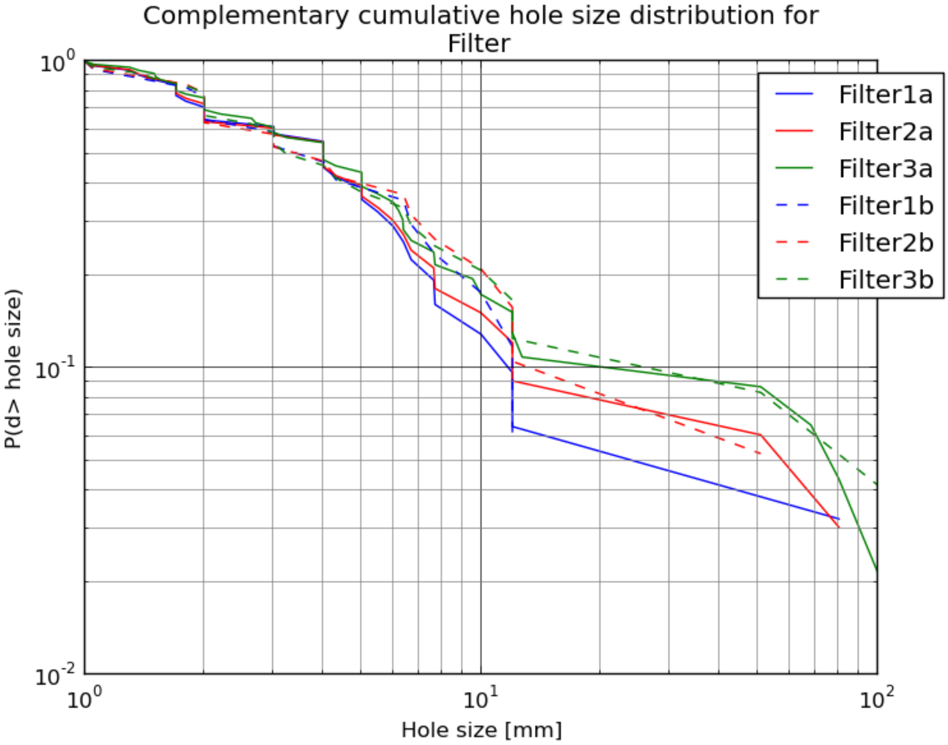

Complementary cumulative hole size distribution for
Pig trap
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b



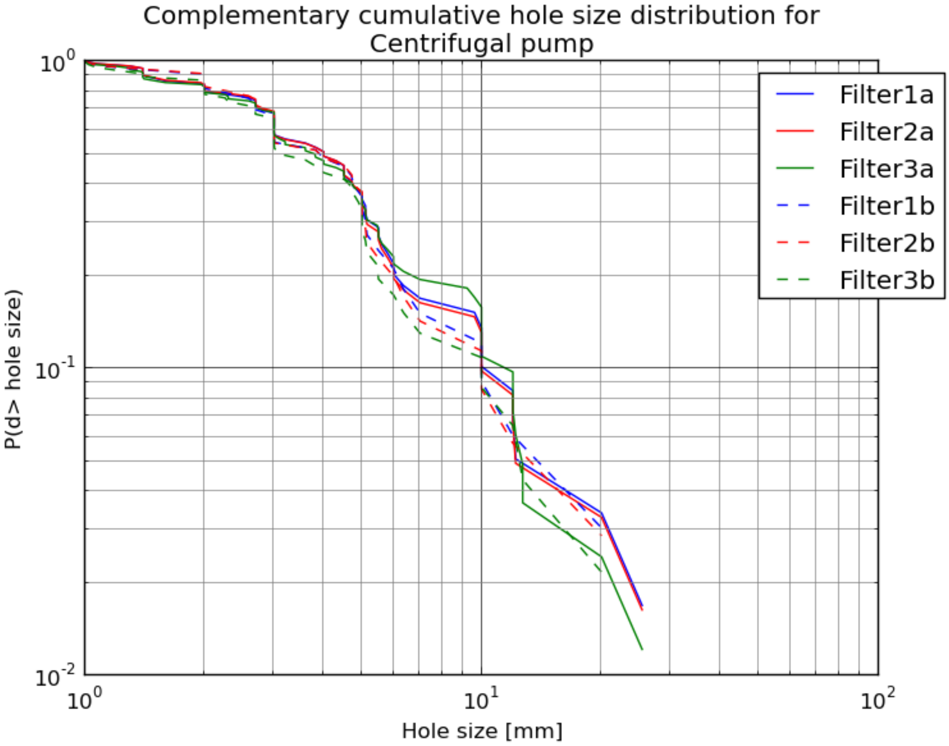
Complementary cumulative hole size distribution for
Instrument
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b



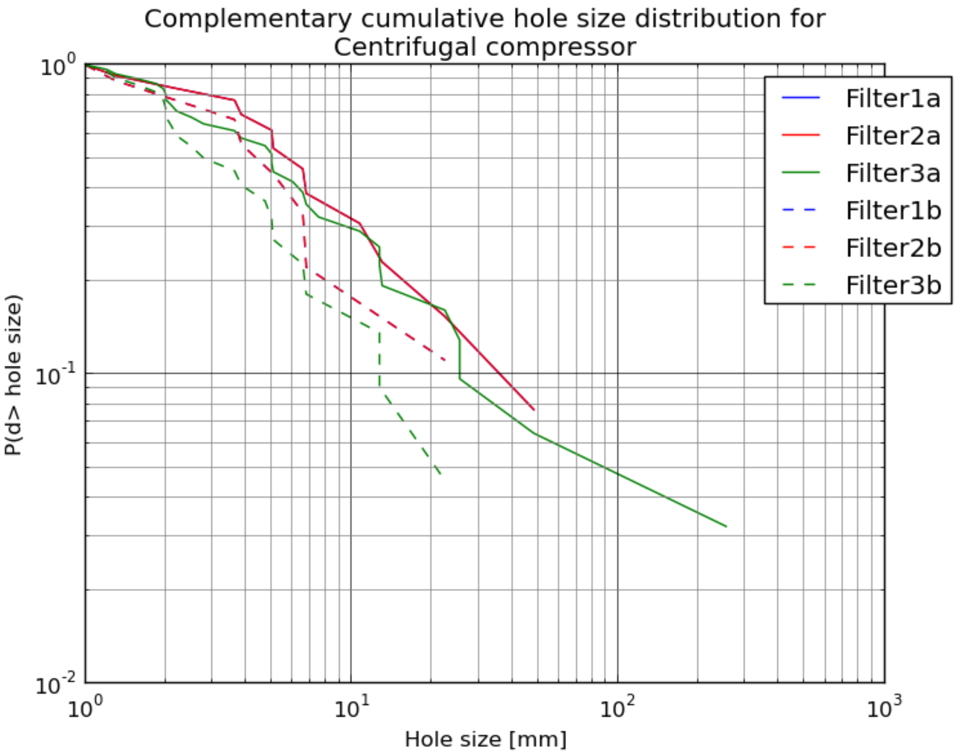
Complementary cumulative hole size distribution for
Flexible pipe
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b



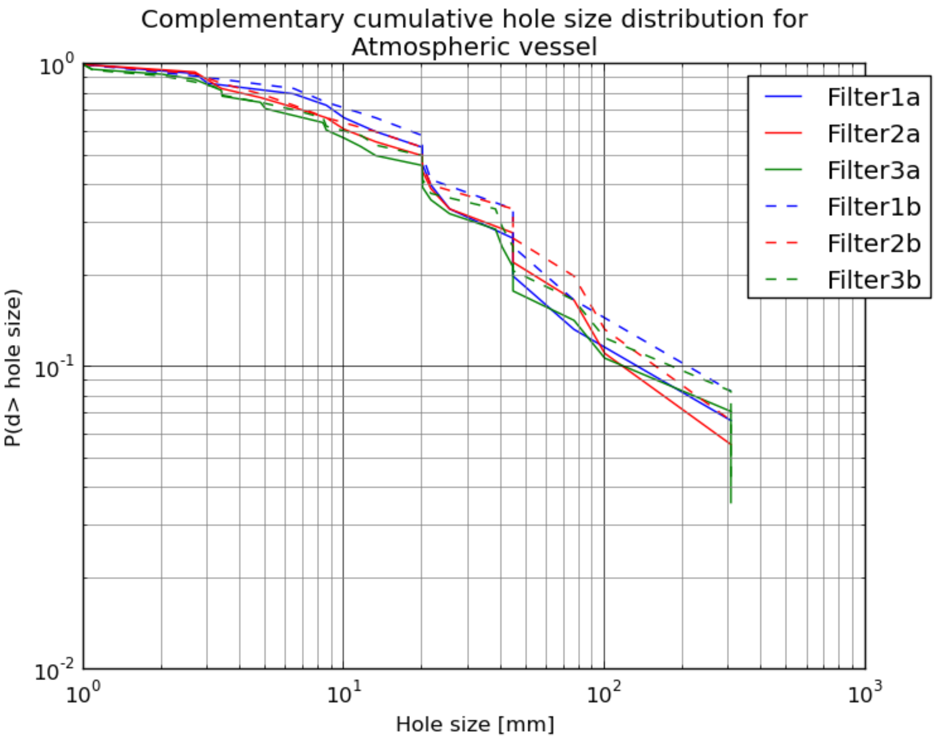
Complementary cumulative hole size distribution for
Filter
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b



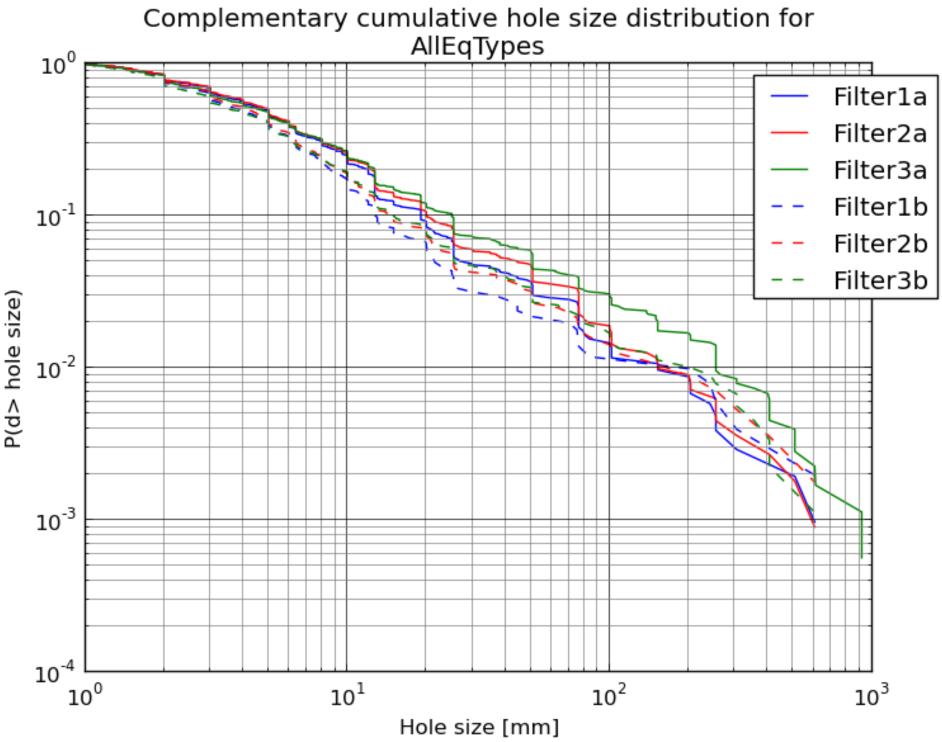
Complementary cumulative hole size distribution for
Centrifugal pump
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

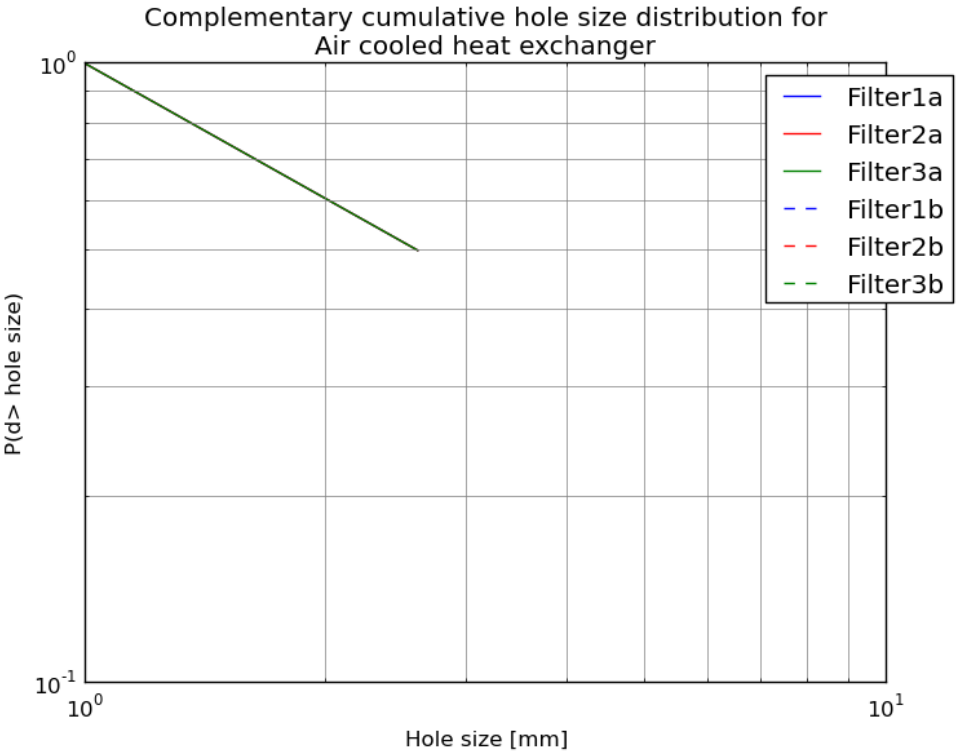


Complementary cumulative hole size distribution for
Centrifugal compressor
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

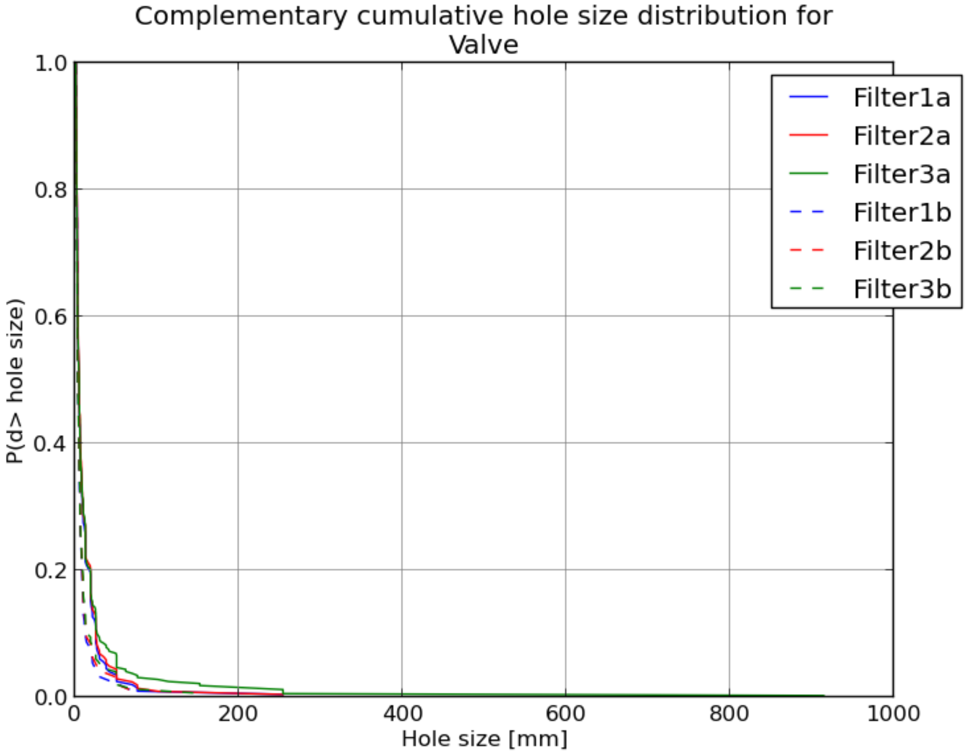


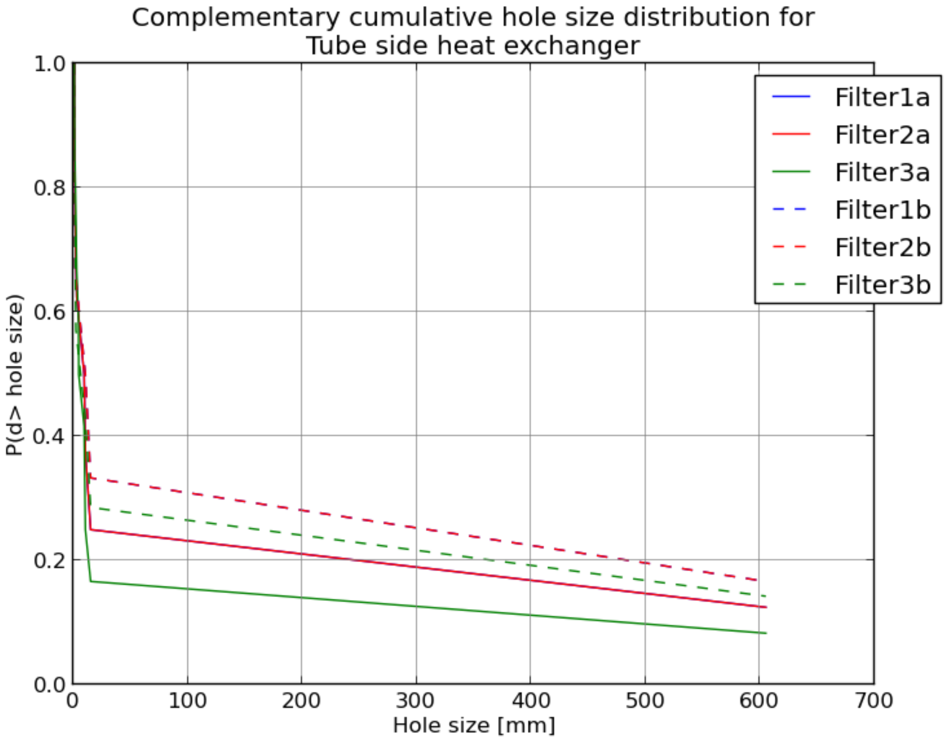
Complementary cumulative hole size distribution for
Atmospheric vessel
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

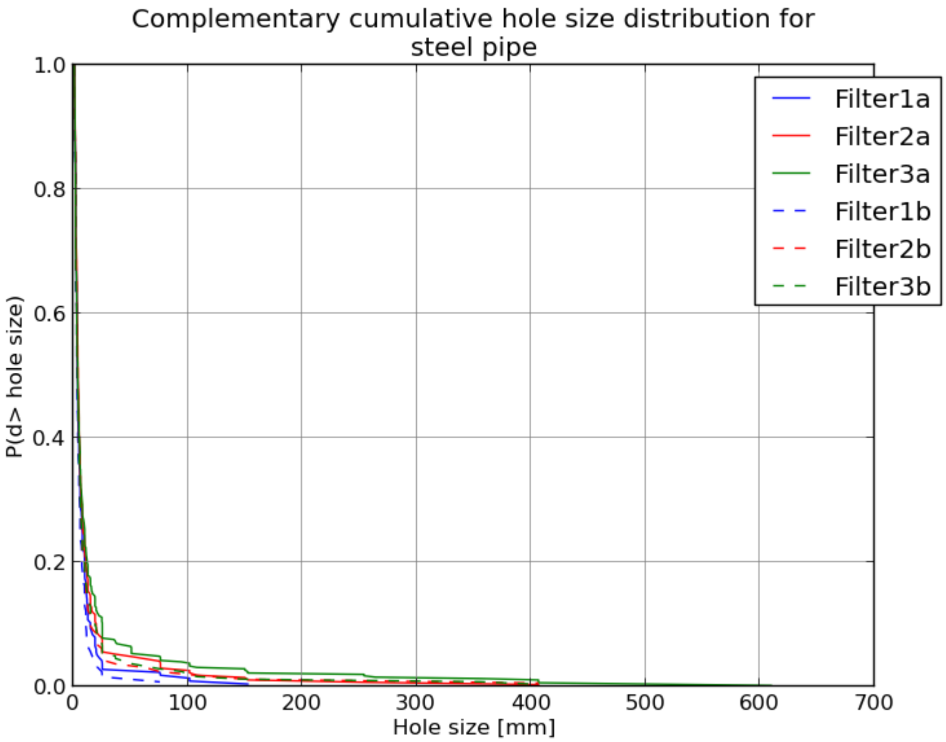

Complementary cumulative hole size distribution for
AllEqTypes
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b
10^0
10^-1
10^-2
10^-3
10^-4
10^0
10^1
10^2
10^3

