LEAK FREQUENCY MODELLING FOR OFFSHORE QRA BASED ON THE HYDROCARBON RELEASE DATABASE

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The HSE Hydrocarbon Release Database (HCRD) is the best quality dataset that exists on offshore releases and has thus become the standard source of leak frequencies for offshore quantitative risk assessment (QRA). StatoilHydro have observed that different solutions by different analysts lead to QRAs having significant inconsistency in leak frequencies despite being based on the same dataset. StatoilHydro therefore initiated a study to standardise the leak frequency model to be used for their offshore facilities in the North Sea. The work and methodology derived in this project has mainly been developed by Det Norske Veritas (DNV), but with significant co-operation and input by Scandpower Risk Management and Safetec in addition to StatoilHydro.

Despite the high quality of the HCRD, there are some significant problems in obtaining credible leak frequencies from it. This paper discusses these problems, and explains the solutions developed by DNV, StatoilHydro and their co-operating partners.

In this project a set of analytical leak frequency functions have been developed from the HCRD data. These provide a standardised approach to obtaining leak frequencies that are compatible with consequence modelling, and hence improve credible risk estimation.

Work in this area has been presented by Spouge at Hazards XIX but has now been reviewed and extended, the work includes analysis of incidents up to March 2008. The extended work has led to a revised process for estimating the proportion of leaks with reduced consequences. In addition, a method for deriving mathematical functions for hole size distributions for various equipment types has been further developed. The resulting data can be readily incorporated into offshore QRA studies to provide a more accurate means of leak frequency estimation.

INTRODUCTION

Hydrocarbon leaks from process equipment make a significant contribution to the risks on offshore installations. When risk management options are evaluated using quantitative risk assessment (QRA), the frequency of such leaks is an input to the study that will have a major influence on the estimated risk, and hence risk management decisions. This paper considers the source of such data, and reviews a recent initiative to improve its quality and consistency.

When performing a QRA, the main challenge is to have access to relevant data, and be able to process and understand such data correctly in order to obtain proper input data to the analyses.

The calculated risk contribution from hydrocarbon leaks on offshore installations depends largely on the quality of the input data used, and the company conducting the actual analyses. It has been identified that the latter is caused by the analysts using different methodologies and assumptions when analysing the data to obtain the results. Therefore, StatoilHydro initiated a project to establish relevant and consistent data sets which should be available and used by all contractors providing QRAs for their facilities in the North Sea. The work has been based upon the UK Health & Safety Executive's (HSE) Hydrocarbon Release Database (HCRD). The HCRD has been in operation since 1992 and contains all reported releases from the UK Continental Shelf (UKCS).

The HSE hydrocarbon release database (HCRD) (Reference 1) has become the standard source of leak frequencies for offshore QRA and provides a large, high-quality collection of leak experience. Where QRAs use the unmodified HSE leak frequencies and assume standard consequences, the risk results tend to be higher than actual experience. Different analysts use different approaches and assumptions in modifying the data for use in their QRA studies. These different types of modification can lead to the frequencies used by analysts being inconsistent despite being based on the same HCRD dataset. Standardisation of leak frequencies based on HCRD is therefore a desirable goal, and is the focus of the present project. Data from 1992 until March 2008 has been used as a basis for this project.

The methodology used for obtaining leak frequencies from HCRD consists of the following three main steps.

- ***Grouping data*** for different types and sizes of equipment, where there is insufficient experience to show significant differences between them.
- ***Fitting analytical leak frequency functions*** to the data, in order to obtain a smooth variation of leak frequency with equipment and hole size.
- ***Splitting the leak frequencies into different leak scenarios*** in order to promote compatibility with different approaches to outflow modelling in the QRA.

These issues have previously been discussed by Spouge (References 2 and 3). These have been reviewed and amended as part of this work. For brevity, only a brief discussion is included in this paper which focuses on the application of the process to achieve a set of rules for establishing an overall frequency model. Again for brevity, the precise details of the calculations are not included here. It is intended to refine the process as more data is entered in the HCRD and interpretation is improved.

GROUPING OF DATA

The DNV analysis covers 17 different types of process equipment and one composite group (valves), as listed in Table 1. Wellhead equipment, drilling equipment, pipelines and risers are all excluded from the analysis, since other more extensive data sources are available for such equipment. The remaining types of equipment are termed "process equipment".

HCRD and the Statistics Report allow 78 separate types and sizes of process equipment to be distinguished. In some cases, there is relatively little leak experience and differences in leak frequencies between certain types and sizes of process equipment have no statistical significance. Such results may be misleading. To avoid this, it is desirable to combine equipment types and sizes with relatively little leak experience. Most HCRD equipment types have therefore been used as defined by HSE, but some with relatively little leak experience have been combined. In the future, as more leaks are reported, it may be possible to subdivide these groups while still having sufficient data to fit the leak frequency functions.

