LEAK FREQUENCIES FROM THE HYDROCARBON RELEASE DATABASE

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The HSE hydrocarbon release database (HCRD) has become the standard source of leak frequencies for offshore quantitative risk assessment (QRA). Despite its exceptionally high quality, there are some significant problems in obtaining credible leak frequencies from it. This paper discusses these problems, and explains the solutions developed by Det Norske Veritas (DNV) for a Norwegian leak frequency standardisation project.

The key challenges are:

- QRAs combining standard consequence modelling with the unmodified HSE leak frequencies, tend to obtain risk results that are much higher than actual experience and previous risk predictions.
- Due to limited experience in some equipment types, the frequencies may be unreliable or even zero in some cases.
- There may be unstable variations of leak frequency with equipment and hole size.

Different solutions by different analysts can lead to QRAs having inconsistent frequencies despite being based on the same HCRD dataset. DNV Consulting has therefore developed a set of analytical leak frequency functions from the HCRD data. These provide a standardised approach to obtaining leak frequencies that are compatible with consequence modelling, and hence produce credible risk estimates.

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 can have a major influence on the estimated risks, and hence the risk management decisions. This paper considers the source of such data, and reviews a recent initiative to improve its quality and consistency.

Some readers may be surprised that this is still an important issue. The HSE hydrocarbon release database (HCRD) has become the standard source of leak frequencies for offshore QRA. Despite its exceptionally high quality, there are some significant problems in obtaining credible leak frequencies from it. This paper discusses these problems, and explains the solutions developed by Det Norske Veritas (DNV) for a Norwegian leak frequency standardisation project.

HSE HYDROCARBON RELEASE DATABASE

HCRD ORIGIN

Until the 1990s, no specifically offshore leak frequency data was available, and offshore QRAs used leak frequencies that had been developed for onshore process QRA. The inquiry into the *Piper Alpha* accident in the North Sea (Cullen 1990) recommended that the Health and Safety Executive (HSE) should collect a database of hydrocarbon leaks from offshore installations in the UK Sector, and provide it to operators to support QRA. The resulting hydrocarbon release database (HCRD) has collected all significant releases in the UK Sector since October 1992. In addition, the HSE has estimated the exposed population of equipment items, and from these has determined leak frequencies and size breakdowns for each equipment type. At the most recent publication of these frequencies (HSE 2002), the database contained 2071 leaks. In the future, the offshore industry will have access to the data through the World Wide Web.

DATA QUALITY

The quality of the HSE offshore dataset is exceptionally high; particularly in comparison to the previous onshore frequencies. For each leak underlying the frequency values, it is possible to establish the hole diameter, the system and equipment type, the hydrocarbon type and pressure, the estimated quantity released, and many other parameters. Figure 1 shows the leak size distribution for all the leaks in the database up to 2001. Convexity in the plot for large hole sizes results from the limited capacity of small diameter equipment to create large holes. Convexity for small holes in this type of plot would suggest under-reporting, which tends to be greater for smaller holes. In this case, the long, relatively straight section of the plot indicates comprehensive reporting.

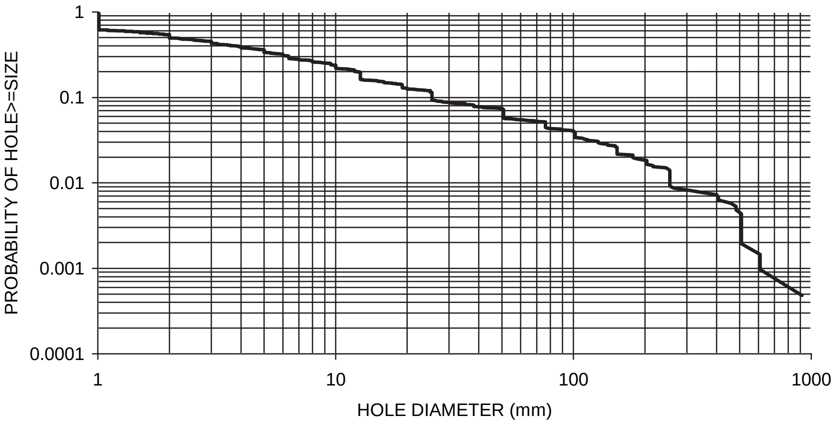


Figure 1. Leak size distribution for HSE offshore data

DATA PROBLEMS

Despite the high quality of the HCRD, several problems have emerged in using it for offshore QRA. The main problem is that when QRAs use the unmodified HSE leak frequencies, the risk results tend to be much higher than actual experience, although comprehensive validation of this is difficult. Analysts may therefore wish to modify the frequencies to align the risks with actual experience.