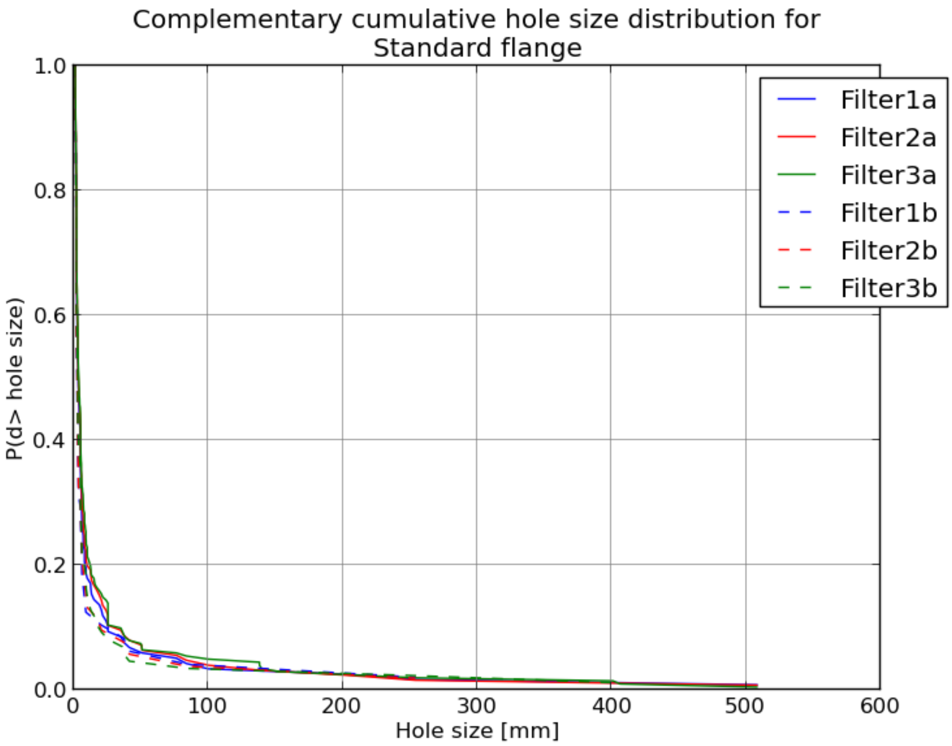

Complementary cumulative hole size distribution for
Air cooled heat exchanger
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b
10^0
10^-1
10^0
10^1

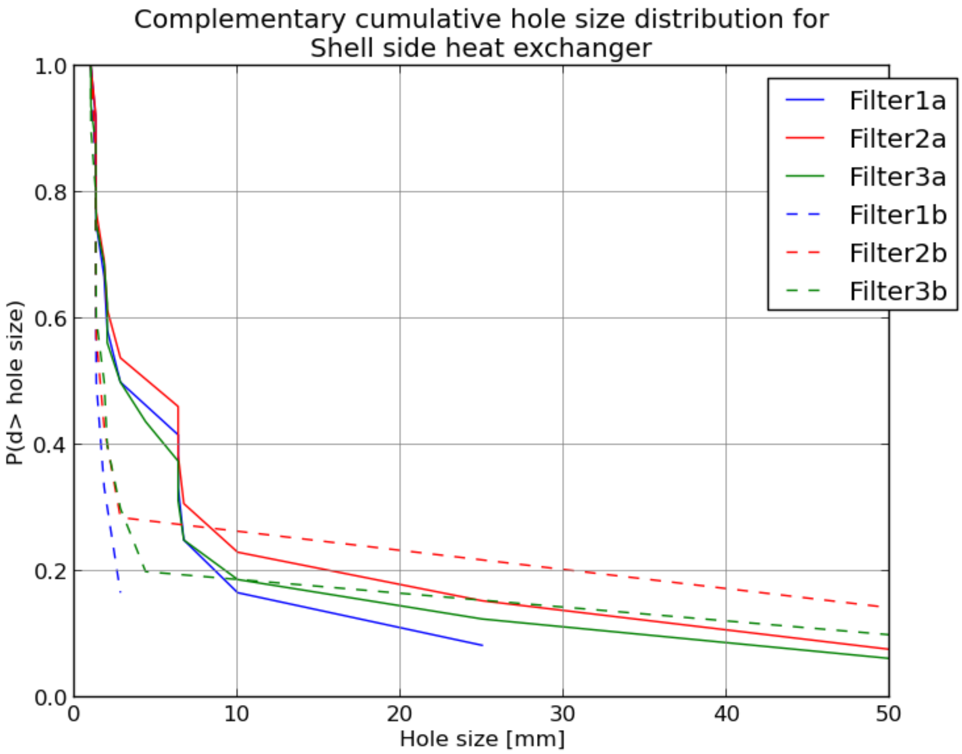
2.2 Linear plots

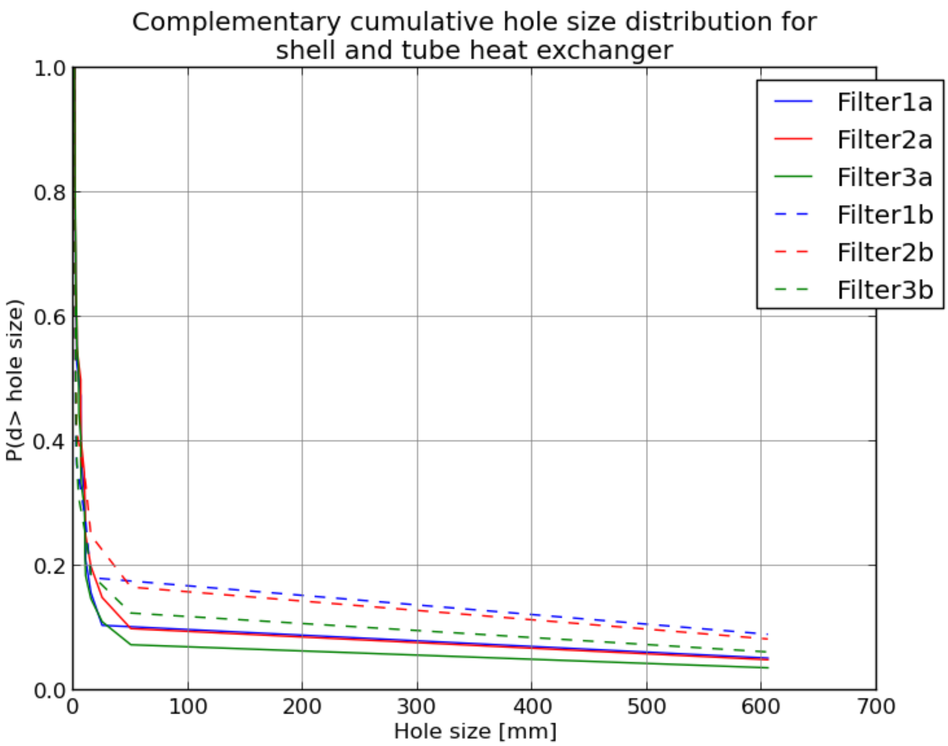


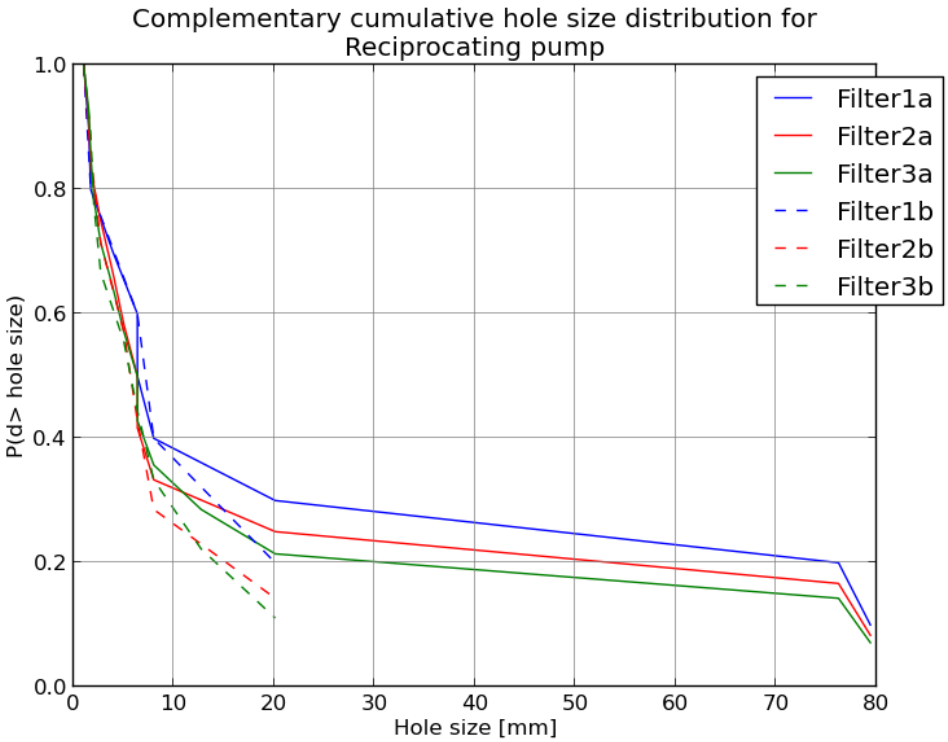


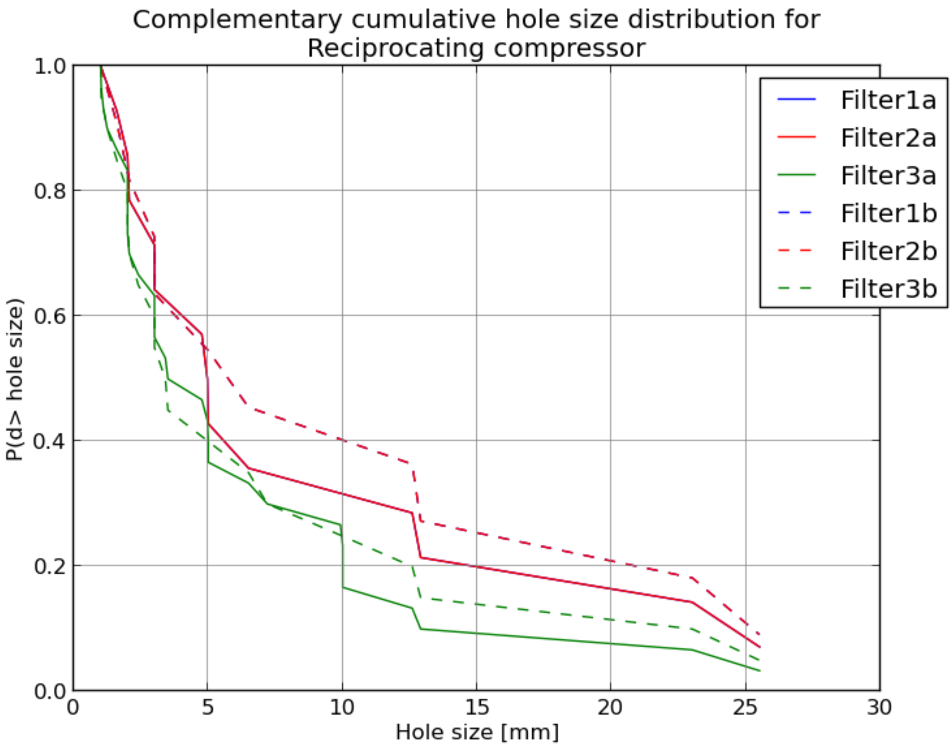

Complementary cumulative hole size distribution for steel pipe
P(d> hole size)
Hole size [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600
700
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

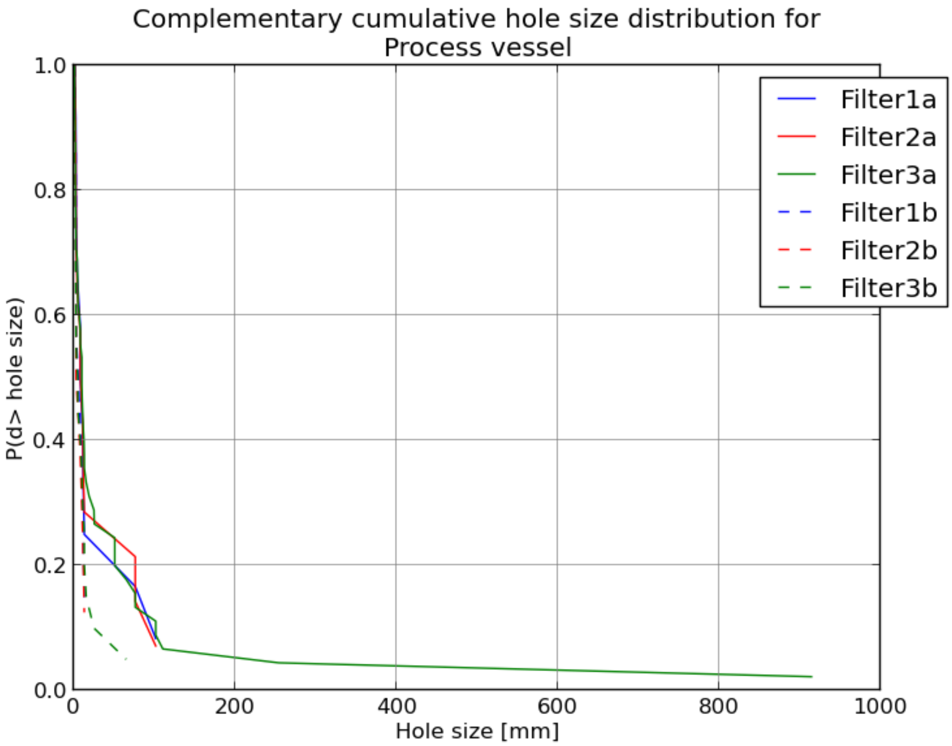

Complementary cumulative hole size distribution for Standard flange
P(d> hole size)
Hole size [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
100
200
300
400
500
600
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

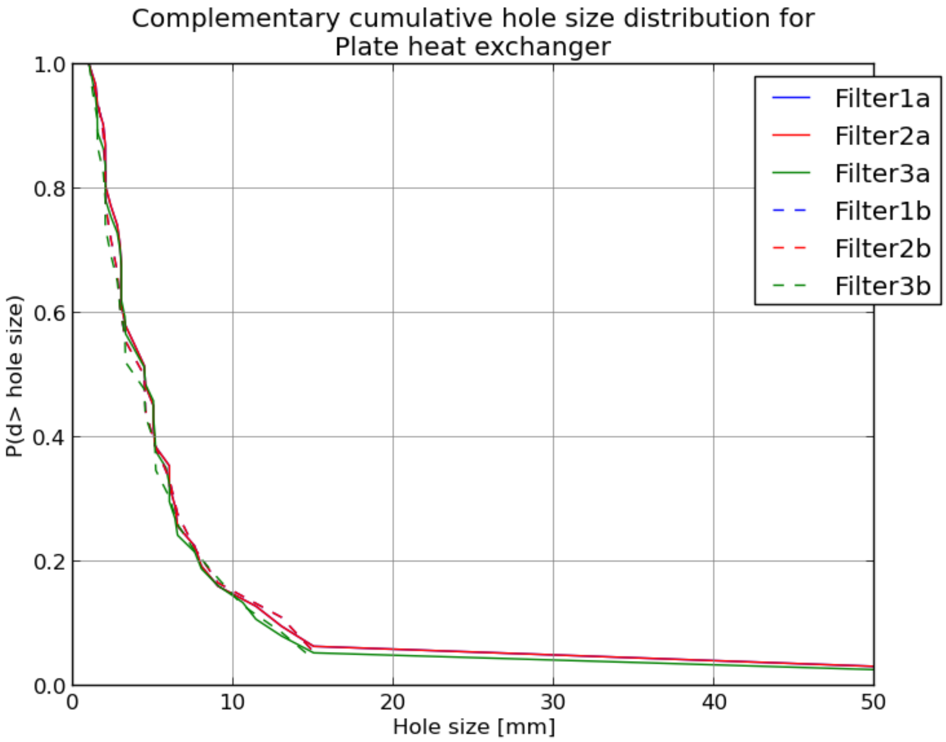

Complementary cumulative hole size distribution for
Shell side heat exchanger
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b
0.0
0.2
0.4
0.6
0.8
1.0
0
10
20
30
40
50

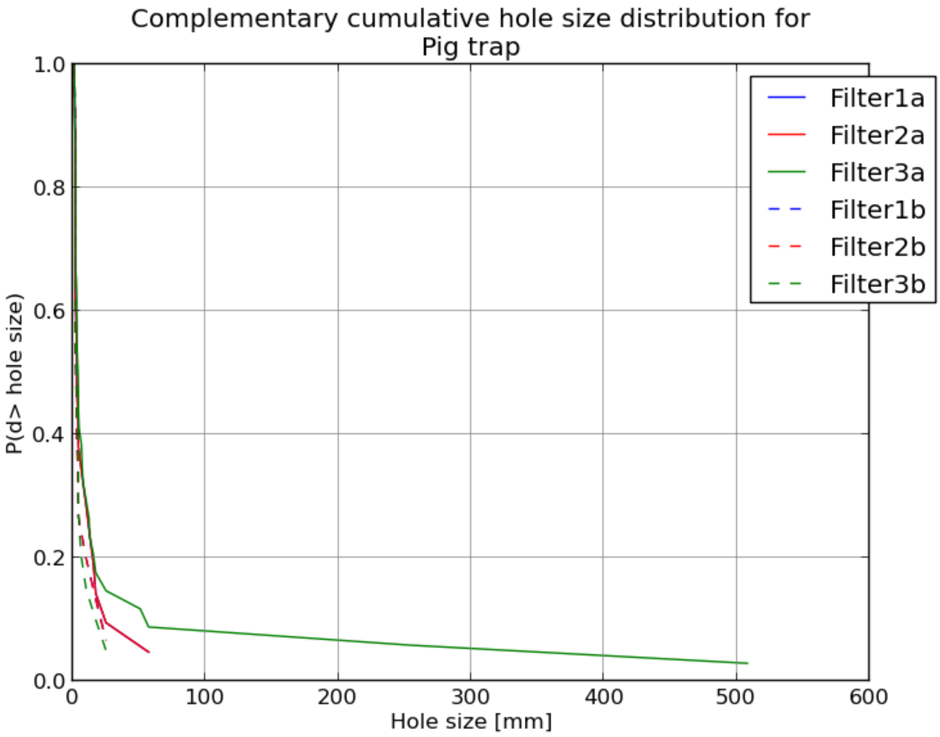

Complementary cumulative hole size distribution for
shell and tube heat exchanger
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b
0.0
0.2
0.4
0.6
0.8
1.0
0
100
200
300
400
500
600
700