Table 1. Equipment type groups

DNV equipment types	HCRD equipment types
Steel pipes	Piping, steel (3 sizes)
Flanged joints	Flanges (3 sizes)
Manual valves	Valve, manual (10 types & sizes)
Actuated valves	Valve, actuated, non-P/L (18 types & sizes)
Valves	The sum of manual and actuated valves
Instruments	Instruments (including connecting tubing)
Process vessels	Pressure vessel (14 types)
Atmospheric vessels	Vessels at atmospheric pressure
Centrifugal pumps	Pumps, centrifugal (2 seal types)
Reciprocating pumps	Pumps, reciprocating (2 seal types)
Centrifugal compressors	Compressors, centrifugal
Reciprocating compressors	Compressors, reciprocating
Shell side heat exchangers	Heat exchangers, HC in shell
Tube side heat exchangers	Heat exchangers, HC in tube
Plate heat exchangers	Heat exchangers, plate
Air cooled heat exchangers	Fin fan coolers
Filters	Filters
Pig traps	Pig launchers & pig receivers (4 sizes)

The leak frequency is very dependant of how the number of leak sources is estimated. In the HCRD, the definition of the different equipment types are given, covering;

- the equipment types that are included in the different equipment categories,
- the scope of the different leak frequency functions, i.e. which leak sources that are included and not.

It is important that the process for estimation of leak sources is consistent with these definitions.

However, in this model the frequencies given for flanges refers to a flanged joint, comprising two flange faces, a gasket (where fitted), and two welds to the pipe (i.e. the frequencies given are adjusted to this definition, which is not the same definition of a flanged joint that is originally used in the HCRD).

The main issues with respect to the scope of other leak categories are:

- For valves, the scope includes the valve body, stem and packer, but excludes flanges, controls and instrumentation.
- The frequency function for instruments includes small-bore connections for flow, pressure and temperature sensing. The scope includes the instrument itself plus up to 2 valves, 4 flanges (faces), 1 fitting and associated small-bore piping, usually 25 mm diameter or less.
- The frequency function for process and atmospheric vessels includes the vessel itself and any nozzles or inspection openings, but excludes all attached valves, piping, flanges, instruments and fittings. The first flange itself is also excluded.
- For equipment such as pumps and compressors the scope includes the equipment itself, but excludes all attached valves, piping, flanges, instruments and fittings beyond the first flange. The first flange itself is normally also excluded.

The definition of the equipment types are given in the report describing the leak frequency model.

LEAK FREQUENCY FUNCTION

The analysis represents the variation of leak frequency with equipment and holesize by the following general leak frequency function:

$$F(d) = f(D)d^m + F_{rup} \quad \text{for } d = 1\,\text{mm to } D \qquad (1)$$

where:

$F(d)$ = frequency (per year) of holes exceeding size d
$f(D)$ = function representing the variation of leak frequency with D

D = equipment diameter (mm)
d = hole diameter (mm)
m = slope parameter
F_{rup} = additional rupture frequency (per year)

Hence the frequency of holes within any range d_1 to d_2 is:

$$F(d_1) - F(d_2) = f(D)(d_1^m - d_2^m) \quad \text{for } d = 1\text{ mm to } D \quad (2)$$

The frequency of full-bore ruptures, i.e. holes with diameter D, is:

$$F(D) = f(D)D^m + F_{rup} \quad (3)$$

For large items of equipment, such as vessels and compressors, the parameter 'D' would be taken as the size of the inlet pipe. However, the number of incidents available in the HCRD is not currently sufficient to be able to draw a correlation between equipment size and leak frequency.

For pipes, flanges, valves and pig traps, HCRD provides data for different equipment size groups. Analysis of these showed significant variations of leak frequency with equipment size for pipes, flanges and valves, whereas the population was too small to show any significant variation of leak frequency with equipment size for actuated valves and pig traps. Size dependence is represented in the leak frequency function using the following general form:

$$f(D) = C(1 + aD^n) \quad (4)$$

where:

C, a and n are constants for each equipment type.

The HCRD provides sufficient data to determine C, a and n to establish $f(D)$ for pipes, flanges and manual valves. For the other equipment types, $f(D)$ is equal to the constant C. The additional rupture frequency F_{rup} and the slope parameter m are assumed to be constants, i.e. not dependent on equipment size, for any equipment type. However, it should be emphasized that this is an addition rupture frequency in the mathematical model. The resulting total calculated leak frequency (and also the rupture frequency) is dependent on equipment size, for all equipment types. In this case the leak frequency function can be simplified to the form:

$$F(d) = Cd^m + F_{rup} \quad \text{for } d = 1\text{ mm to } D \quad (5)$$

The hole size in HCRD is represented by an equivalent diameter, d, of a circular hole with area equal to the actual hole. Fitting $F(d)$ is complicated by some characteristic in the available data as shown in Figure 1 below. These show both historic distributions and corresponding mathematical functions over the range 0.1 mm to 100 mm. This is done for completeness although the shape of the curves below 1 mm are significant since many leaks in this range may not be recorded and holes of this size are typically excluded from risk assessments.