In addition, practical application of the HSE data has revealed the need for several types of adjustments:

- Frequencies are available for 89 separate types and diameters of process equipment (excluding wellhead equipment, drilling equipment, pipelines and risers). These groups may need to be combined to match the QRA parts counts.
- Many of these groups do not have sufficient exposure to show reliable leak frequencies and size distributions. Up to 2003, among the 89 process equipment groups, only 27 have more than 20 leaks, and 18 have no leaks at all. These groups may need to be combined to avoid large changes in leak frequency as further data is added.
- The Statistics Report (HSE 2002) gives hole size distributions for 7 hole size groups ($<$10 mm, 10 $<$ 25 mm, 25 $<$ 50 mm, 50 $<$ 75 mm, 75 $<$ 100 mm, $\geq$100 mm and "Not applicable"). If the QRA needs to model different hole size categories, this again requires adjustments. Due to the small populations, the frequency is zero for many hole size and equipment type combinations, especially for the larger hole sizes that tend to dominate QRA results. Non-zero frequencies are required to avoid bias in the risk results.

PROJECT ORIGIN

In addressing the problems above, different analysts have processed the data in different ways. The Norwegian operators Statoil and Norsk Hydro therefore established a project to develop standardised leak frequencies. DNV Consulting was commissioned to undertake the work, involving contractors Scandpower and Safetec in the project (DNV 2004).

The project decided to make use of the HSE data from the UK Sector, since all three contractors were already using this data, although in different ways. Available Norwegian data (PSA 2003) is suitable for validating the approach, but due to lack of equipment populations it does not give generic frequencies per equipment item. The Norwegian hydrocarbon leak and ignition probability (HCLIP) database is currently being constructed and will eventually provide suitable Norwegian data.

GENERAL APPROACH

DNV's method of obtaining leak frequencies from HCRD has 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 steps are described in turn below.

GROUPING EQUIPMENT TYPES

The DNV analysis combines the 89 separate types and diameters of process equipment from HCRD into 17 types of process equipment, 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 them. The effects of equipment size are considered separately below. 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.

LEAK FREQUENCY FUNCTIONS

HISTORICAL BACKGROUND

The use of smooth functions to interpolate and extrapolate leak frequency data began with the nuclear industry in the 1970s. An early reference is AEC (1972), which gave the frequency of pipe failures as $F = 1.0 \times 10^{-6}\,L/D$ per year, where $L/D =$ pipe

Table 1. Equipment Type Groups

DNV EQUIPMENT TYPE	HCRD EQUIPMENT TYPES
Steel pipes	Piping, steel (3 sizes)
Flanged joints	Flanges (3 sizes)
Manual valves	Valve, manual (10 types & sizes)
Actuated non-P/L valves	Valve, actuated (18 types & sizes)
Pipeline valves	Valve, actuated, P/L (10 types & sizes)
Instruments	Instruments
Process vessels	Pressure vessel (14 types)
Centrifugal pumps	Pumps, centrifugal (2 seal types)
Reciprocating pumps	Pumps, reciprocating (2 seal types)
Centrifugal compressors	Compressors, centrifugal
Reciprocating compressors	Compressors, reciprocating
Heat exchanger (h/c in shell)	Heat exchangers, HC in shell
Heat exchanger (h/c in tube)	Heat exchangers, HC in tube
Heat exchanger (plate)	Heat exchangers, plate
Fin-fan cooler	Fin fan coolers
Filters	Filters
Pig traps	Pig launchers & pig receivers (4 sizes)

length/diameter ratio. In effect, this assumed that leak frequency is proportional to pipe length and inversely proportional to pipe diameter, although AEC gave no evidence to support this.

The same function was adopted by the chemical process industry in the late 1970s. ICI credited the source to Gulf Oil (Hawksley 1984), although the source of the data (or judgement) has never been traced. The leak frequency function $F = 4.72 \times 10^{-7}$ L/D per year for process pipes was used in early offshore QRAs by Technica and is still used in many onshore QRAs today. However, this was only applied to pipes, and not to other process equipment.