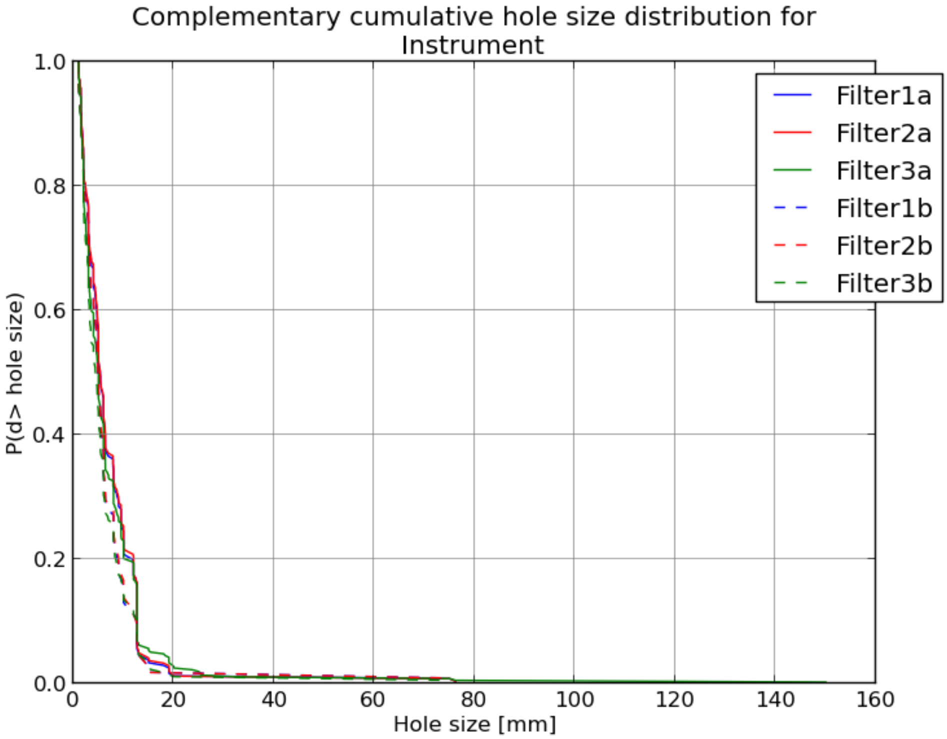

Complementary cumulative hole size distribution for
Reciprocating pump
1.0
0.8
0.6
0.4
0.2
0.0
P(d> hole size)
0
10
20
30
40
50
60
70
80
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

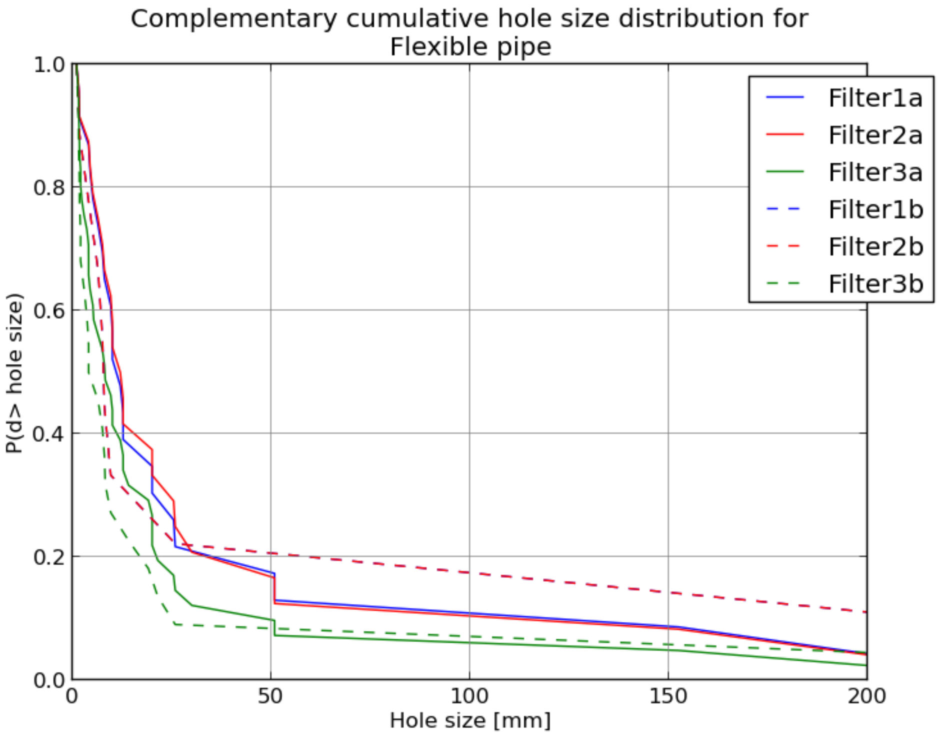

Complementary cumulative hole size distribution for
Reciprocating compressor
1.0
0.8
0.6
0.4
0.2
0.0
P(d> hole size)
0
5
10
15
20
25
30
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

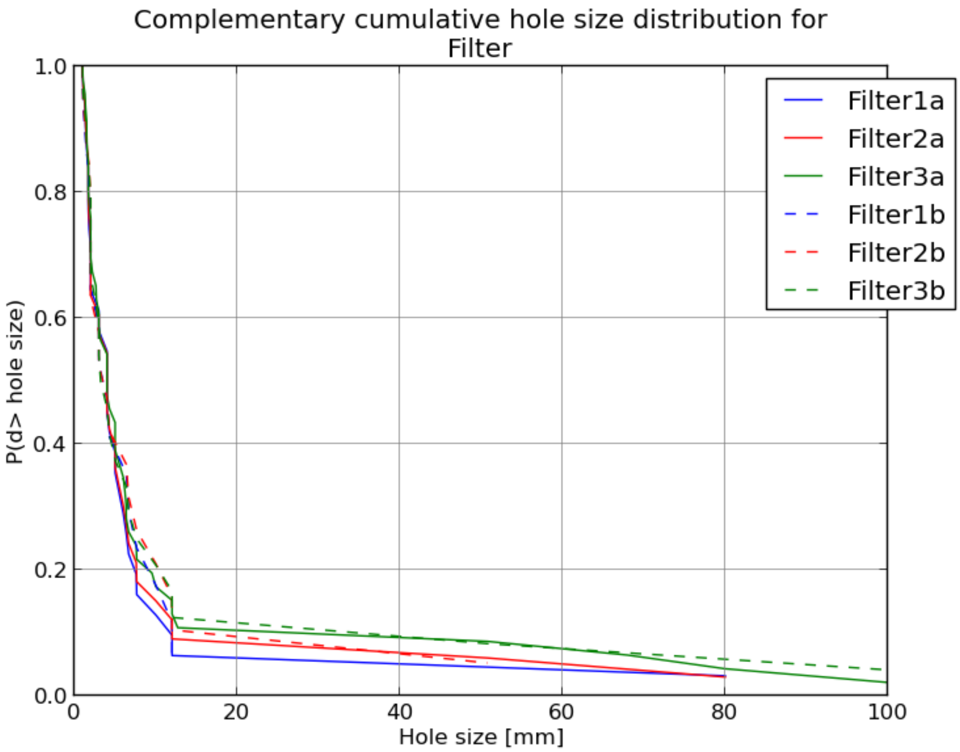

Complementary cumulative hole size distribution for
Process vessel
P(d> hole size)
Hole size [mm]
0.0
0.2
0.4
0.6
0.8
1.0
0
200
400
600
800
1000
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

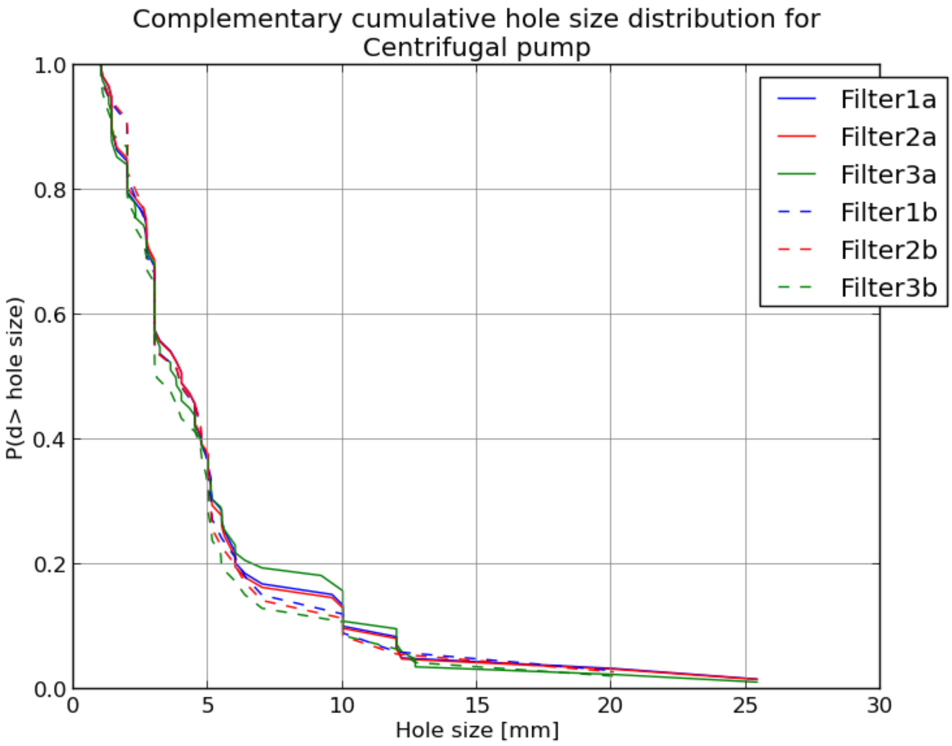

Complementary cumulative hole size distribution for
Plate heat exchanger
P(d> hole size)
Hole size [mm]
0.0
0.2
0.4
0.6
0.8
1.0
0
10
20
30
40
50
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

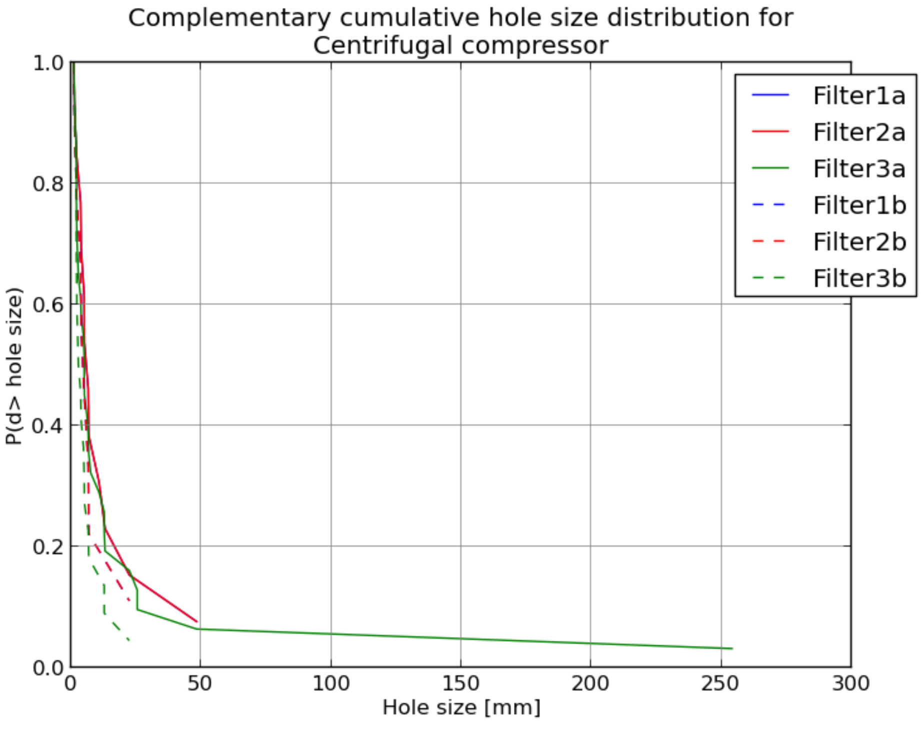

Complementary cumulative hole size distribution for
Pig trap
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b
0.0
0.2
0.4
0.6
0.8
1.0
0
100
200
300
400
500
600

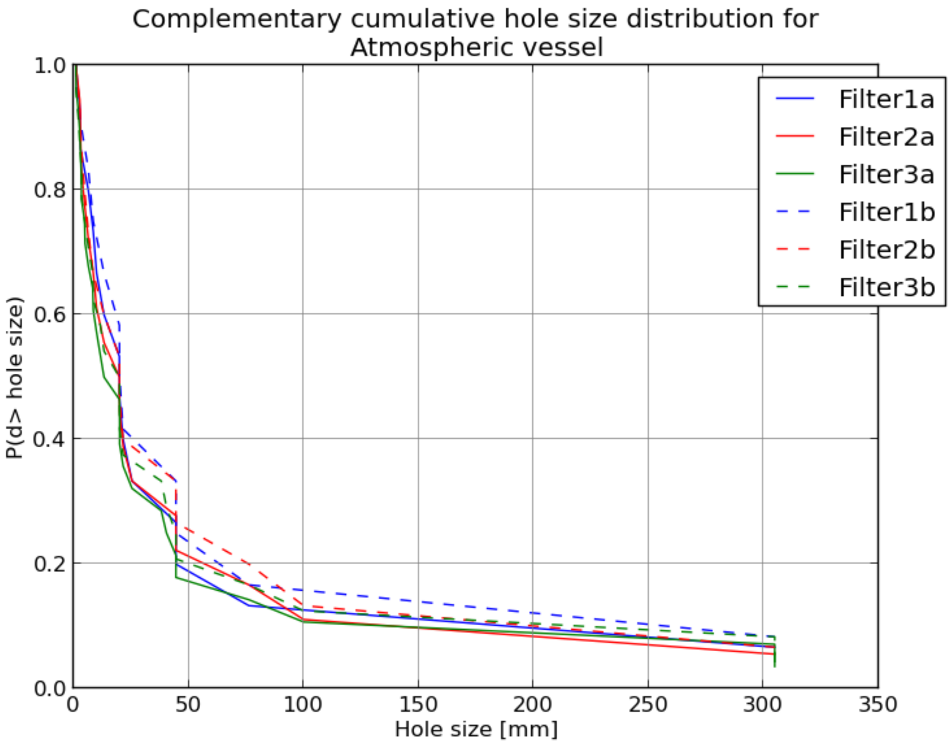

Complementary cumulative hole size distribution for
Instrument
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b
0.0
0.2
0.4
0.6
0.8
1.0
0
20
40
60
80
100
120
140
160

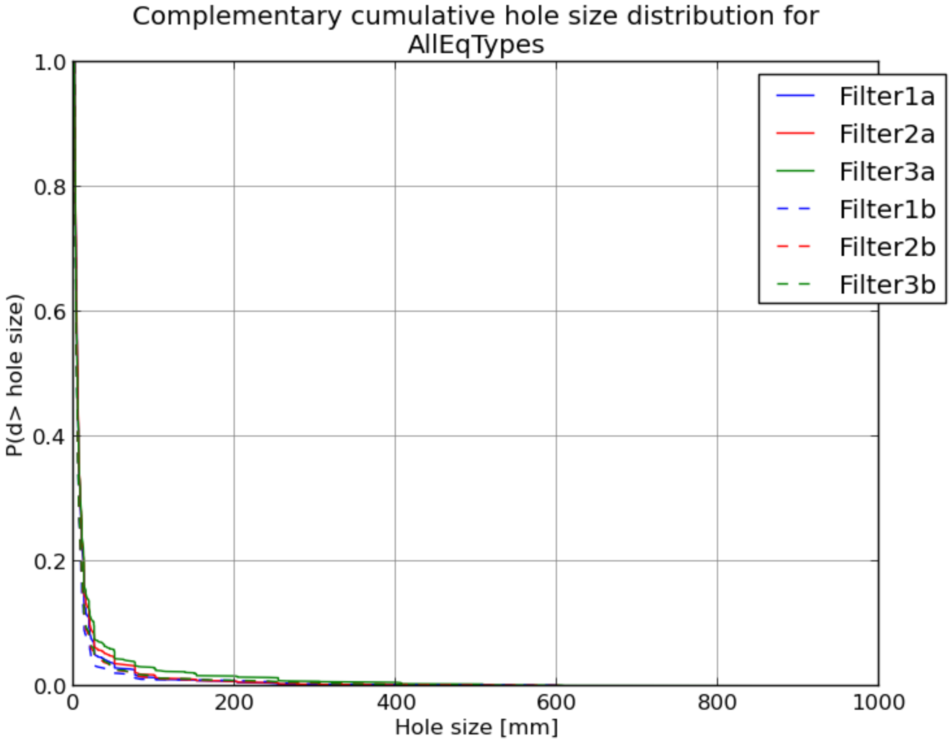

Complementary cumulative hole size distribution for
Flexible pipe
P(d> hole size)
Hole size [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

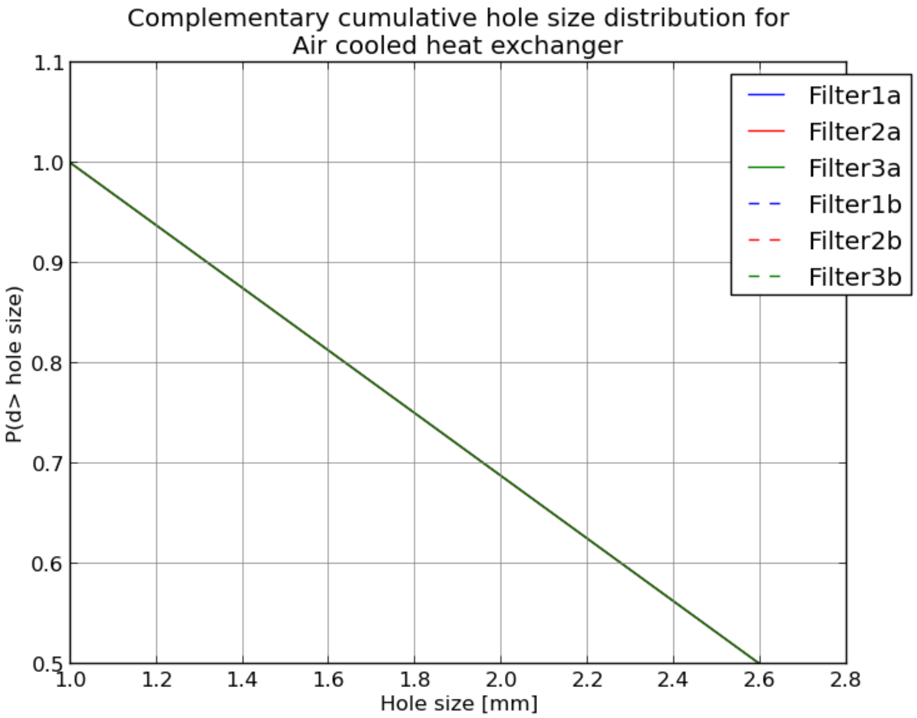

Complementary cumulative hole size distribution for
Filter
P(d> hole size)
Hole size [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