When fitting $F(d)$, the following key assumptions are made:

- A hole size of 1 mm is assumed to be the effective threshold size for the data. The fit is therefore constrained to match the recorded frequency $F(d \geq 1\text{ mm})$.
- The slope parameter m is then based on the average slope between $F(d \geq 1\text{ mm})$ and data points in the range $2 \leq d \leq 100$ mm. This assumes that hole sizes in the range $1 < d \leq 2$ mm may have been rounded down to 1 mm. It also acknowledges that holes sizes above 100 mm are no longer reported with an explicit hole diameter in the HCRD but registered as ">100 mm".
- The additional rupture component F_{rup} is determined by the curvature needed to match the recorded frequency $F(d \geq 100\text{ mm})$, when this is above the slope fitted above. F_{rup} is for all equipment types except pipes, valves and tube sides on heat exchanges set to zero.

The constants C, a and n are added manually, so that the modelled $F(d \geq 1\text{ mm})$ matches the values estimated from the data for each available equipment size group, or at least lies within the 90% confidence range of the estimate.

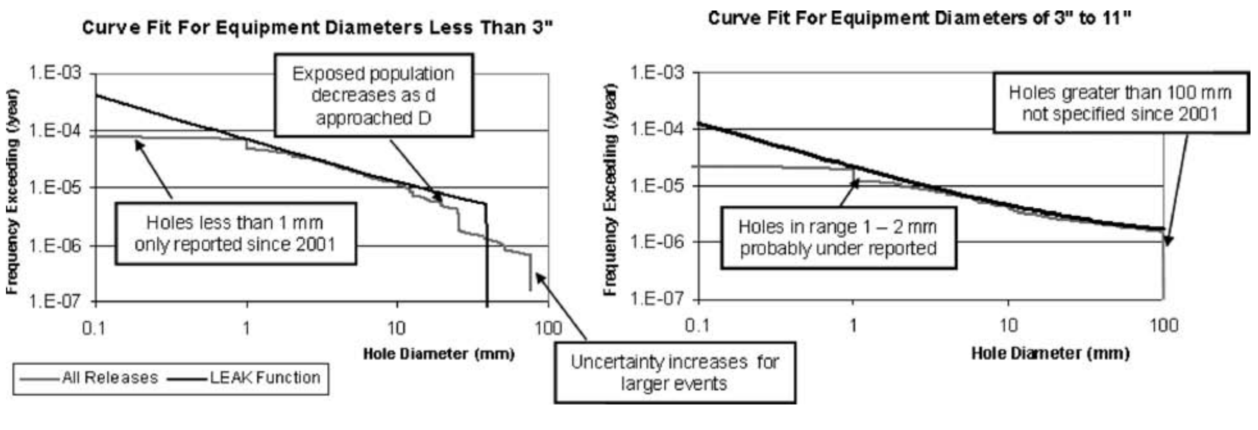

Figure 1. Typical characteristics of historic exceedance curves

DNV has developed a spreadsheet based tool which uses incident and population data available from the HCRD. This has been used to group the incidents into composite categories and establish the overall leak frequencies of these equipment types. A process is provided for estimating the likely release quantities and comparing these with the recorded estimates in order to classify each leak in accordance with the release scenarios described below. A semi-automated process is used to establish the mathematical functions for the overall frequency and each of the leak scenario type. Further functionality provides options for graphing and tabulating the results.

LEAK SCENARIOS

COMPARISON OF ESTIMATED AND RECORDED OUTFLOW

Standard methods were used in order to estimate the minimum quantity of hydrocarbon which would be released under the conditions indicated by the incident data in the HCRD. Figure 2 shows a scatter diagram for a number of leak scenarios from the HCRD where these are estimated and the recorded outflows have been compared. There were 3644 incidents recorded in the HCRD database at 31st March 2008. 755 of these incidents were related to equipment and systems that are not included in the DNV analysis. Some of the remaining incidents in the database have no recorded hole diameter. In addition all incidents with a leaking hole diameter larger than 100 mm are recorded as "$>$100 mm" in the database. Furthermore, most of the leaks have an estimated initial leak rate that is less than the cut-off criterion of 0.1 kg/s typically used in QRAs. After exclusion of the above mentioned scenarios, there are 892 incidents left as basis for the leak categorisation analysis.

As shown in the diagram there is a large spread in the data. This indicates a large number of scenarios with a significant difference between the recorded released mass and the equivalent mass that would be estimated by using a standard QRA methodology based on the recorded incident data.