When leak frequencies were first estimated from offshore industry experience (E&P Forum 1992), there was sufficient data to give frequencies for three pipe size groups. The frequencies decreased with pipe diameter, although not in the proportion predicted by the AEC/Gulf formula. However, the leak size distribution for all process equipment types was defined as a step function of d/D = hole/pipe diameter ratio.

The current DNV leak frequency functions were developed in 1993 as part of a project to establish consistent leak frequency functions for all offshore topside equipment. The functions were fitted to the E&P Forum data, and subsequently HCRD.

LEAK FREQUENCY FUNCTION

A leak frequency function is an analytical representation of the variation of leak frequency with equipment and hole size. The DNV leak frequency function has been chosen to meet the following general principles:

- There should be a smooth variation of leak frequency with hole size and equipment size.
- The probability of a given hole size should decrease logarithmically up to equipment diameter.
- An additional element may be added to represent ruptures, with a hole size equal to the equipment diameter.

This leads to the following general leak frequency function:

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

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)

The function is not defined for holes larger than D, but is normally taken as zero in this range. The function is not defined for holes smaller than the threshold 1 mm, as HCRD only started recording holes smaller than this in 2001, but it might be extrapolated to smaller sizes.

EFFECT OF EQUIPMENT SIZE

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 manual valves, and hence the f(D) term has been defined for these types. The additional rupture frequency F_{rup} and the slope parameter m are assumed to be constants, i.e. not to be dependent on equipment size, for any equipment type.

In order to fit the size-dependent term f(D), the 3 data points from HCRD must be plotted on a base of equipment diameter, and a suitable function fitted to pass within the uncertainty ranges. The mean diameter of the equipment population is unknown, and the diameters of the leaking events were only supplied by HSE until 1997, so these are used as the basis for the plots. An example is shown in Figure 2. (Note: Equipment size groups are given in inches in HCRD, and these units are retained for size groups in this paper, while actual diameters are converted to millimetres for use in the functions.)

The following general model of equipment size is used:

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

where:

C, a, n = constants for each equipment type

For the other equipment types, a constant frequency is used, i.e. a = n = 0, since HCRD provides no data on the variation of leak frequency with equipment size.

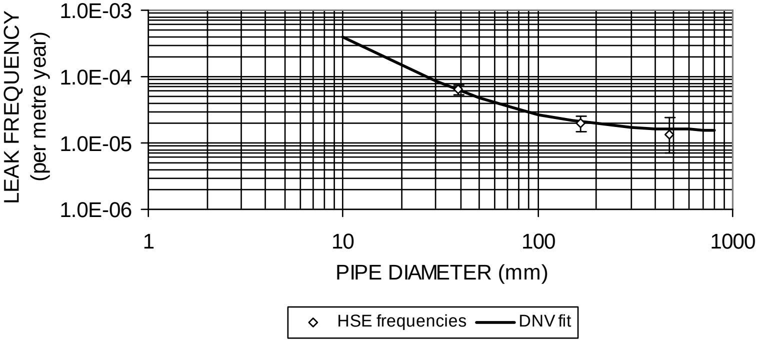
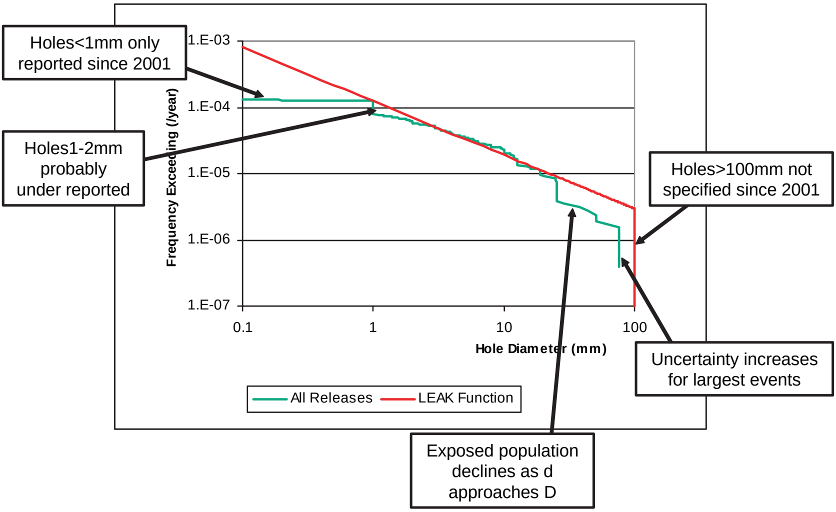