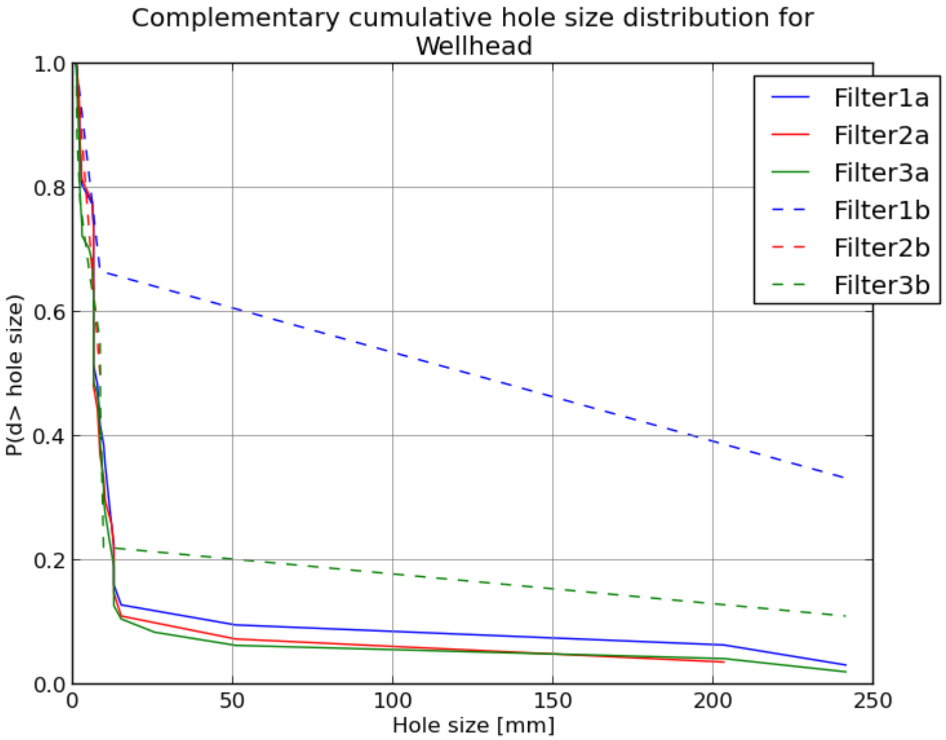

Complementary cumulative hole size distribution for
Centrifugal pump
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
20
25
30


Complementary cumulative hole size distribution for
Centrifugal compressor
P(d> hole size)
Hole size [mm]
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300


Complementary cumulative hole size distribution for
Atmospheric vessel
P(d> hole size)
Hole size [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b


Complementary cumulative hole size distribution for
AllEqTypes
P(d> hole size)
Hole size [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

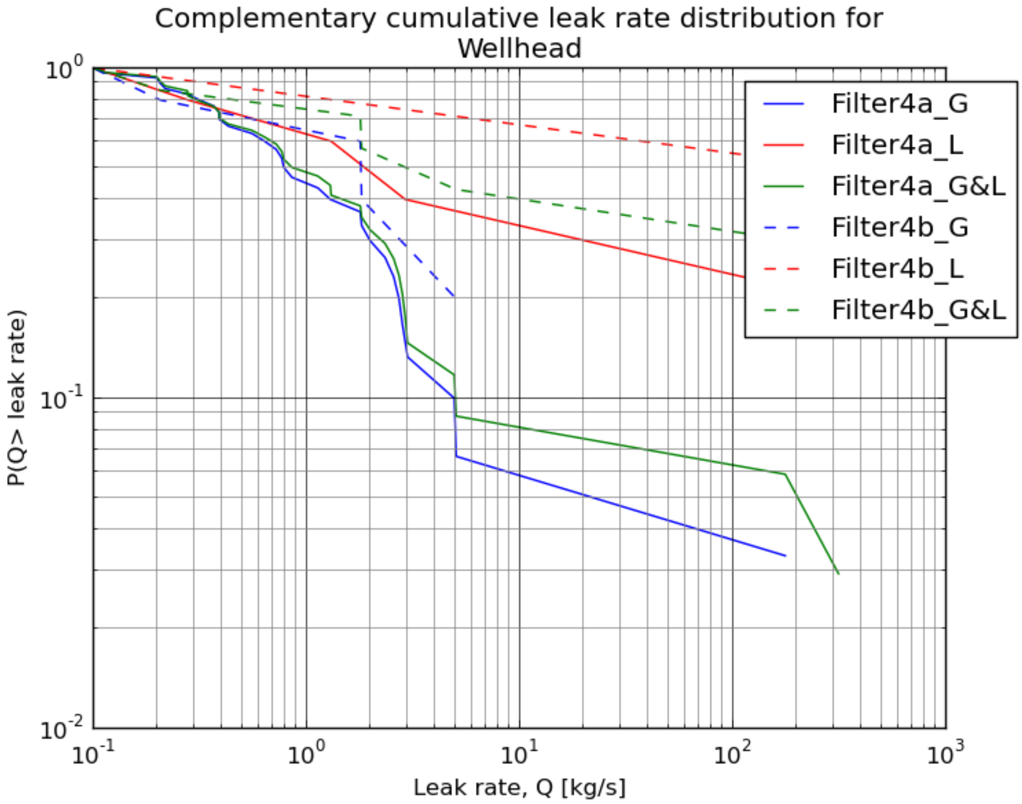

Complementary cumulative hole size distribution for
Air cooled heat exchanger
P(d> hole size)
Hole size [mm]
1.1
1.0
0.9
0.8
0.7
0.6
0.5
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

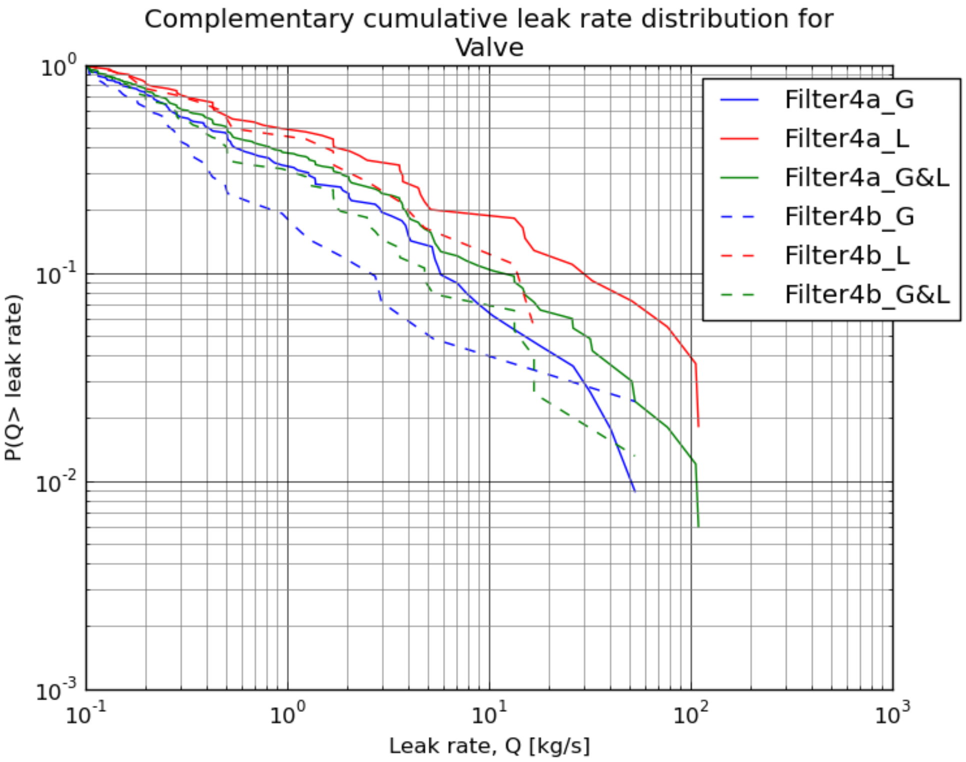

Complementary cumulative hole size distribution for
Wellhead
P(d> hole size)
Hole size [mm]
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
Filter1a
Filter2a
Filter3a
Filter1b
Filter2b
Filter3b

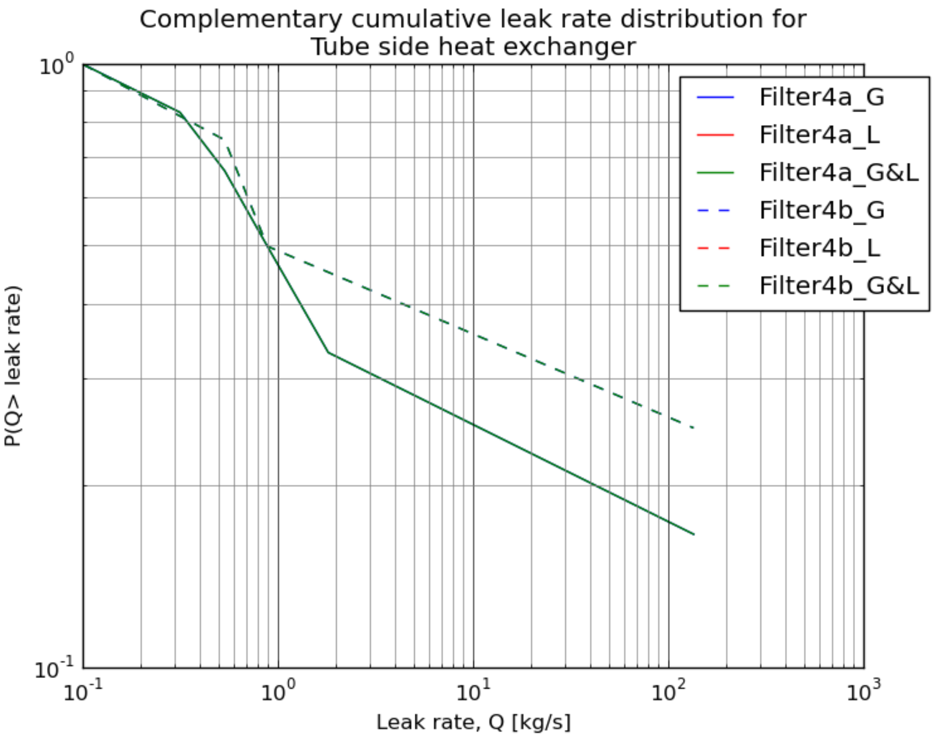
3 Complementary cumulative leak rate distributions based on HCRD

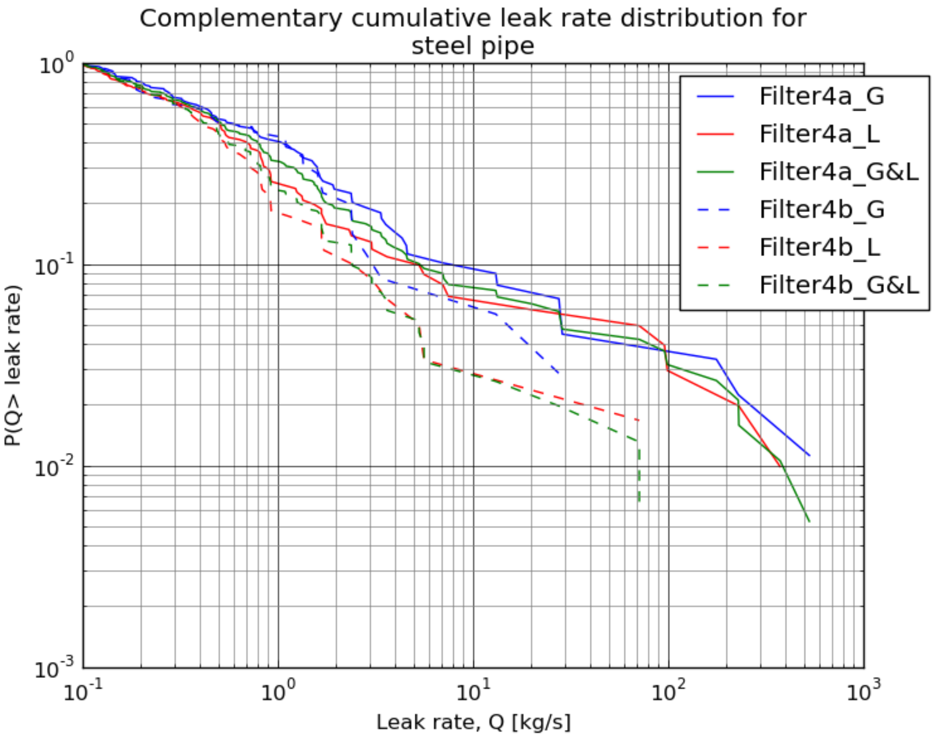
The complementary cumulative leak rate distributions are calculated based on hole size and available process conditions in HCRD.

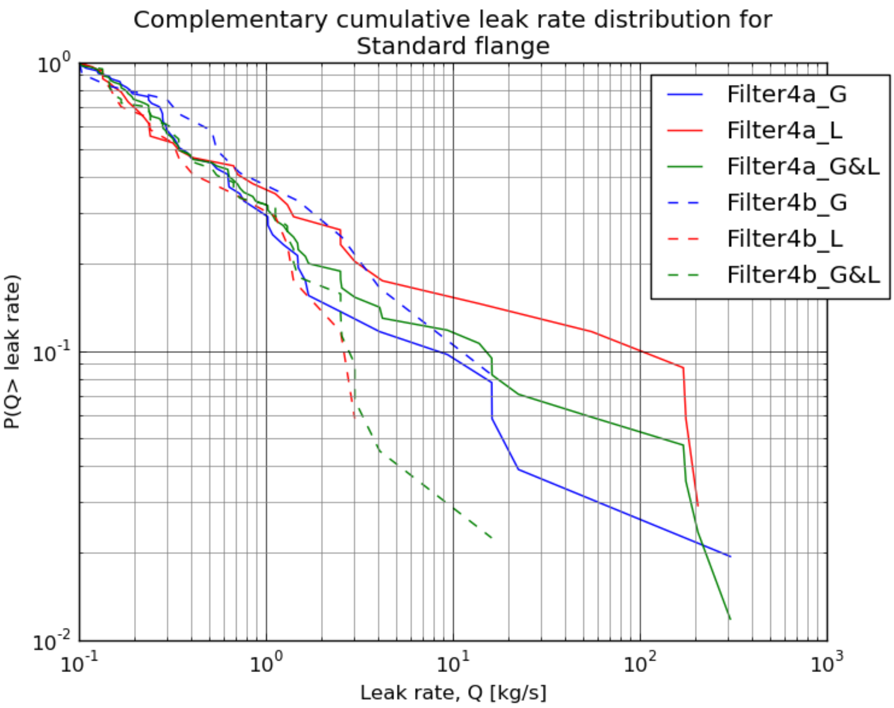
3.1 Log-log plots

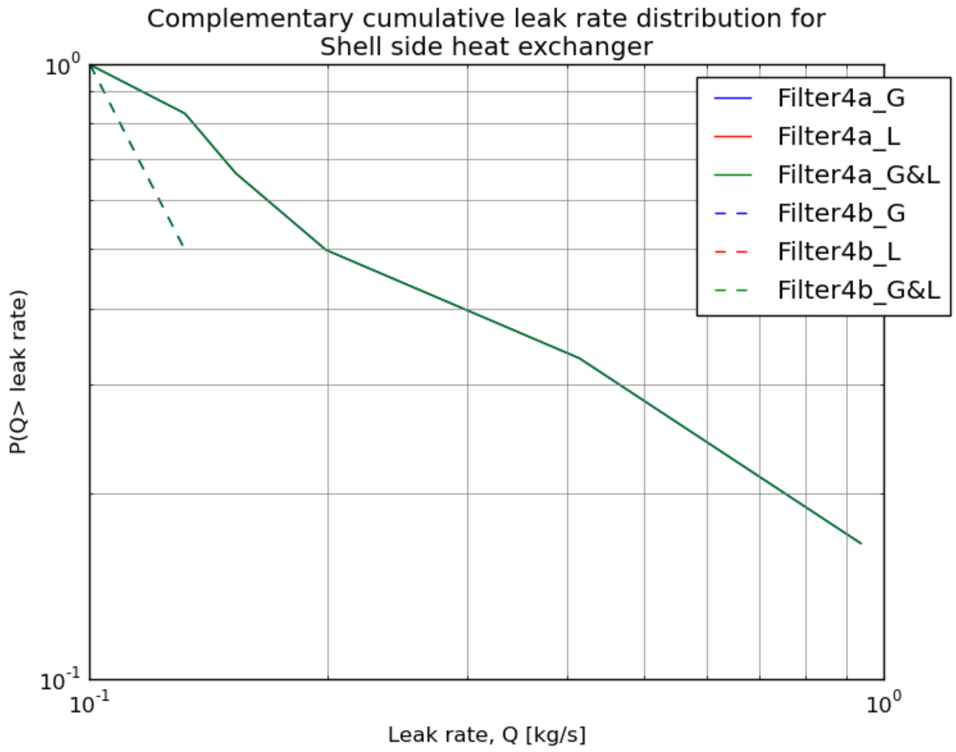


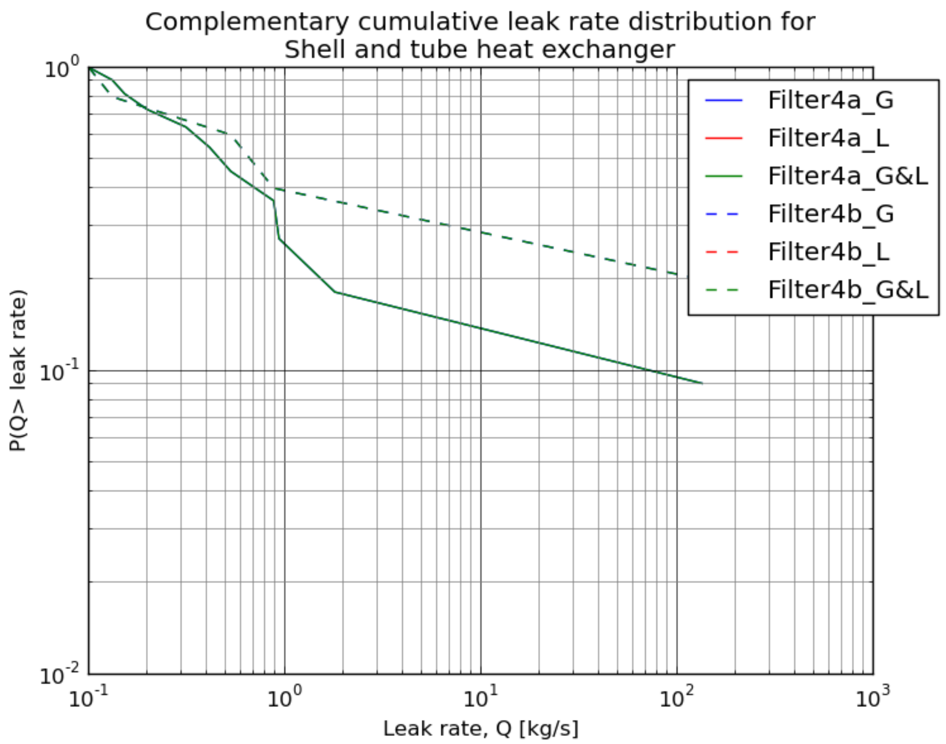

Complementary cumulative leak rate distribution for
Valve
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

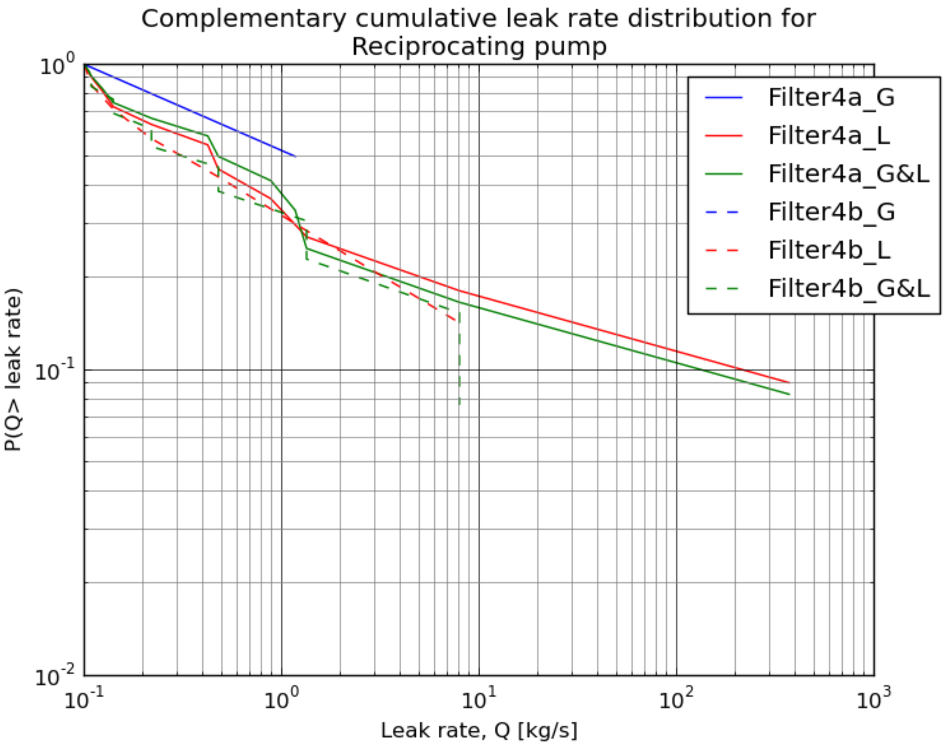

Complementary cumulative leak rate distribution for
Tube side heat exchanger
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L