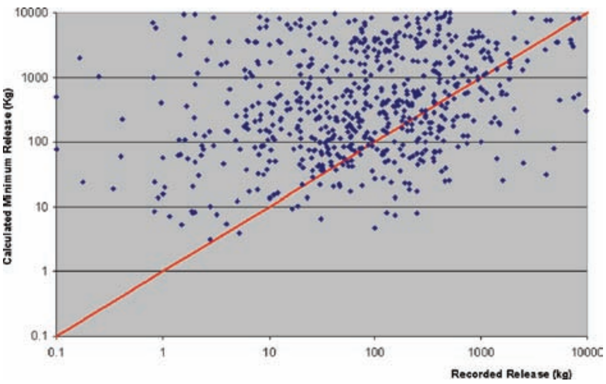

Figure 2. Scatter diagram for calculated versus recorded release quantities

DEFINITION OF SCENARIOS

As shown in the previous section, experience shows that when using all data from the HCRD to establish leak frequencies, the calculated leak frequencies of released quantities above a given magnitude may differ significantly from what is actually experienced. Thus, in order to promote compatibility with different approaches to leak outflow modelling in the QRA, the existing method divides the leaks in HCRD into two main scenarios; full pressure leaks and zero pressure leaks.

Full Pressure Leaks

This scenario is intended to be a leak through the defined hole, beginning at the normal operating pressure, until controlled by emergency shutdown (ESD) and blowdown, with a probability of ESD/blowdown failure. This is subdivided as follows:

- *Full leaks*, which occur under normal operating pressure, until controlled by ESD[1] and blowdown, with a small probability of ESD/blowdown failure.
  - *ESD isolated* leaks, ESD isolated leaks are defined as cases where the recorded outflow is greater than the outflow predicted for a leak at the operational pressure controlled by the quickest credible ESD and blowdown, but less than predicted from the slowest credible ESD and no blowdown.
  - *Late isolated leaks*, presumed to be cases where there is no effective ESD of the leaking system, resulting in a greater outflow. ESD isolated leaks are defined as cases where the outflow is greater than predicted for a leak at the operational pressure controlled by the slowest credible ESD and no blowdown.
- *Limited leaks*, presumed to be cases where the outflow is less than from a leak at the operational pressure controlled by the quickest credible ESD (after 30 seconds) and blowdown (according to common industry practice with half of the initial pressure or 7 barg, whichever is lowest, within 15 minutes) initiated 60 seconds later. This is presumed to be cases where there are restrictions in the flow from the system inventory, as a result of local isolation valves initiated by human intervention or process safety systems other than ESD and blowdown. With consideration for the uncertainties inherent in this process it may be appropriate to introduce a factor by which the recorded release mass is less than the calculated value in order to be given this classification.

Full leaks have the potential of developing into serious events endangering personnel and critical safety functions. This includes probabilities for ESD and blowdown failure.

Limited leaks may be of as much concern for personnel risk as full leaks in the period immediately following the start of the release, but they will have a shorter duration to

[1] On the assumption that PSD is the shutdown of a particular section rather than the whole platform the PSD system may have the same effect as far as QRA modelling of release rates is concerned.

any specified reduced release rate. The potential for it to develop into a major concern for other safety functions, such as structural integrity, evacuation means, escalation, etc. may therefore be less.

Zero Pressure Leaks

This scenario includes all leaks where the pressure inside the leaking equipment is virtually zero (0.01 barg or less). This may be because the equipment has a normal operating pressure of zero, or because the equipment has been depressurised for maintenance. These leaks may typically be ones which release small quantities of gas, short lasting oil spills, or liquid releases from atmospheric tanks. The hole size recorded in the HCRD may be very large, for instance indicating the removal of a cover plate from a vessel which was assumed to be at atmospheric pressure, but which released a small quantity of hydrocarbon. Such a release poses a significantly lower risk compared to the releases from a full pressure system, so if included in the overall analysis and accorded the same consequences as a leak at normal operating pressure, this would influence the overall results of the analysis to produce a more adverse risk estimate. Zero pressure leaks should therefore be modelled with a system pressure of 0.01 barg.

Most releases occur in the normal production operational mode, followed by start up and reinstatement. The data analysis shows no significant differences between the different leaking scenarios with respect to operational pressure, but leaks from intermediate pressure levels (not full and not zero) may occur. Currently these scenarios will be interpreted as full pressure leaks making a conservative approach. A more thorough analysis of typical records may help to provide a deeper understanding of how to model the different leaks and their causes.