Figure 2. Effect of equipment size for pipes

EFFECT OF HOLE SIZE

Hole size in HCRD is measured by the diameter d of a circular hole with area equal to the actual hole. Fitting F(d) is complicated by some characteristic patterns in the data (Figure 3):

- Hole sizes less than 1 mm have been reported since 2001/02, but previously 1 mm was the smallest hole size. It is assumed that the reporting criteria are unchanged but HSE previously rounded up reported holes smaller than 1 mm. Holes less than 1 mm are difficult to measure and likely to be incompletely reported. The fit should therefore not attempt to model the distribution in this region.
- Hole sizes between 1 mm and 2 mm are rarely reported. It is assumed that these are commonly rounded down to 1 mm, leading to under-reporting in this region. The characteristic concave step in the data in this range can therefore be ignored in the fit.
- Hole sizes greater than 100 mm have been reported only as ">100 mm" since 2001/02, whereas previously the precise size was reported. This may be to preserve anonymity in the data. It prevents fitting data above 100 mm.
- For hole sizes greater than the smallest equipment size, the exposed population declines as hole size increases, causing a progressive downward bias in the right-hand side (high-D end) of the distribution. Since the leak frequency function is to be applied to specific equipment diameters, it is important **not** to represent this downward curvature in the fits.



Holes<1mm only reported since 2001

Holes1-2mm probably under reported

Holes>100mm not specified since 2001

Uncertainty increases for largest events

Exposed population declines as d approaches D

Figure 3. Effect of hole size for pipes <3″ diameter

- Uncertainty increases towards the right-hand side (high-D end) of the distribution, and for the largest events the distribution may vary significantly year-on-year as additional events occur. The fit should therefore not follow this end of the distribution too closely.

Judgement is needed to obtain a good fit to the data while allowing for the above features. However, in order to make the process of fitting F(d) systematic, the following key assumptions are made (Figure 4):

- A hole size of 1 mm is assumed to be the effective threshold size for the data. In other words, the number of leaks in HCRD with $d < 1$ mm is assumed equal to the number of leaks with $d \geq 1$ mm that have occurred but are not reported in HCRD. Hence the fit is constrained to pass through $F(d \geq 1 \text{ mm})$ as recorded in HCRD.
- The best fit to the data is determined using the average slope parameter between $F(d \leq 1 \text{ mm})$ and data points in the range $2 \leq d \leq 100$ mm. This assumes that hole sizes in the range $1 \leq d < 2$ mm may have been rounded down to 1 mm. It also acknowledges that holes sizes above 100 mm are no longer reported in HCRD.
- A rupture frequency F_{rup} is added when the recorded frequency F(100 mm) is significantly higher than that predicted from the slope and intercept above.
- Holes whose size is reported as “N/A” are treated as less than 1 mm, and hence not included in the fits.

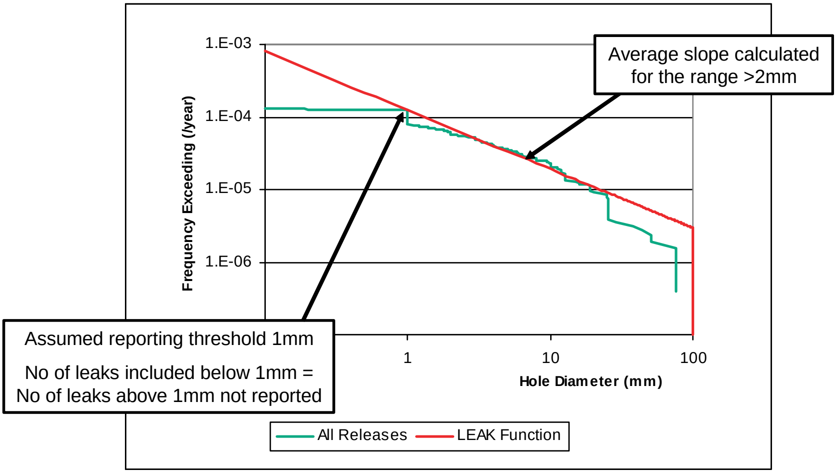


Figure 4. Effect of hole size for pipes <3″ diameter

LEAK SCENARIOS

HISTORICAL BACKGROUND

When leak frequencies were first estimated from offshore industry experience (E&P Forum 1992), they were evidently much higher than the then standard values based on those used in the onshore process industry. Since this followed the *Piper Alpha* accident, which originated as a process leak, the difference was not questioned at first.