Complementary cumulative leak rate distribution for
steel pipe
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

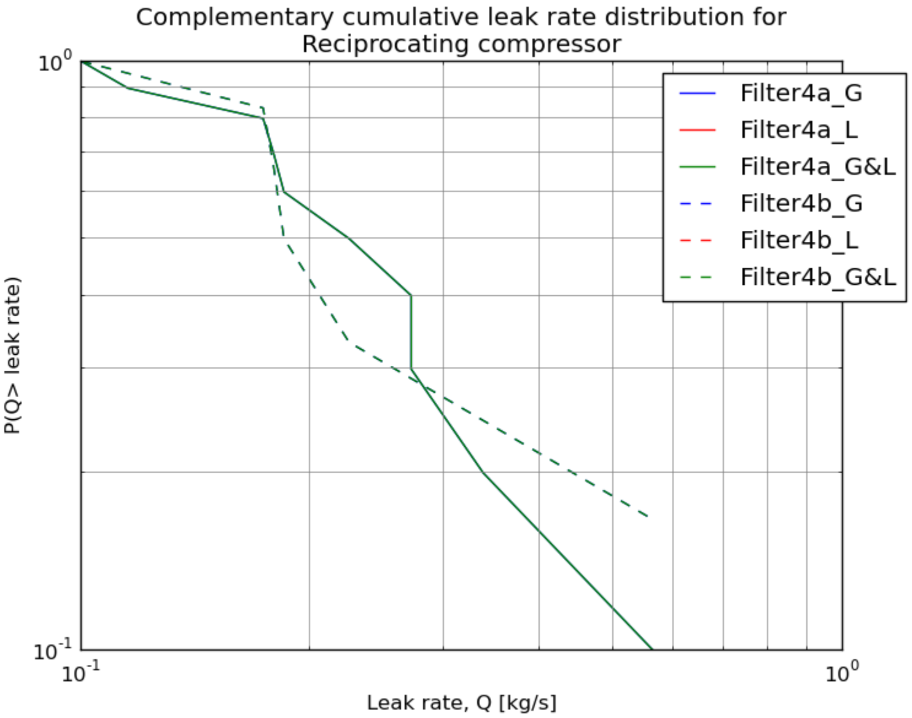

Complementary cumulative leak rate distribution for
Standard flange
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L


Complementary cumulative leak rate distribution for
Shell side heat exchanger
10^0
10^{-1}
10^{-1}
10^0
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

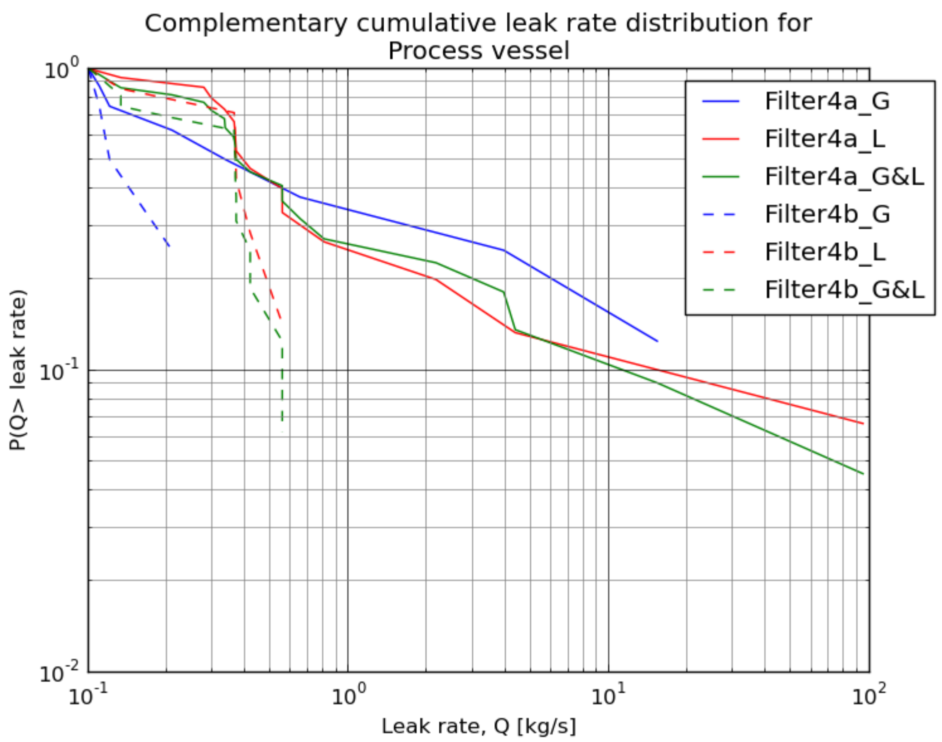

Complementary cumulative leak rate distribution for
Shell and tube heat exchanger
10^0
10^{-1}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

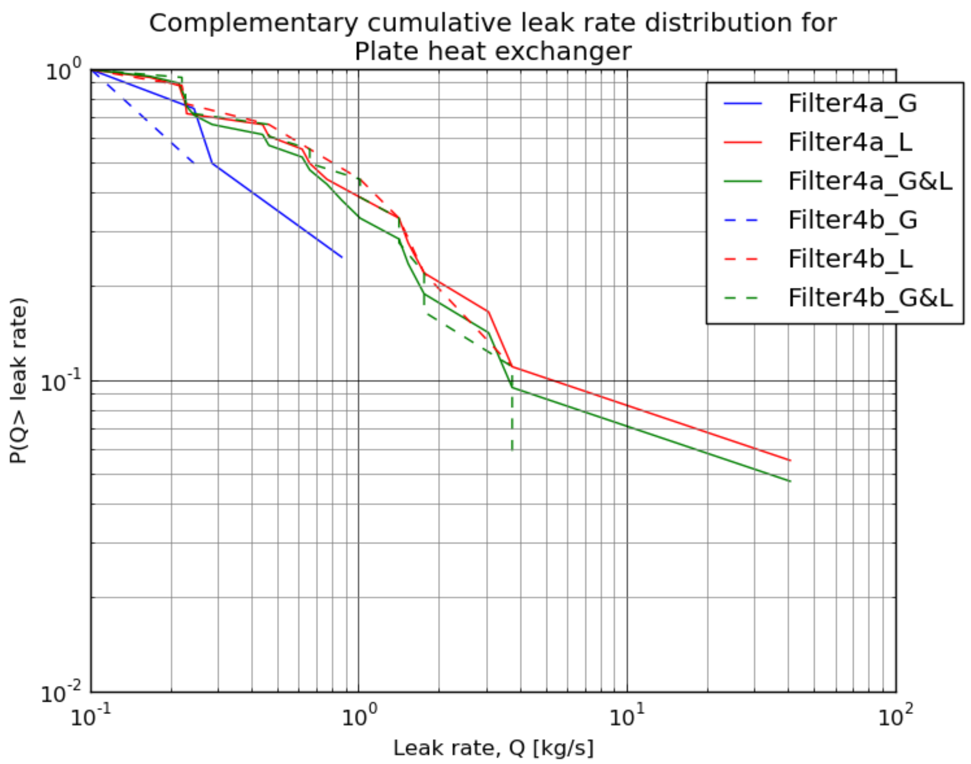


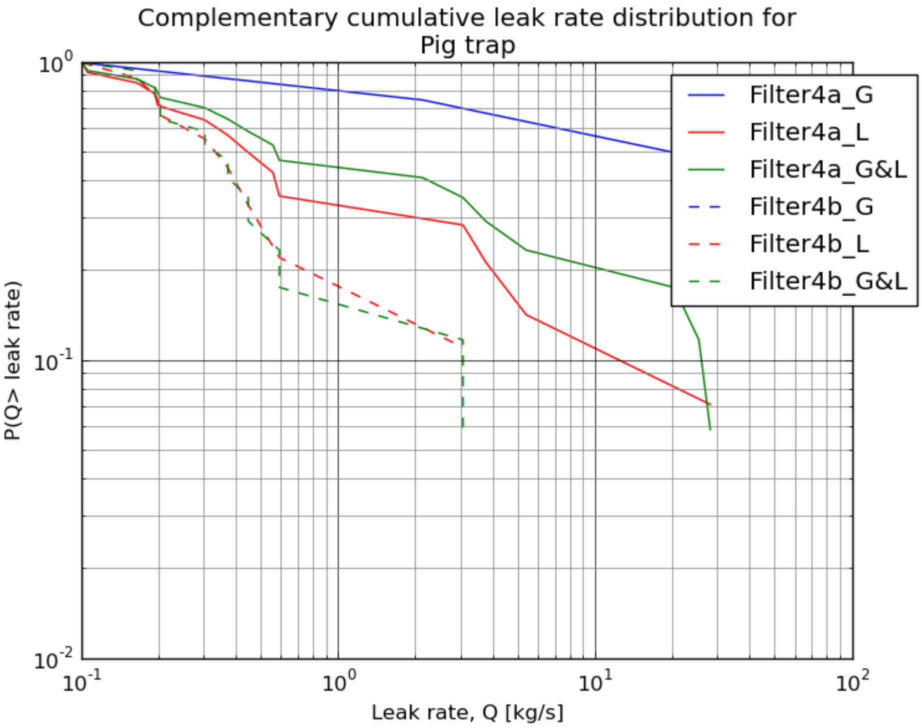
Complementary cumulative leak rate distribution for
Reciprocating pump
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

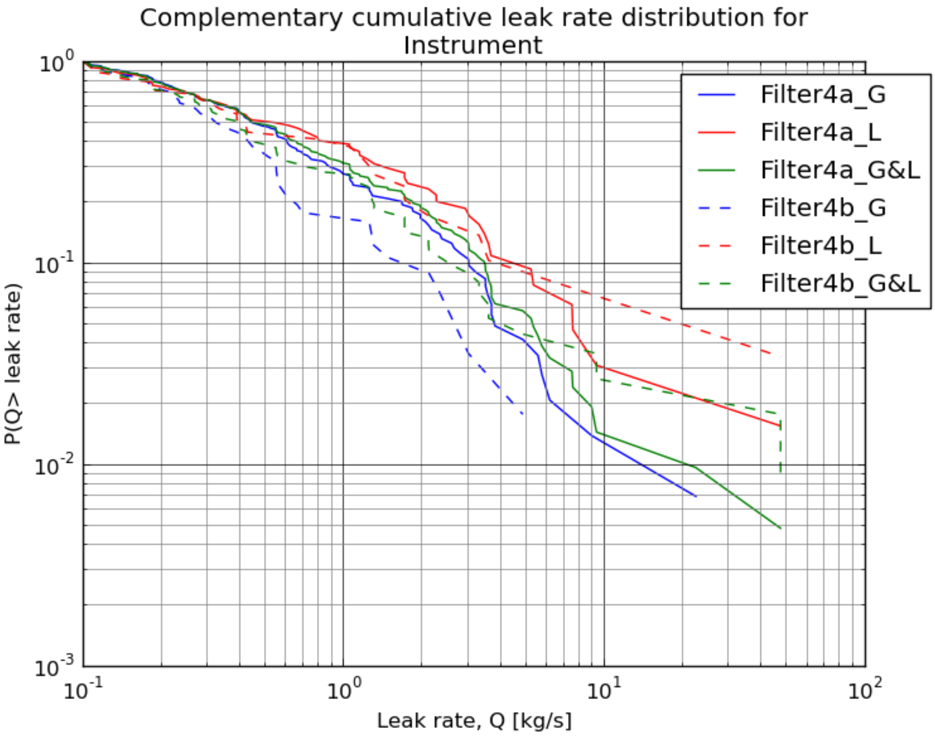


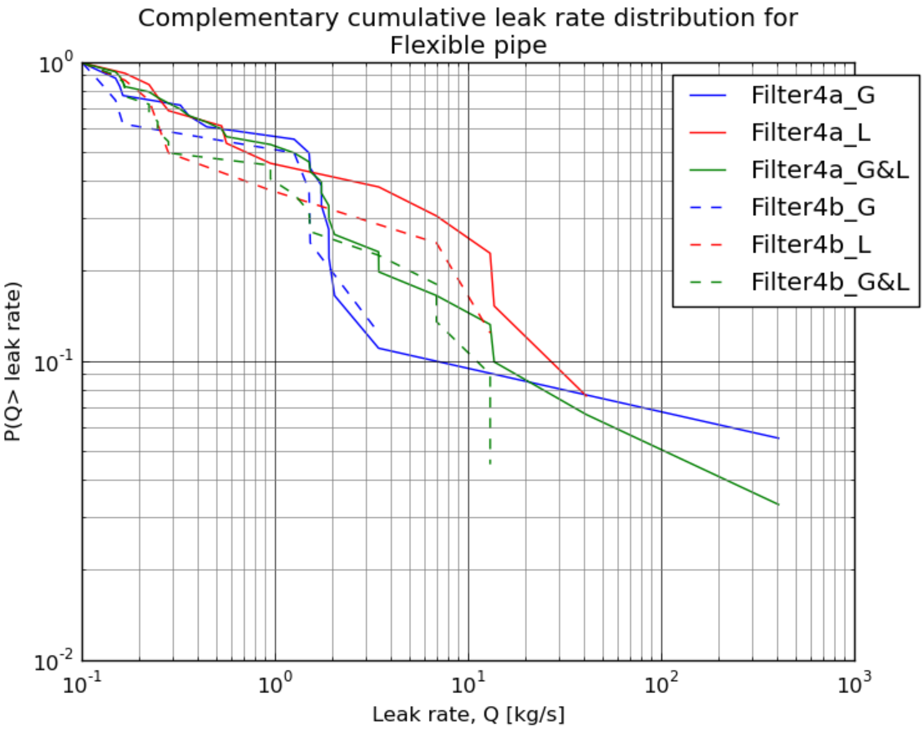
Complementary cumulative leak rate distribution for
Reciprocating compressor
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L


Complementary cumulative leak rate distribution for
Process vessel
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

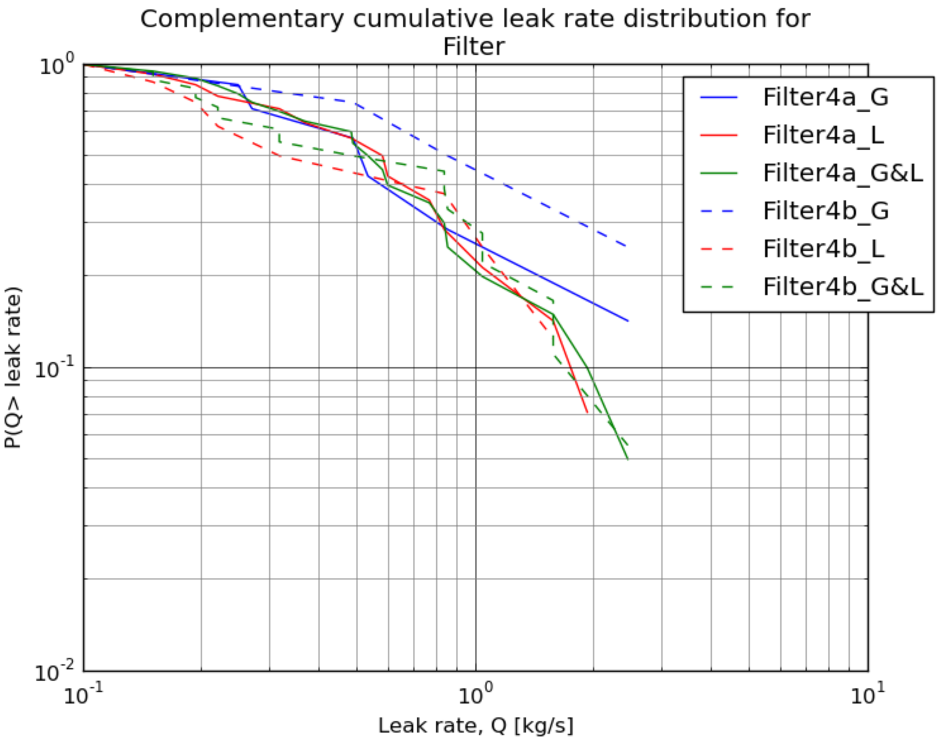

Complementary cumulative leak rate distribution for
Plate heat exchanger
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L


Complementary cumulative leak rate distribution for
Pig trap
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

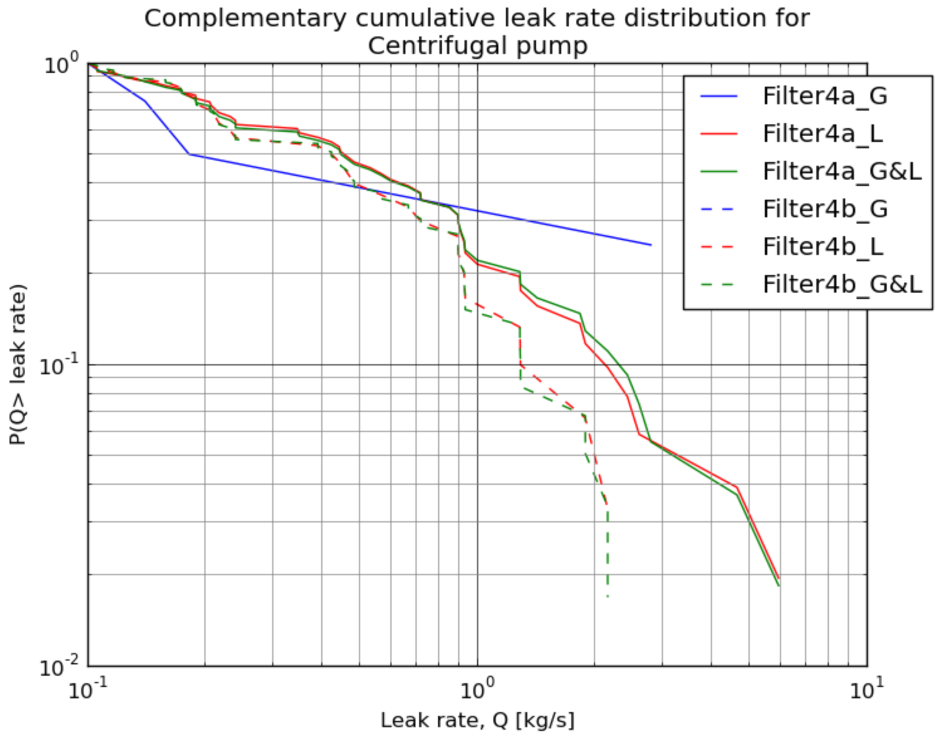

Complementary cumulative leak rate distribution for
Instrument
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