ALLOCATING LEAK RECORDS

The method of allocating leak records in HCRD into the scenarios outlined above has been developed and can be summarised as follows:

- Estimate the initial release rate Q_o from the hole, based on parameters recorded in HCRD.
- Estimate a range of plausible release quantities, M_{min} to M_{max}, based on typical ESD and blowdown response,
- Examine the recorded actual pressure of the equipment at the time of the release and compare the recorded release quantity in HCRD to the estimated release quantity range to determine the scenario.
  - ○ Zero pressure leaks – actual pressure in HCRD < 0.01 barg.
  - ○ Full pressure leaks.
    - ■ Limited leaks – recorded release quantity in HCRD $< M_{min}$.
    - ■ Full leaks – recorded release quantity in HCRD $> M_{min}$. This is split into:
      - – ESD isolated leaks – recorded release quantity in HCRD in the range M_{min} to M_{max}.
      - – Late isolated leaks – recorded release quantity in HCRD $> M_{max}$.

In some cases there are insufficient data recorded in the HCRD for a given incident to calculate the expected quantity of released material. In these cases, median values for the system type were calculated and adopted.

The registered hole size, actual pressure, leaking phase, volume and quantity as given in the HCRD has been used as basis for allocating the records in HCRD into different scenarios as described above. A release model that calculates a reduction of release rate as a function of time as the system depressurises has been used as shown in Figure 3.

It should be emphasized that when analyzing the different scenarios in a QRA using the functions as described in Section 3, a release model taking the actual process conditions, estimated hole size and the decline of release rate with time into account shall be used.

Figure 4 shows the breakdown of all leaks in HCRD for the period 1992–2008. This shows that approximately 6% of leaks are at zero pressure, and that 50% are limited leaks. Of the remaining 44% of leaks, 2% are consistent with late isolation. The various proportions were also found to vary between different hydrocarbon phases.

The breakdown of leaks in HCRD into the scenarios varies between equipment types, phase of leaking hydrocarbon and also with hole size. In the model each leak in the HCRD is allocated to a single scenario, and then the leak frequency functions for pressurized and non pressurized leaks are fitted for each equipment type.

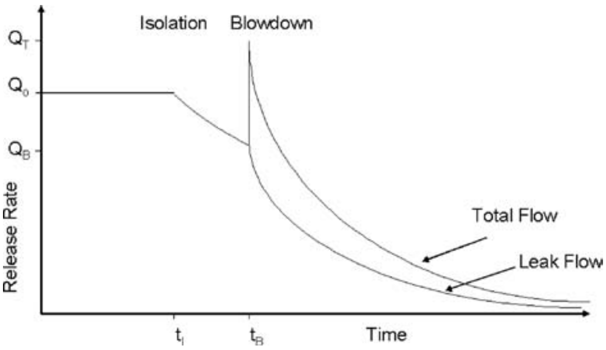

Figure 3. Principal of time dependant release model

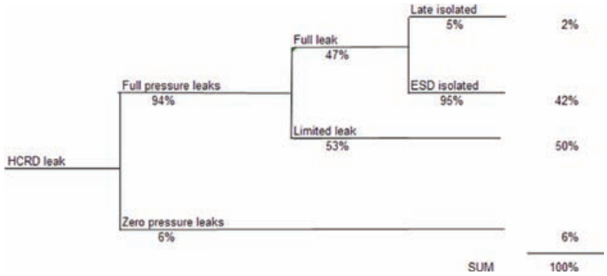

Figure 4. Event tree presentation of leak scenarios

Table 2. Defined parameters for the definition of leak frequency curves for flanges

Scenario	C	a	m	n	F_{rup}
Total leaks	5.4×10^{-5}	1.0×10^{-2}	-0.93	0.93	6.0×10^{-6}
Full leaks	5.4×10^{-5}	6.0×10^{-3}	-0.93	1.0	5.0×10^{-6}
Zero pressure	4.1×10^{-6}	5.0×10^{-11}	-0.32	4.2	5.0×10^{-7}

Range of validity: $D = 10$ to 600 mm; $d = 1$ mm to D.

The function is calculated separately for each equipment type and covering

- Total leak frequency
- Full pressure leak frequency, and
- Zero pressure leak frequency using separate parameters C, a, n, m and F_{rup}.

Given the above conclusions, the objective of the uncertainty factors are to ensure a slightly conservative estimation of the fraction of limited leaks in order not to underestimate the risk. It should be noted that because coefficients for frequency functions are carried out independently of each other the curves produced for "zero pressure" and "full pressure" leaks do not necessarily add to give a curve which exactly matches the "total" curve.

EXAMPLE CASE

Table 2 presents the estimated coefficients for the leak frequency curve for all flanges using the approach described above. The frequencies refer to a flanged joint, comprising two flange faces, a gasket (where fitted), and two welds to the pipe. Flange types include ring type joint, spiral wound, clamp (Grayloc) and hammer union (Chiksan).

An example of a 6 inch flanges is given in Figure 5.