Once the first results from the HCRD were published, UKOOA commissioned an analysis from AEA (1998), which attempted to reduce the frequencies by splitting them into continuous and discrete operating modes, on the basis that many leaks occurred during start-up and maintenance. However, this split had weak justification, since the operating modes were not clearly defined, separate exposure data was not available, and the release quantities were similar in both groups of operating mode.

As experience was accumulated without further major offshore process accidents, it became apparent that, if leak frequencies based on HCRD were combined with standard QRA models of outflow, ignition and impact, the resulting risks would be much greater than actually experienced on offshore installations. In 2000, DNV first divided the leak events in HCRD into scenarios, only some of which were compatible with conventional QRA modelling. This work was further developed during the Norwegian standardisation project described above, leading to the leak frequency functions presented below.

Meanwhile, having reviewed the available sources of leak frequency data, both onshore and offshore, DNV concluded that HCRD was the best quality dataset, and apparently suitable for use in onshore as well as offshore QRA. However, most analysts found that combining the HCRD leak frequencies with standard onshore QRA models gave unrealistically high risks, as for offshore.

BP also considered HCRD to be the best dataset, but found that it tended to predict many more large leaks than had been experienced in practice. BP therefore reanalysed the HCRD data, using the recorded release quantities and standard outflow models to estimate equivalent hole sizes for each event (Hall 2002). This interim solution gave smaller hole sizes than recorded, but did not explain why this delivered consistency with actual experience.

COMPARISON OF HCRD LEAKS WITH QRA

Are the leak events in HCRD consistent with conventional QRA consequence modelling? To investigate this, standard manual consequence models (CMPT 1999) have been applied to each of the 2071 leak events in HCRD for the period 1992–2001. In each case, the outflow was modelled based on information normally assumed or available in a QRA (i.e. hole size, maximum allowable pressure, fluid density etc). Large discrepancies were obtained in many cases. This is to be expected when predicting release quantities from such limited information. However, when combined, many of these individual discrepancies would be expected to cancel out.

Adding all the events together, the total modelled outflow was 31,000 tonnes of hydrocarbon, whereas the total recorded release quantity in HCRD was only

Table 2. Comparison of Modelled and Recorded Outflow

HYDROCARBON TYPE	LEAK EVENTS	MEAN RECORDED QUANTITY (kg per leak)	MEAN MODELLED QUANTITY (kg per leak)	MODELLED QUANTITY / RECORDED QUANTITY
2-Phase	184	347	15,426	44.5
Condensate	151	506	6,220	12.3
Gas	1150	2,033	4,959	2.4
Non-Process	239	1,697	49,805	29.3
Oil	347	895	26,806	29.9
TOTAL	2071	1,542	14,817	9.6

3,200 tonnes. In other words, standard QRA models would give an outflow approximately 10 times greater than recorded in HCRD.

Table 2 expresses the released quantity in terms of mean outflow per leak event, and gives the breakdown by fluid type. These results should be treated with caution, because the mean values are distorted by a few large events in the data, especially for gas releases. However, the table suggests that the difference between data and model is much larger for liquid and two-phase leaks than gas leaks.

The following explanations might be considered to explain the discrepancy:

- The recorded quantities could be under-estimated. There is a natural tendency to under-estimate release quantities, in order to minimise the seriousness of any accident. There is much more opportunity for this bias in gas releases, where the evidence quickly disappears. However, such a theory is not supported by Table 2, where model and data are in relatively good agreement for gas leaks.
- The simplified models above could over-estimate release quantities compared to a standard QRA. This is most likely for 2-phase releases, which are most difficult to approximate. This may explain the lack of agreement for this fluid type. However, there is little difference between the models used here for other fluids and those routinely adopted in QRA.
- The standard models in a QRA could over-estimate release quantities. Since the other explanations seem unable to explain the discrepancies, it is concluded that the standard QRA models do indeed over-estimate the release quantities.

Inspection of the individual events in HCRD shows that they include many that occurred at zero pressure or whose recorded sizes, pressures and released quantities indicate that they were quickly isolated. These are not compatible with typical QRA outflow modelling, which assumes continuous flow from the full hole diameter at full system pressure until controlled by emergency shut down (ESD), blowdown or inventory exhaustion.