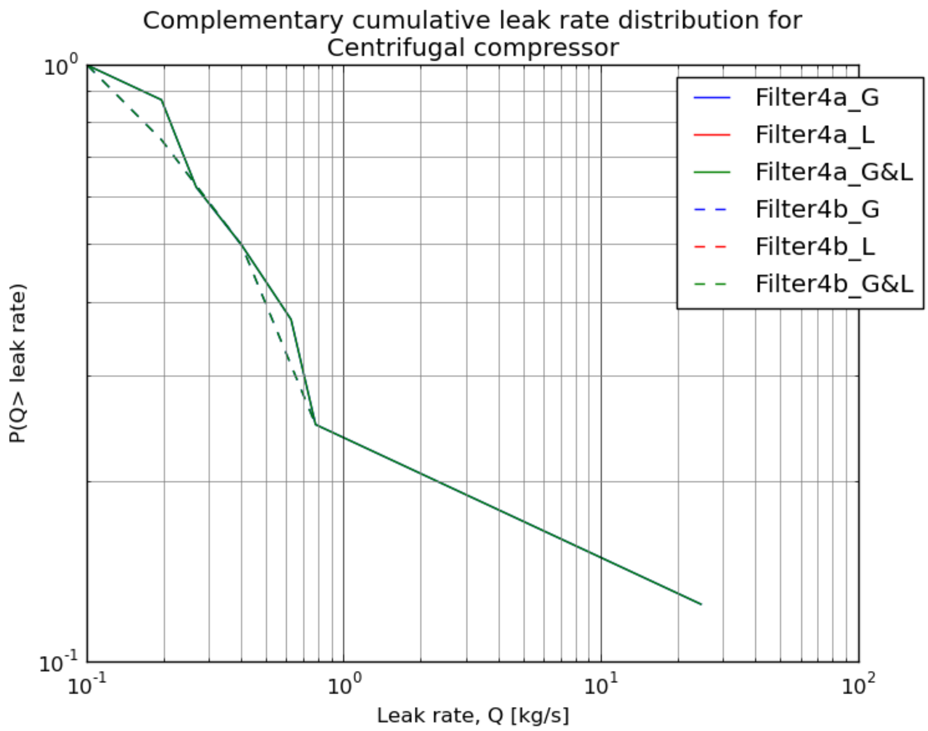


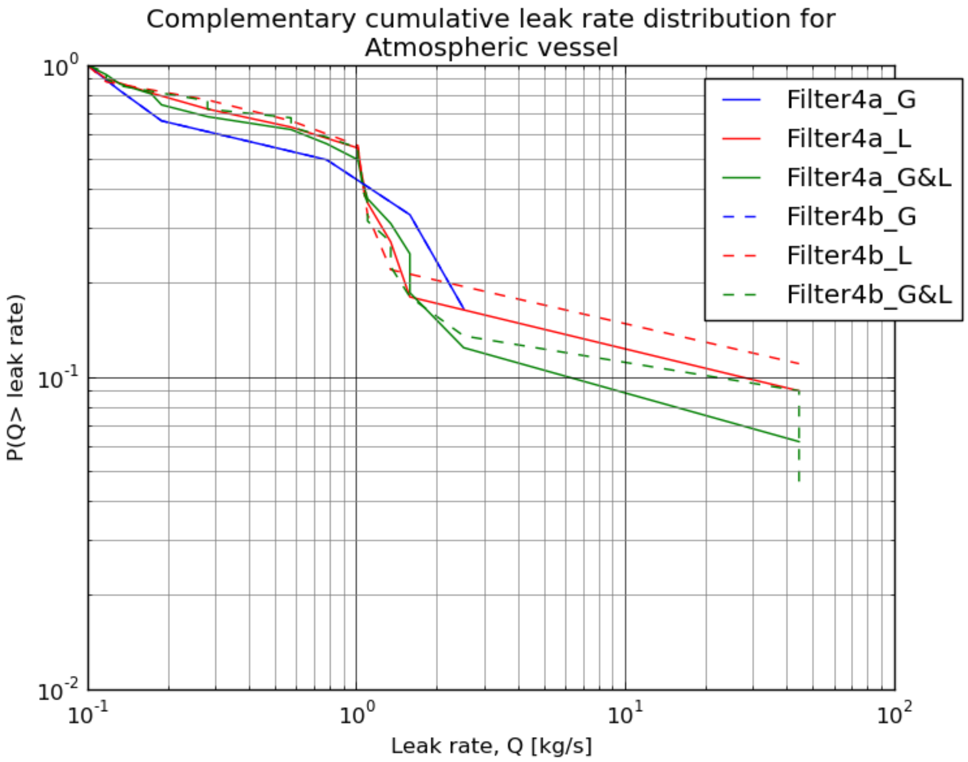
Complementary cumulative leak rate distribution for
Flexible pipe
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

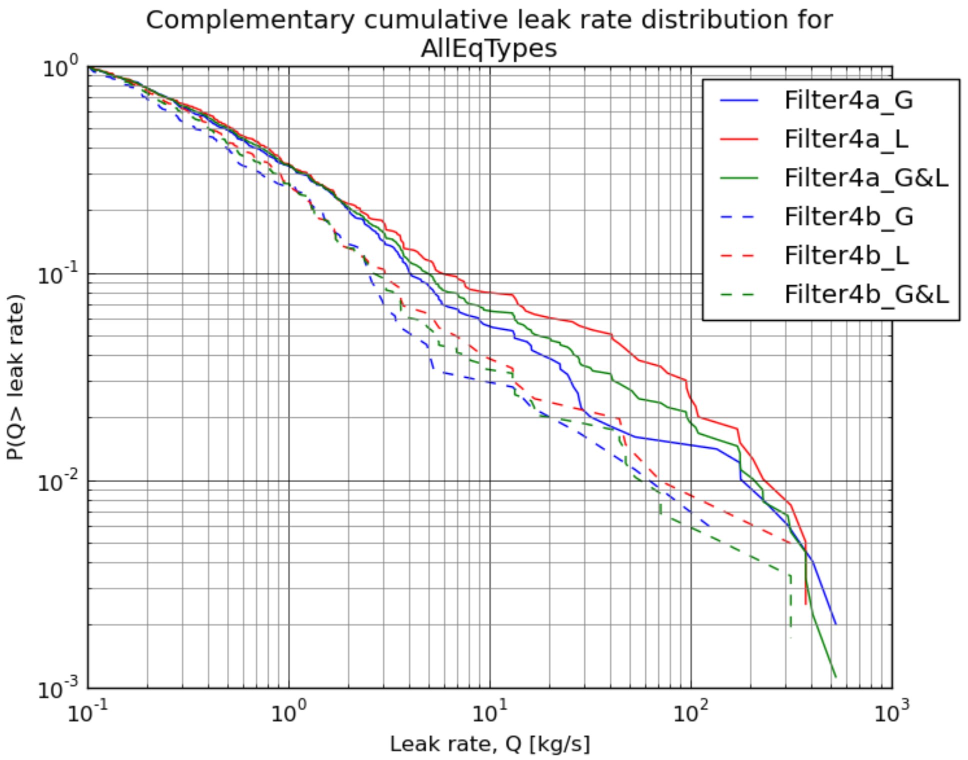


Complementary cumulative leak rate distribution for
Filter
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

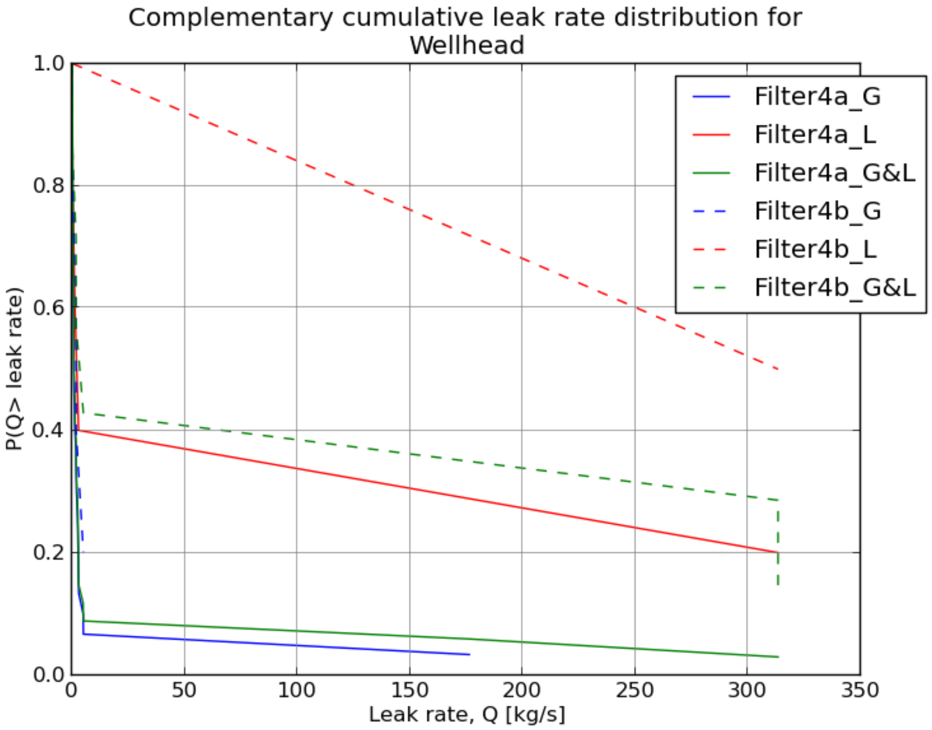

Complementary cumulative leak rate distribution for Centrifugal pump
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

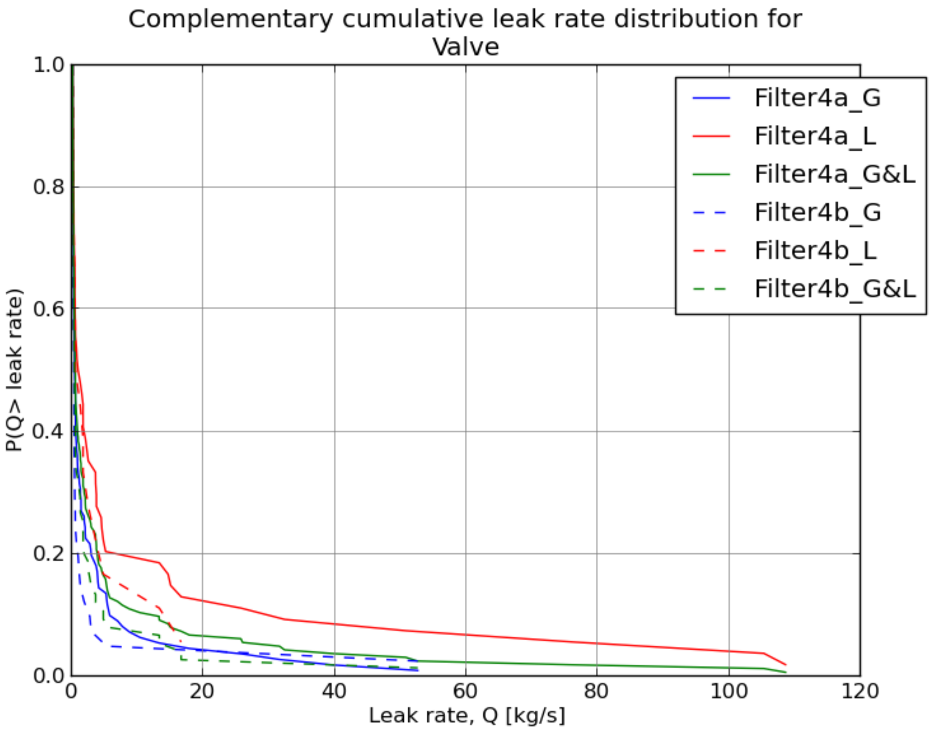

Complementary cumulative leak rate distribution for Centrifugal compressor
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

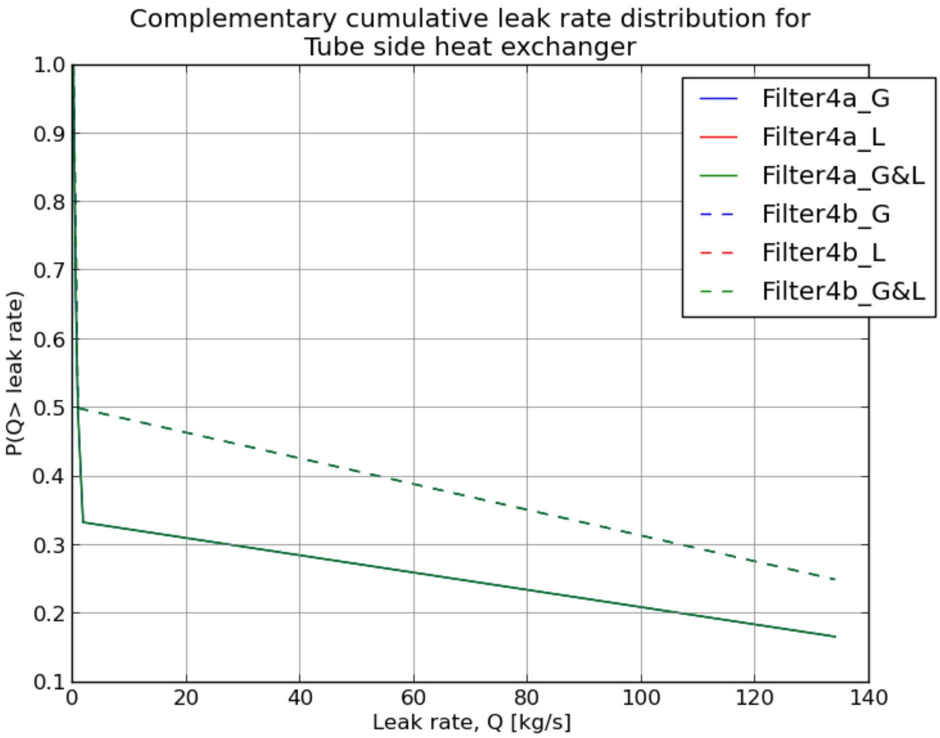

Complementary cumulative leak rate distribution for
Atmospheric vessel
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

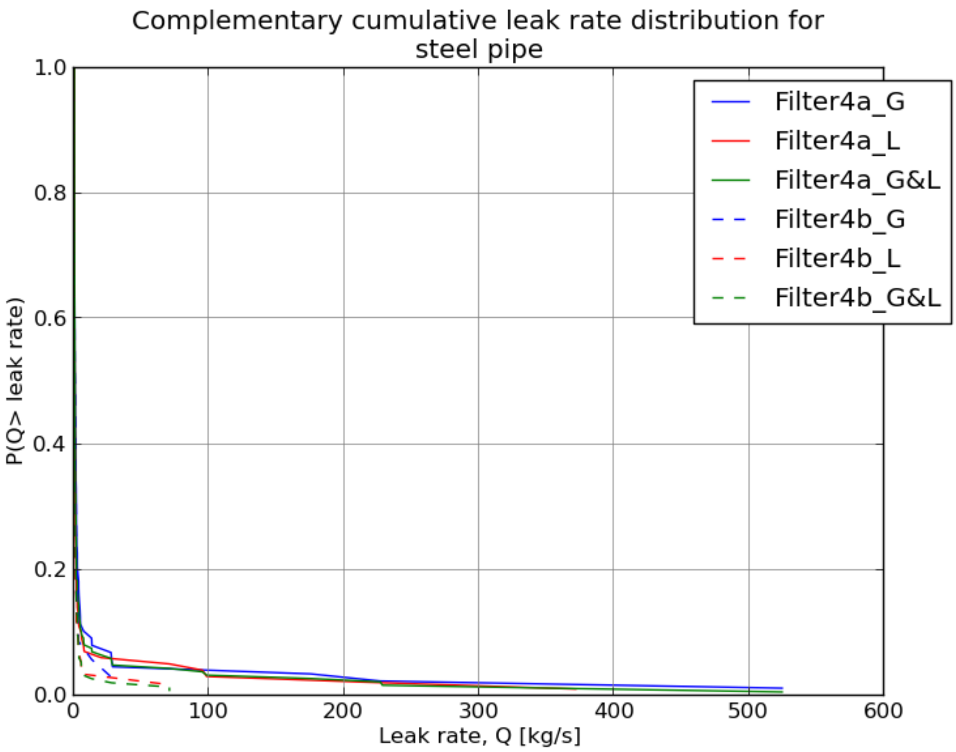

Complementary cumulative leak rate distribution for
AllEqTypes
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

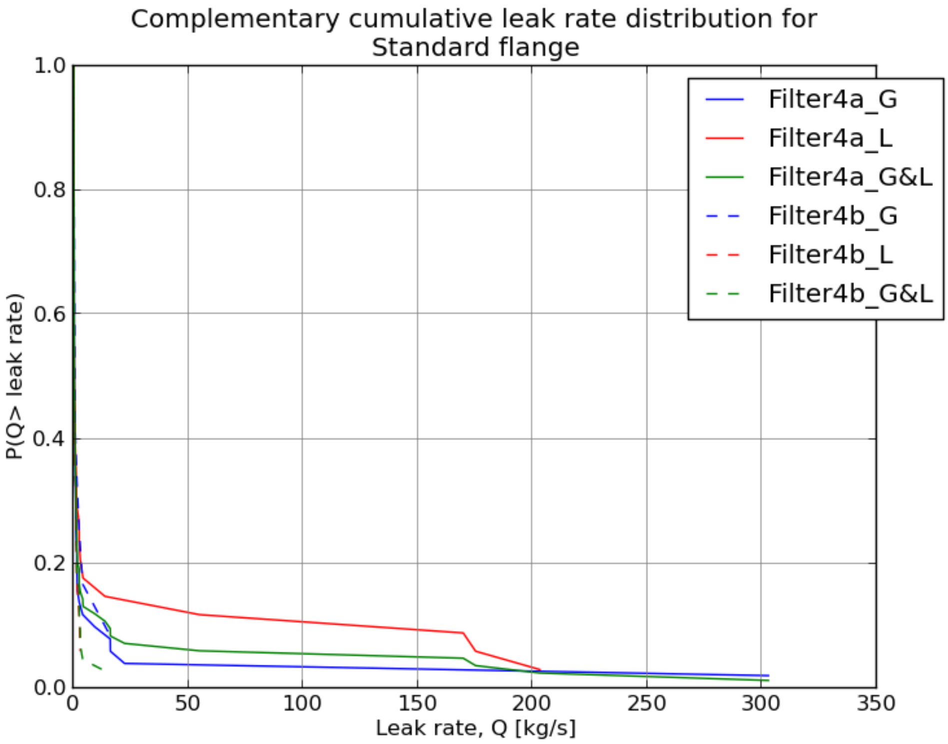
3.2 Linear plots



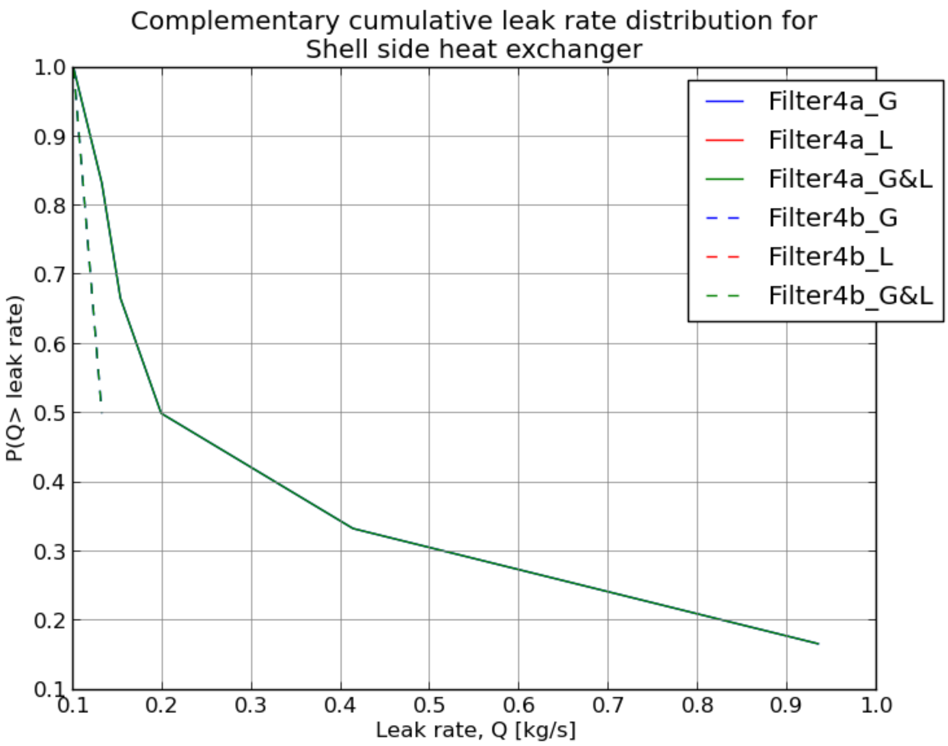



Complementary cumulative leak rate distribution for
Tube side heat exchanger
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