APPLICATION

The leak frequencies for *zero pressure* leaks are estimated using an operating pressure of 0.01 barg and below. The leak frequency for *limited leaks* is established by multiplying the full pressure leak frequency according to the proportion distribution as given in Table 3 below. It should be emphasized that the figures below are only intended to be used for establishing the release frequency for limited leaks. When analysing the different initial hazards in a QRA, probabilities for ESD and blowdown shall be applied. The leak frequency for *Full leaks* (ESD isolated and late isolated leaks) are established by using the full pressure leak frequency as calculated by the leak frequency function and subtracting the frequency for limited leaks.

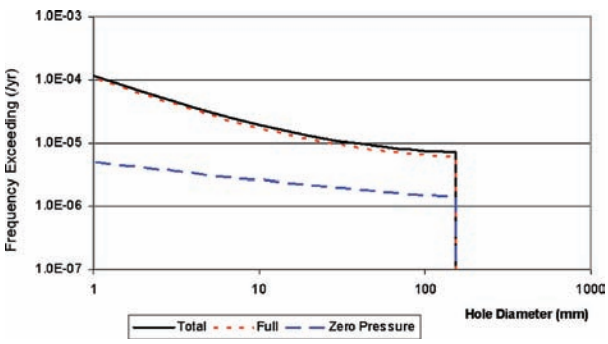

Figure 5. Example of leak frequency function for a 6 inch flange

For example, the overall annual leak frequency for a hole size of between 10 mm and 50 mm is 1.03×10^{-5} for a 6 inch flange. This is a combination of 9.52×10^{-6} for full pressure leaks and 8.54×10^{-7} for zero pressure leaks.

From table 2 the full leaks can be further subdivided to annual leak frequencies as follows;

Limited Flow: $9.52 \times 10^{-6} \times (34\%/94\%) = 3.44 \times 10^{-6}$

ESD Isolated: $9.52 \times 10^{-6} \times (57\%/94\%) = 5.77 \times 10^{-6}$

Late Isolated: $9.52 \times 10^{-6} \times (3\%/94\%) = 3.04 \times 10^{-7}$

UNCERTAINTIES

Uncertainties in the estimated leak frequencies arise from four main sources:

- Leaks are required be reported in HCRD if they meet certain criteria on release rate or mass, or if they ignite. This means that not all small leaks that occur will be reported in the HCRD because they fall outside the criteria. It is also possible that some leaks above the criteria are not reported. This will probably be the case particularly for small leaks. In addition, other faults such as errors in measuring the hole diameter or estimating the quantity released can be foreseen. Although the data in the HCRD appears to be of high quality relative to other data sources, the possibility of bias or error is recognised and the frequency results may be sensitive to it.
- Inappropriate categorisation of the leaks into the different scenarios. This includes the methodology and the simplifications made. The total leak frequency of the equipment may not be sensitive to this, but the frequency for the individual scenarios (limited leak, full leak etc.) may be.
- Inappropriate representation of the leak frequency distributions by the fitted leak frequency distributions. This results in part from the small datasets, but also from

Table 3. Proportion distribution of leak incidents in the HCRD (%)

Release type	Total	Gas	Oil	Condensate	2-Phase	Non-process
Zero Pressure	6%	6%	7%	7%	2%	9%
Limited Flow	49%	34%	75%	66%	69%	52%
ESD isolated	42%	57%	16%	25%	29%	36%
Late Isolated	2%	3%	2%	1%	0%	3%

*The phases in the table above shall be interpreted as the initial phase of the fluid inside the equipment.

the simplifications inherent in the chosen functions and their use to extrapolate frequencies in areas where no leaks have yet been recorded.

- The proportion of leak frequency from piping is higher compared to other equipment than would otherwise be expected. The fraction of piping leaks recorded in the HCRD and from Norwegian sources was found not to be significantly different. Population data available from the HCRD suggests that overall the ratio of metres of piping to flanges is less than two. However, as part of this project, Scandpower RM performed counts on 3-D CAD models representing three Norwegian installations. They found a ratio of around seven meters of piping to each flange. It was concluded that this indicated that the recorded number of leaks was reasonable, while the recorded exposure data might be underestimated.

The uncertainty tends to be greatest for large hole sizes, for equipment sizes far from the centres of the ranges of validity above, and for equipment types where fewer leaks have been recorded, as indicated in the tables of input data included in the datasheets. It should be emphasised that these are the low frequency, potentially high consequence events which is why this continues to be an important topic, and needs re-visiting as additional data becomes available.

In order to test the robustness of the model for categorisation of the incidents into the different scenarios, and to investigate how vulnerable these results are to changes in the data, a set of uncertainty parameters was introduced to the model in order to adjust:

- recorded release quantity,
- calculated blowdown diameter,
- recorded hole diameters,
- recorded segment volume.

An inspection of the recorded incidents suggests that some of the incidents are likely to be incorrectly recorded. At the same time a number of sensitivities have been performed showing that the conclusions do not change dramatically by changes of input data. This results in the following conclusion:

- The scattered distribution as shown in Figure 2 is a result of a combination of uncertain data and actual interventions by operators or process safety system.
- The proportion of limited leaks versus full leaks are dependant on the isolatable section and are different for the various leaking phases.
- In order to account for the uncertainty of the data it has been concluded that a conservative approach should be used when classifying release types between limited and full leaks using the above uncertainty parameters. This will ensure a slightly reduced proportion of limited leaks giving a conservative overall approach.

MODELLING OF LEAKING SCENARIOS

ANALYSIS OF THE DIFFERENT SCENARIOS

Analysis as shown Figure 2 indicates a very large scattering of the result. A thorough analysis of the incidents within the different scenarios was performed

- The analysis shows that the there are some differences in the distribution of limited leak versus full leaks for the different leaking phases. Initial tests also show that the fraction of limited leaks is higher for oil leaks than for gas leaks. This seems sensible as many of the oil systems do not have blowdown, and that QRAs have a tendency to model all liquid leaks as located at the lowest point, emptying all the liquid inside the segment (worst case). In a real situation it is anticipated that some liquid will be left within the leaking system, while all the gas will escape.
- In order to test the uncertainties of the data in the database, it was anticipated that the uncertainty should be less for large leaks as their behaviour would be more known to the operators. The results show however that the fraction of limited leaks is independent of the leak size. The fraction of zero pressure leaks is however significantly increased with the hole diameter. This means that including the zero pressure leaks in the overall analysis has a significant influence on the calculation of risks from large hole sizes.
- In the HCRD database, both the actual pressure and the maximum operational pressure are recorded. It was anticipated that a limited leak would have a lower initial pressure compared to full leaks and that these leaks are concentrated around certain operations. However, a comparison of the initial pressure of the leaking system and the operational mode when the different incident occurred provides no justification for

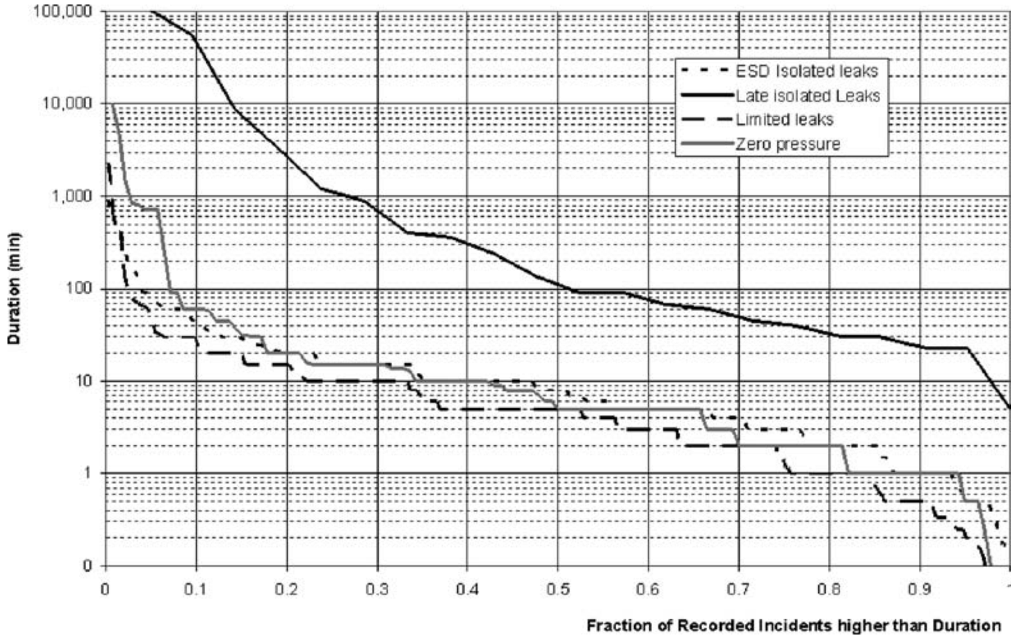

Figure 6. Normalised duration (min) for the different leak categories

such a conclusion. The results show that limited leaks occur basically during the same operations, and with the same initial pressure as a full leak.
- For limited and ESD isolated leaks a fraction of 70–80% of all leaks are recorded in the HCRD as isolated. The fraction for zero pressure leaks are 40% while the fraction for late isolated leaks are below 30%. Blowdown is initiated in only 20–40% of all leaks. However, the fraction is higher for ESD isolated leaks than for limited leaks. It is also interesting to see that the fraction of successful initiation of blowdown is lower for late isolated leaks than for both ESD isolated and limited leaks.