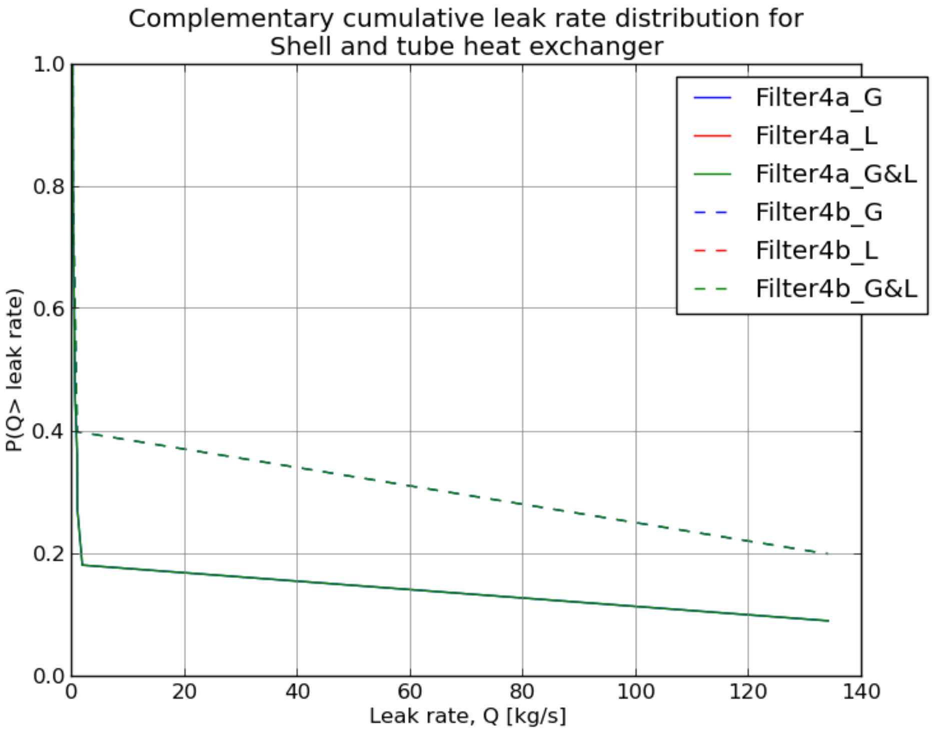

Complementary cumulative leak rate distribution for
steel pipe
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

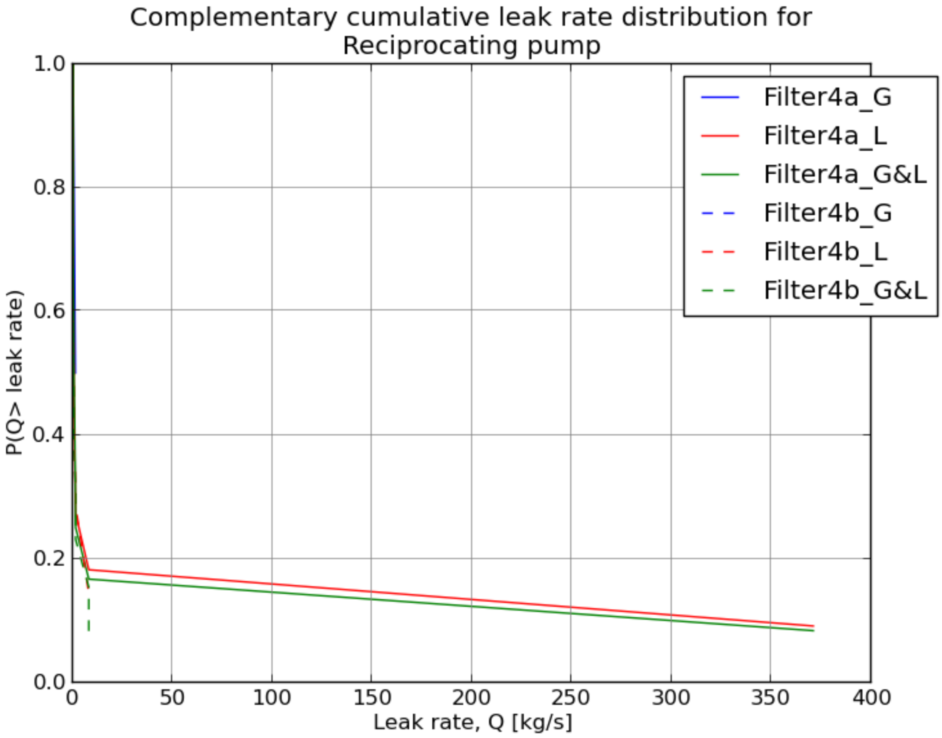


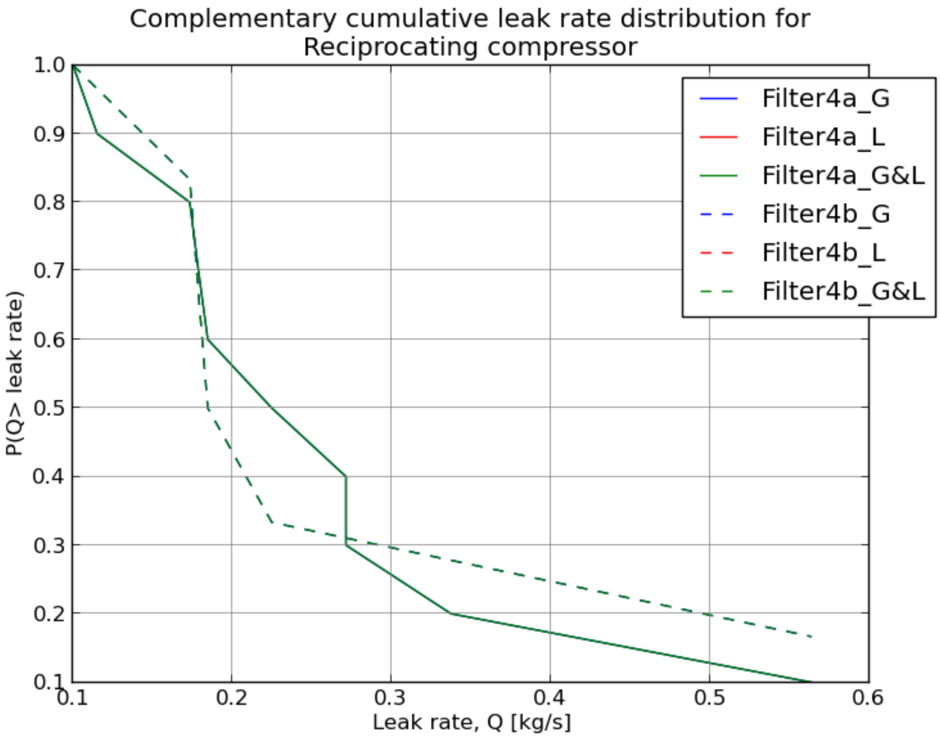
Complementary cumulative leak rate distribution for
Standard flange
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

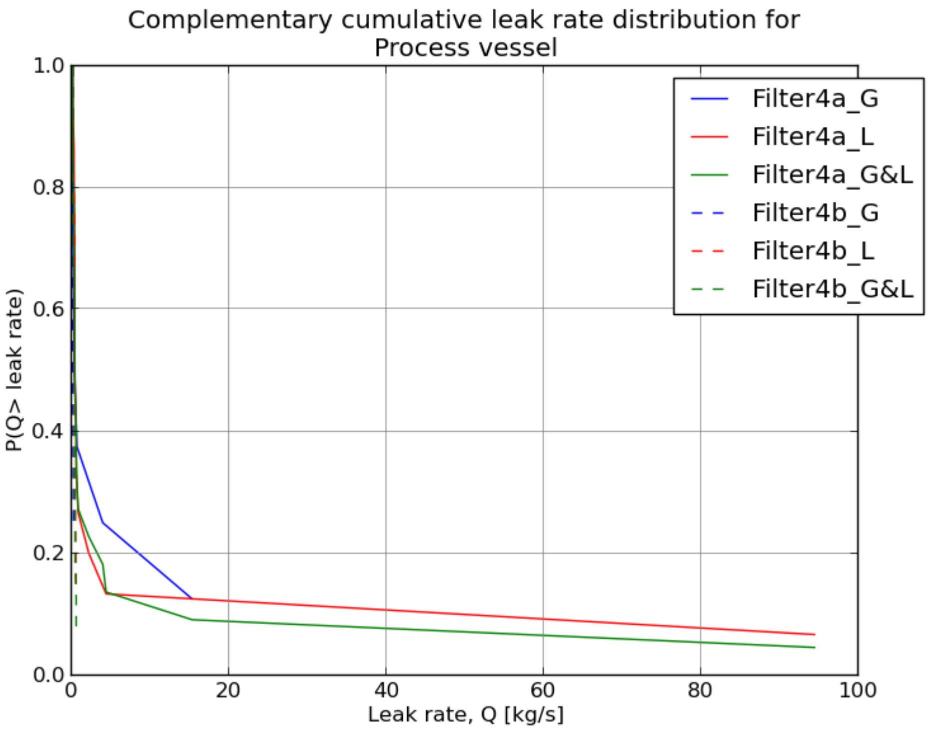


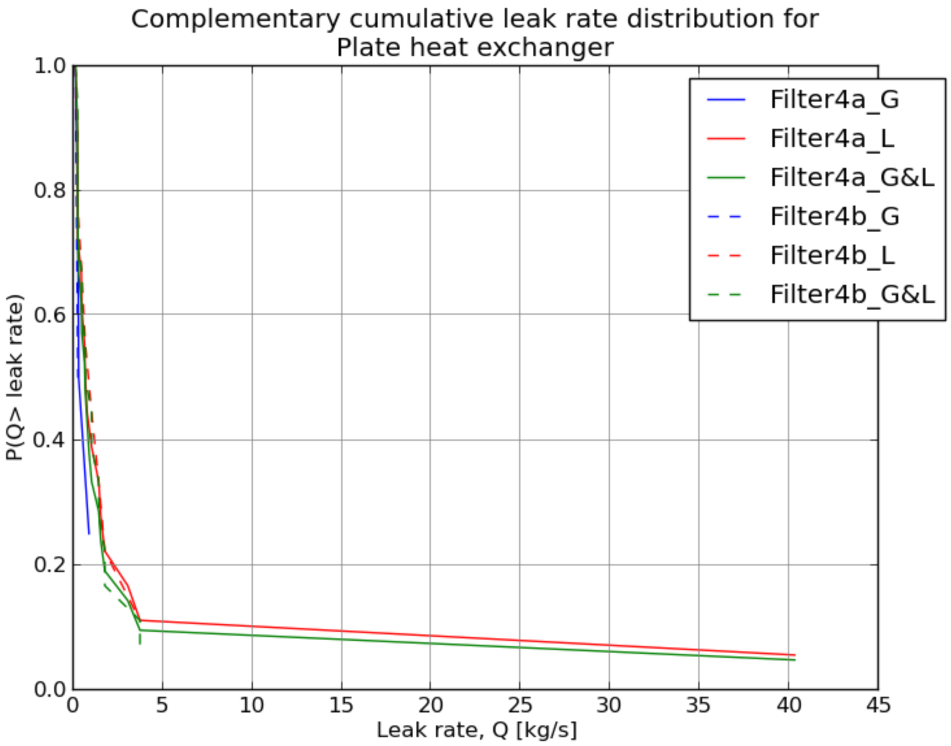
Complementary cumulative leak rate distribution for
Shell side heat exchanger
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L


Complementary cumulative leak rate distribution for
Shell and tube heat exchanger
P(Q> leak rate)
Leak rate, Q [kg/s]
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

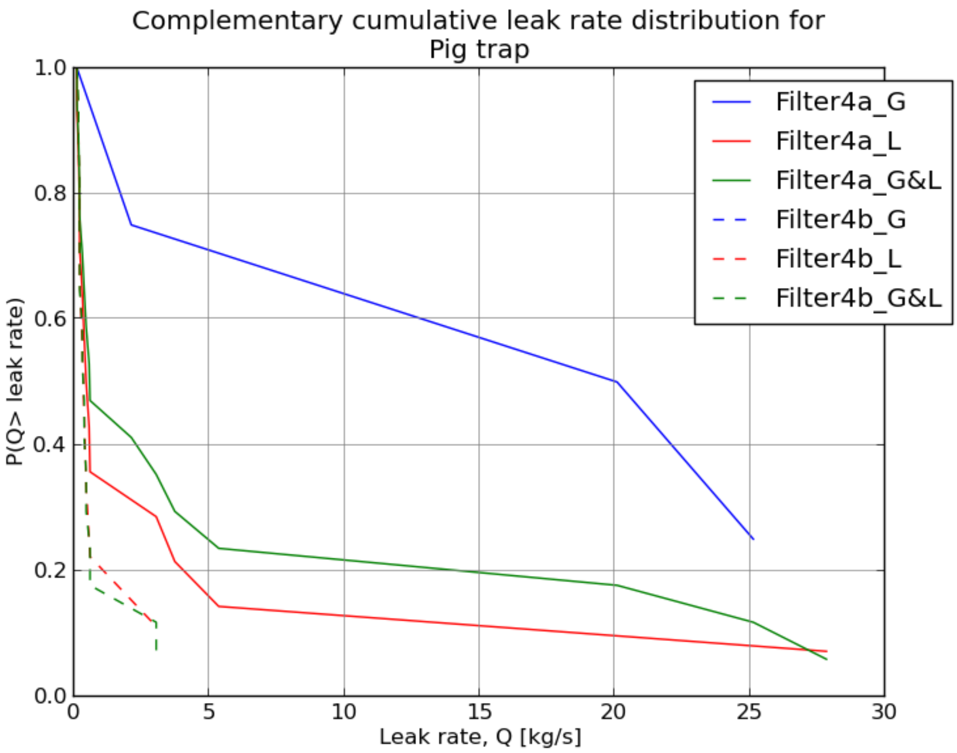

Complementary cumulative leak rate distribution for
Reciprocating pump
P(Q> leak rate)
Leak rate, Q [kg/s]
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L


Complementary cumulative leak rate distribution for
Reciprocating compressor
P(Q> leak rate)
Leak rate, Q [kg/s]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.1
0.2
0.3
0.4
0.5
0.6
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

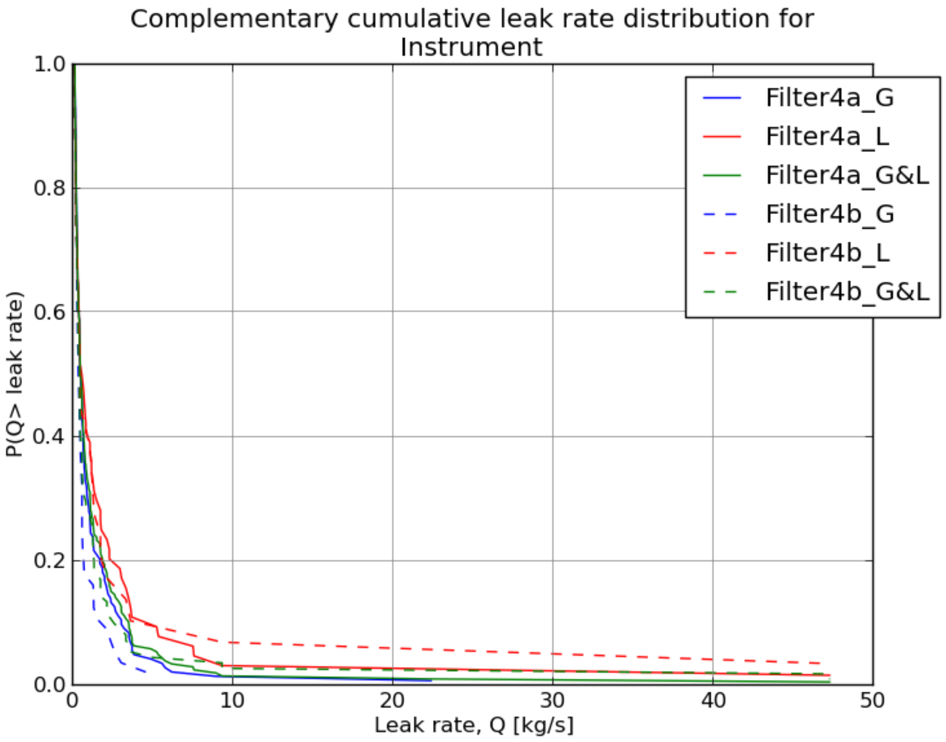

Complementary cumulative leak rate distribution for
Process vessel
P(Q> leak rate)
Leak rate, Q [kg/s]
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

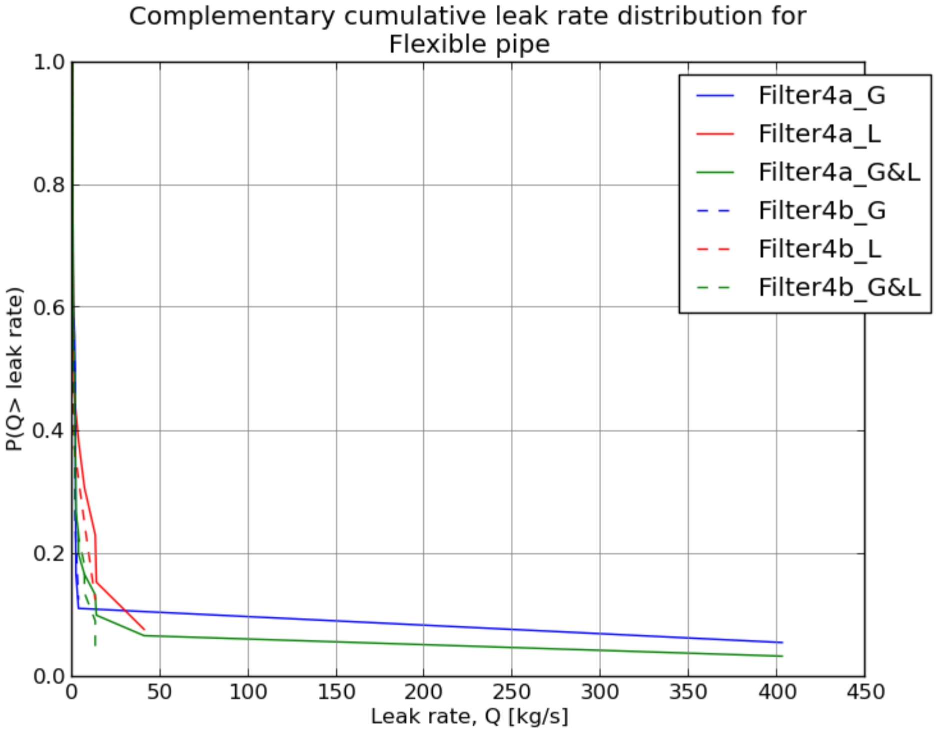


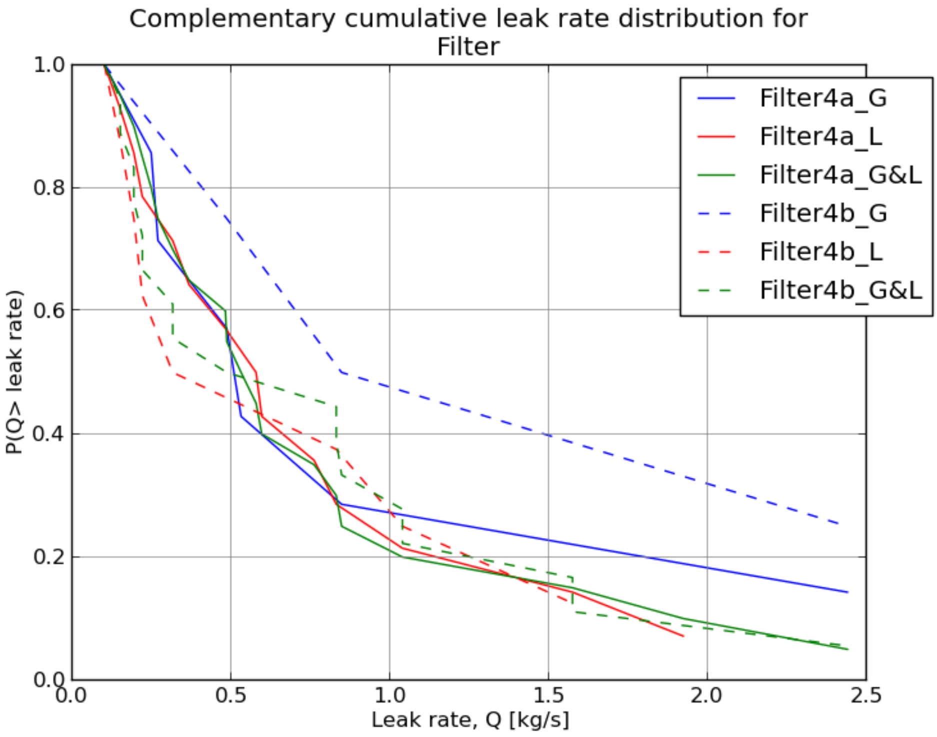
Complementary cumulative leak rate distribution for
Plate heat exchanger
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