The results show that limited leaks have a shorter duration, release less quantity of hydrocarbons and have a lower average leak rate compared with an ESD isolated leak. At the same time the figures show that a late isolated leak has a much longer duration, release much higher quantity of hydrocarbons, but at a similar average leak rate compared with an ESD isolated leak.

The following conclusions are therefore made:

- There are no significant differences in the distribution of ratio of actual to design pressure for the different leak categories (excluding zero pressure leaks).
- Limited leaks have a shorter duration, a smaller release quantity and a lower average release rate compared to ESD isolated and late isolated leaks.
- Limited leaks are likely to be cases where there are restrictions in the flow from the system inventory, as a result of local isolation valves initiated by human intervention or process safety systems other that ESD and blowdown.
- The results are not very sensitive to the choice of isolation and blowdown times due largely to large degree of scatter as depicted in Figure 2.
- There is no close link between operating mode as recorded in HCRD and leak scenario.
- The results are relatively sensitive to the accuracy of the recorded release quantities and volumes. This seems an unavoidable limitation of the approach.
- The distribution between different leaking phases are different (oil vs. gas).

Based on the above results the following hypothesis was set up with respect to limited leaks.

A limited leak represents a leak from a fully pressurised process system but where the outflow is less than from a leak at the operational pressure controlled by the quickest credible ESD (within 1 minute) and blowdown (according to common industry practice with half pressure or 7 barg whichever is lowest within 15 minutes.). This is due to restriction in the flow from the system inventory, as a result of local isolation valves initiated by human intervention or the process safety system (e.g. leaks of fluid accumulated between pump shaft seals).

Local isolation of the leaking source itself (e.g. closing an inadvertently opened valve) will not give the behaviour as described above as the average release rate

[2]The figures take account of HCRD data until March 2008.

[3]To be used with care as it is significantly higher than for the other leak categories, and the data set on which is based is scarce.

Table 4. Time reduction factors for limited leaks[2]

Leak duration	Gas	Oil	Condensate	2-Phase[3]	Non-process
Time Factor	2.6	1.7	2.6	7.1	2.3

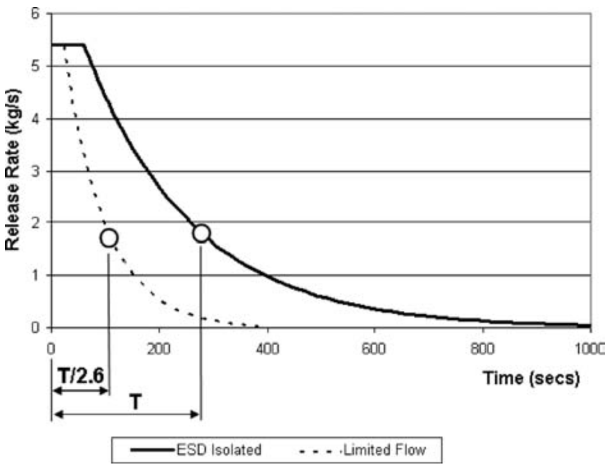

Figure 7. Application of time reduction factor for a gas leak

for limited leaks would be higher than for ESD isolated leaks.

The reduced leak volume and leak duration for limited leaks should be modelled as a reduced leak volume that represents a specific reduced leak duration.

ESTIMATION OF REDUCED LEAK DURATION FOR LIMITED LEAKS

Given the above conclusion, the reduced leak duration for limited leaks is estimated based upon the differences between the curves as shown in Figure 5. This reduced leak duration is established for each leak category separately and is given in Table 4.

The duration of the limited leak can then be calculated by the following equation.

$$D_L = \frac{D_F}{R} \qquad (6)$$

where:

D_L = Leak duration of limited leaks.
D_F = Leak duration of full leaks.
R = Time reduction factor.

The time reduction factor can be used for all leak rates over the duration and is illustrated for a gas leak in Figure 7.

CONCLUSIONS

The hydrocarbon release database collected by the HSE in the UK offshore industry contains data of high quality, which has rightly become the standard source of leak frequencies for offshore QRAs. Nevertheless, analysts experience problems because of the need to derive the frequencies for specific types and sizes of equipment because of a desire to obtain consistency between the modelled risks and actual accident experience. The approach described here solves these problems by dividing leaks into different scenarios, allowing analysts to use frequencies for only those scenarios that are compatible with their QRA outflow modelling. Standardised leak frequencies have been developed for different types of process equipment, using leak frequency functions to ensure that consistent values are available for any equipment type and hole size.

Given this approach, there still exist uncertainties in the recorded data related to detailed information of the different scenarios and how they have been interpreted. A more thorough analysis of typical records may therefore help to provide a deeper understanding of how to model the different leaks and their cause. Such a deeper understanding may allow modifications to the standard method described in this paper.

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