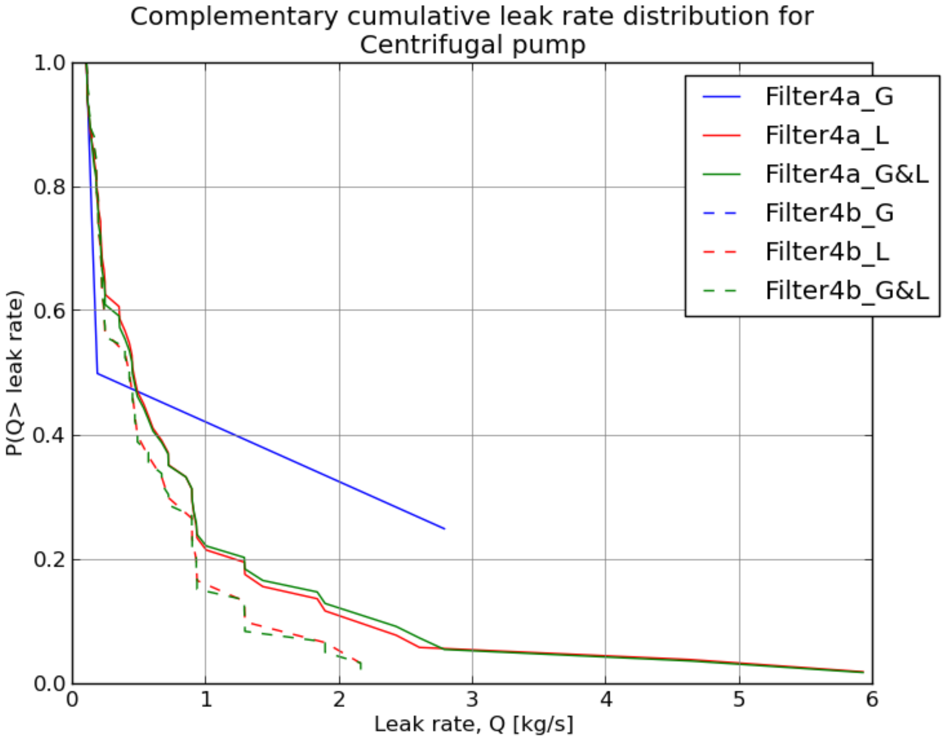


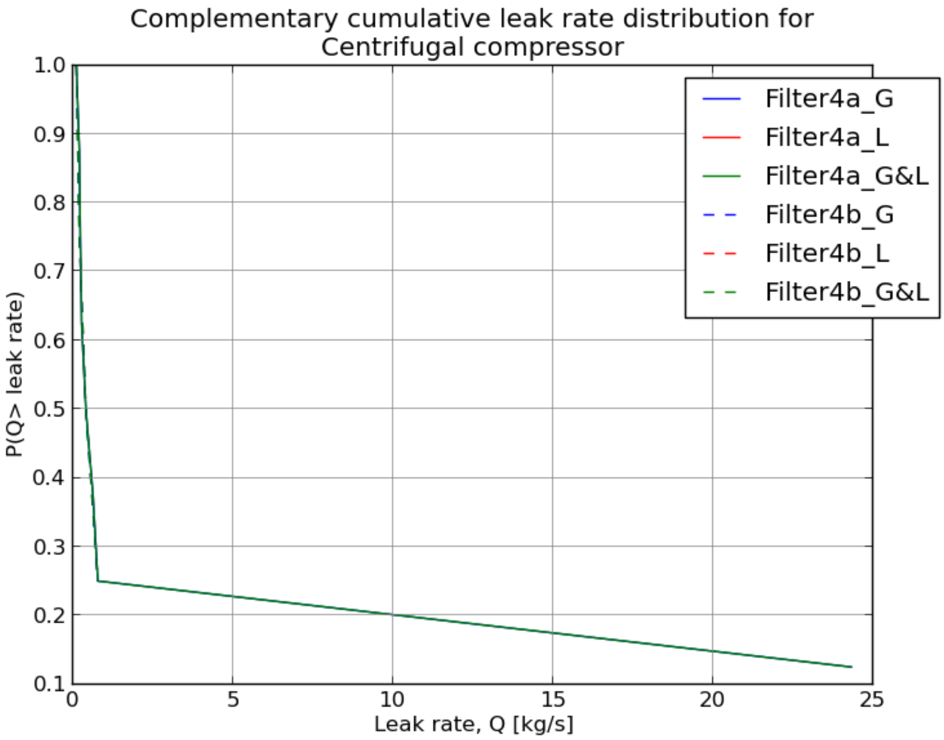
Complementary cumulative leak rate distribution for
Pig trap
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L


Complementary cumulative leak rate distribution for Instrument
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

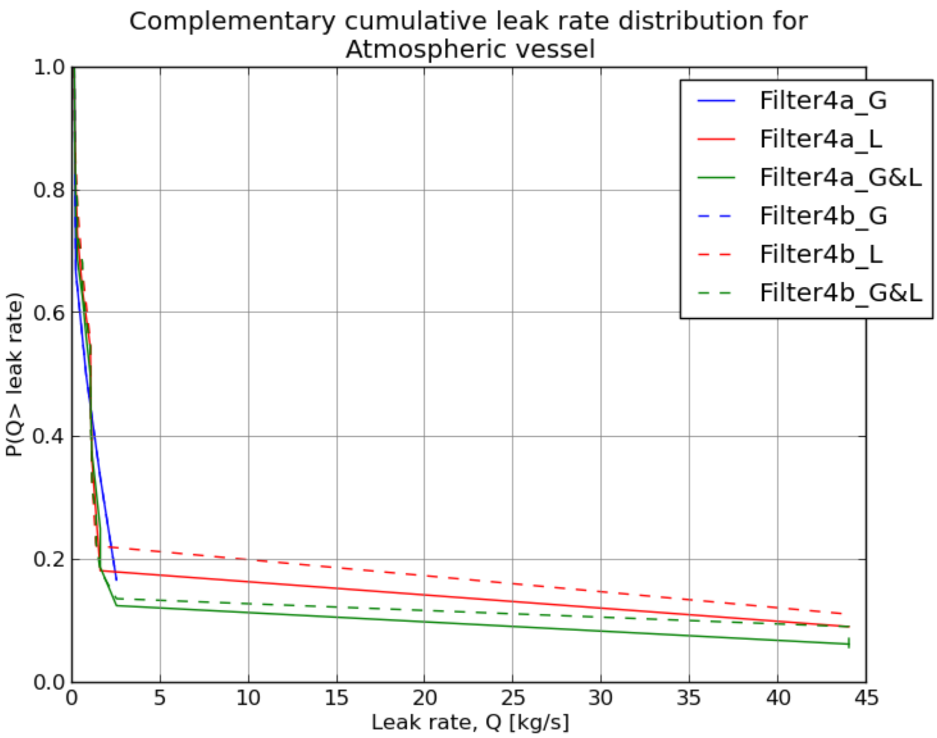

Complementary cumulative leak rate distribution for Flexible pipe
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L


Complementary cumulative leak rate distribution for Filter
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
2.5
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

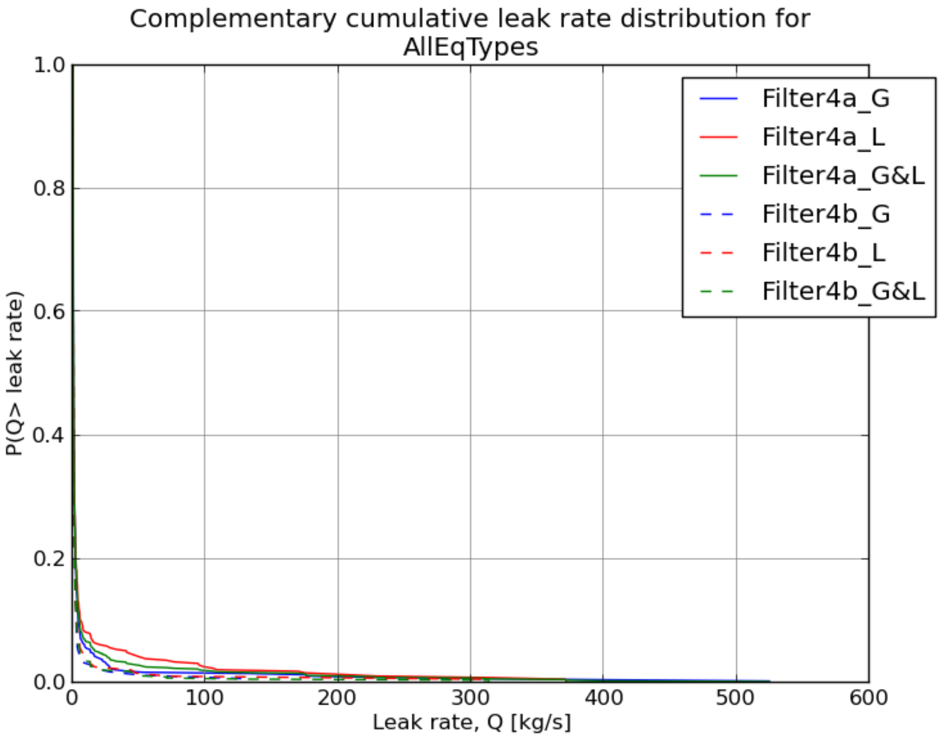

Complementary cumulative leak rate distribution for Centrifugal pump
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
P(Q> leak rate)
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L



Complementary cumulative leak rate distribution for
Centrifugal compressor
P(Q> leak rate)
Leak rate, Q [kg/s]
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L



Complementary cumulative leak rate distribution for
Atmospheric vessel
P(Q> leak rate)
Leak rate, Q [kg/s]
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
45
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L



Complementary cumulative leak rate distribution for
AllEqTypes
1.0
0.8
0.6
0.4
0.2
0.0
P(Q> leak rate)
0
100
200
300
400
500
600
Leak rate, Q [kg/s]
Filter4a_G
Filter4a_L
Filter4a_G&L
Filter4b_G
Filter4b_L
Filter4b_G&L

Appendix D

Recorded incidents at UKCS 2015 - 2017

Table of contents

Page

1 Introduction

This appendix is a part of TN-3 and lists

- updated population data for all installations at UKCS covering the period Q2 1992 – Q4 2016
- the relevant incidents recorded at UKCS with initial leak rate ≥ 0.1 kg/s, in the period Q1 2015 – Q4 2017

2 Updated population data

Table 2.1 shows relevant systems and equipment used to extract population data from HCRD. Table 2.2 displays the extracted equipment years per year.

Table 2.1 – Relevant systems and equipment applied to extract population data

System	Equipment
IMPORT_OIL	COMPRESSORS_CENTRIFUGAL
IMPORT_GAS	COMPRESSORS_RECIPROCATIN
IMPORT_CONDENSATE	EXPANDERS
EXPORT_OIL	FILTERS
EXPORT_GAS	FINFANCOOLER
EXPORT_CONDENSATE	FLANGES (all sizes) [1)]
MANIFOLD_OIL	HEATEXCHANGE_HCINSHELL
MANIFOLD_GAS	HEATEXCHANGE_HCINTUBE
MANIFOLD_OTHERCONDENS	HEATEXCHANGE_PLATE
FLOWLINES_GAS	INSTRUMENTS
FLOWLINES_OIL	PIGLAUNCHERS and PIGRECEIVERS (all sizes)
FLOWLINES_OTHERCONDENS	PRESSUREVESS (all types)
UTILITIES_GAS_FUELGAS	PUMPS_CENTRIFUGAL_DOUBLESEAL
GASCOMPRESSI	PUMPS_CENTRIFUGAL_SINGLESEAL
SEPARATION_OILPRODUCTIO	PUMPS_RECIPROCATIN_DOUBLESEAL
SEPARATION_GASPRODUCTIO	PUMPS_RECIPROCATIN_SINGLESEAL
SEPARATION_OILTEST	TURBINES_GAS
SEPARATION_GASTEST	VALVE (all types)
PROCESSING_OIL_PRODWATERTRE	
PROCESSING_GAS_PRODWATERTRE	
PROCESSING_GAS_DEHYDRATION	
PROCESSING_GAS_LPGCONDENSAT	
PROCESSING_OIL_OILTREATMENT	
PROCESSING_GAS_SOURH2SCO2TR	
METERING_OIL	
METERING_GAS	
METERING_CONDENSATE	

Table 2.2 – Total equipment years per year UKCS installations (exclusive steel pipes)

Year	Equipment year (exclusive steel pipes)
1992	308,831 [1)]
1993	411,608
1994	444,984
1995	455,959
1996	477,349
1997	489,941
1998	522,817
1999	543,082
2000	546,856
2001	533,469
2002	524,530
2003	529,687
2004	530,462
2005	534,336
2006	538,283
2007	548,648
2008	550,231
2009	545,788
2010	545,997
2011	543,403
2012	538,461
2013	541,974
2014	537,646
2015	537,646 [2)]
2016	537,950
Total	**12,819,938**

1) HCRD report data for 50% of year. Figure from HCRD multiplied with 1.5 to adjust for that incidents recorded for ¾ of year.

2) Population data adjusted with fraction of year included in HCRD (0.753).

3 Recorded incidents at UKCS 2015-2017

In total, 382 incidents are recorded (93 for 2015 + 289 for 2016/2017). They are given a unique ID in HCRD. 36 of the incidents are regarded as relevant, and are listed in Table 3.2. Detailed description of the data fields in Table 3.2 are given in Table 3.1.

Table 3.1 - Detailed description of the data fields in Table 3.2

Heading	Description
HCR ID	Unique ID per leak in HCR
Incident year (Calendar)	Year incident occurring
Severity	HCR classification (not relevant for PLOFAM)
System Primary	System according to definition in HCRD
Equipment Primary	Main equipment leak originating from according to HCRD
Inventory (kg)	Data collated by PLOFAM project based on data provided in various fields in HCRD
Duration (sec)	Data collated by PLOFAM project based on data provided in various fields in HCRD
Average leak rate (kg/s)	'Inventory (kg/s)' divided by 'Duration (sec)'
Classification of leak scenario according to definition in PLOFAM	Marginal: inventory ≤ 10 kg Significant: inventory > 10 kg

Table 3.2 – All relevant incidents recorded at UKCS, with initial leak rate ≥0.1 kg/s, in the period 01.01.2015 – 31.12.2017. In total 36 relevant incidents are recorded. They are given a unique ID in HCRD

HCRD ID	Incident Year (Calendar)	Severity	System Primary	Equipment primary	Inventory (kg)	Duration (sec)	Average leak rate (kg/s)	Leak scenario according PLOFAM definition
6578	2015	SIGNIFICANT	FLOWLINES	PIPING	220	700	0.31	Significant
6579	2015	SIGNIFICANT	GAS COMPRESSION	INSTRUMENTS	104	360	0.29	Significant
6584	2015	MINOR	BLANK	BLANK	18	60	0.30	Significant
6558	2015	SIGNIFICANT	FLOWLINES	PRESSURE VESSEL	56	360	0.16	Significant
6553	2015	SIGNIFICANT	FLOWLINES	FLANGES	11	60	0.19	Significant
6610	2015	SIGNIFICANT	DRAINS	PIPING	1360	600	2.27	Significant
6611	2015	SIGNIFICANT	GAS COMPRESSION	INSTRUMENTS	1	10	0.10	Marginal
6526	2015	SIGNIFICANT	PROCESSING	CRUDE OIL STORAGE	2000	900	2.22	Significant
6530	2015	SIGNIFICANT	METERING	PRESSURE VESSEL	115	300	0.38	Significant
6520	2015	SIGNIFICANT	EXPORT	COMPRESSORS	1670	180	9.28	Significant
6535	2015	MAJOR	EXPORT	PIPING	20000	1020	19.61	Significant
6513	2015	SIGNIFICANT	SEPARATION	PRESSURE VESSEL	30	540	0.06	Significant
6510	2015	SIGNIFICANT	EXPORT	VALVE MANUAL	304	180	1.69	Significant
6505	2015	SIGNIFICANT	PROCESSING	HEAT EXCHANGERS	135	600	0.23	Significant
6578	2015	SIGNIFICANT	FLOWLINES	PIPING	220	700	0.31	Significant
6862	2017	Awaiting Classification	GAS COMPRESSION	PIPING		300	0.27	1
6810	2017	SIGNIFICANT	PROCESSING	PUMPS	81	120	1.67	Significant
6786	2017	SIGNIFICANT	DRAINS	FLANGES	200	30	2.73	Significant
6772	2017	SIGNIFICANT	EXPORT	VALVE ACTUATED	82	600	0.64	Significant
6764	2017	MINOR	SEPARATION	PIPING	385	600	0.25	Significant

HCRD ID	Incident Year (Calendar)	Severity	System Primary	Equipment primary	Inventory (kg)	Duration (sec)	Average leak rate (kg/s)	Leak scenario according PLOFAM definition
6758	2017	SIGNIFICANT	GAS COMPRESSION	FLANGES	150	600	0.15	Significant
6750	2017	SIGNIFICANT	FLARE	FLANGES	89	15	0.42	Marginal
6745	2017	SIGNIFICANT	METERING	PIPING	6	240	0.50	Significant
6732	2017	MINOR	GAS COMPRESSION	VALVE MANUAL	120	2	0.08	Marginal
6712	2017	SIGNIFICANT	FLOWLINES	VALVE ACTUATED	0	10	0.35	Marginal
6720	2016	MINOR	UTILITIES	VALVE MANUAL	4	4	0.11	Marginal
6714	2016	MINOR	SEPARATION	DRAIN OPENING	0	10	0.14	Marginal
6696	2016	SIGNIFICANT	PROCESSING	PRESSURE VESSEL	1	43	1.58	Significant
6689	2016	SIGNIFICANT	PROCESSING	HEAT EXCHANGERS	68	300	0.53	Significant
6680	2016	MINOR	GAS COMPRESSION	COMPRESSORS	160	20	0.18	Marginal
6673	2016	SIGNIFICANT	PROCESSING	PIPELINES	4	540	0.20	Significant
6661	2016	MAJOR	GAS COMPRESSION	HEAT EXCHANGERS	110	600	1.05	Significant
6651	2016	MAJOR	GAS COMPRESSION	PIPING	632	390	2.48	Significant
6649	2016	SIGNIFICANT	SEPARATION	PIPING	966	18	2.96	Significant
6646	2016	SIGNIFICANT	GAS COMPRESSION	COMPRESSORS	54	300	0.13	Significant
6642	2016	SIGNIFICANT	SEPARATION	INSTRUMENTS	40	5160	0.21	Significant
6631	2016	SIGNIFICANT	BLANK	HEAT EXCHANGERS	1072	600	0.17	Significant