More detailed investigation that would explain the reasons for such discrepancies is prevented by the limited detail of the HCRD records, and the confidentiality of the original investigations. Clearly it would be desirable for operators to make the necessary information available to clarify this.

QRA COMPATIBLE LEAK SCENARIOS

In order to promote compatibility with different approaches to leak outflow modelling in the QRA, the DNV method divides the leaks in HCRD into 3 main scenarios:

- Zero pressure leaks, where the actual pressure inside the equipment is <0.01 barg. This may be because the equipment has a normal operating pressure of zero (e.g. open drains), or because the equipment has been depressurised for maintenance.
- Limited leaks, where the equipment is under pressure but the outflow is much less than from a leak at the operating pressure controlled only by ESD and blowdown. This may be because the leak is isolated locally by human intervention (e.g. closing an inadvertently opened valve), or by a restriction in the flow from the system inventory (e.g. leaks of fluid accumulated between pump shaft seals).
- Full leaks, where the outflow is consistent with or greater than a leak at the operating pressure controlled by ESD and blowdown. This includes:
    - ESD isolated leaks, presumed to be controlled by ESD and blowdown of the leaking system.
    - Late isolated leaks, presumed to be cases where there is no effective ESD of the leaking system, resulting in a greater outflow.

The method of allocating leak records in HCRD into the scenarios is as follows. The initial release rate from the hole is estimated using simplified equations (CMPT 1999), based on the hole size, maximum allowable pressure and fluid density recorded in HCRD. A range of plausible release quantities is estimated based on the system inventory recorded in HCRD and possible ESD and blowdown responses. Where the recorded release quantity in HCRD is within this range, these are defined as ESD isolated leaks. Late-isolated and limited leaks are cases where the recorded release quantity is respectively above or below this range.

As a simple indication of the relative importance of each leak scenario using the methods and criteria above, Figure 5 shows the breakdown of all leaks in HCRD for the period 1992–2003. This shows that approximately 10% of leaks are at zero pressure and 59% are limited leaks. Of the remaining 31% of leaks, 3% are consistent with late isolation, implying that on average ESD has been unavailable on 9% of occasions when it was needed.

The breakdown of leaks in HCRD into the scenarios is largely independent of hydrocarbon type, but varies significantly between equipment types and also with hole size. It may therefore be misleading to apply the constant probabilities above for each equipment type and hole size. Instead, DNV allocates each leak in HCRD to a single scenario, and then fits the leak frequency functions for each scenario and each equipment type.

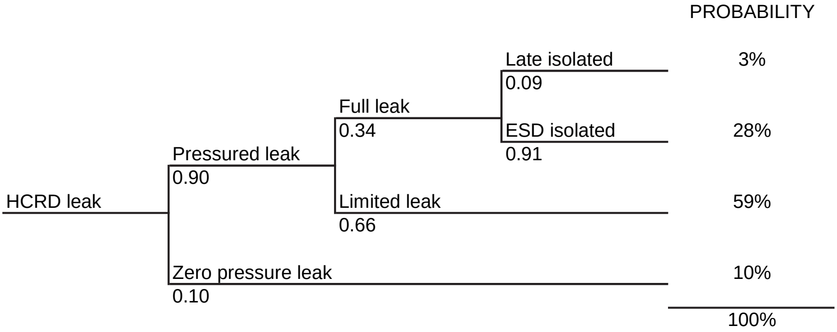


Figure 5. Event tree presentation of leak scenarios

APPLICATION

The analysis requires leak frequency functions for all leaks together, and the 3 leak scenario types. Different QRAs may wish to include different scenarios. Most QRAs will model ESD response for the specific installation, and hence will require generic frequencies of full leaks, without distinguishing late and ESD isolated cases. A coarse QRA, concerned only about long-duration flows, might only model these full leaks, while neglecting zero pressure and limited leaks. A detailed QRA might model all 3 scenarios, using different outflow modelling for each. It is important that the analyst selects the appropriate functions matching the outflow modelling in their particular QRA. This provides a standardised approach, while recognising that QRAs may legitimately differ in their level of detail and hence in the type of scenarios that must be included in the leak frequencies.

The leak frequency functions provide data equivalent to that used in risk-based approaches to area classification (IP 2005). They can provide hole size and leak scenario combinations corresponding to a given leak frequency. Further investigation is needed to show whether they are consistent with the existing data (which covers pumps, compressors, flanges and valves) and whether they can be extrapolated to estimate frequencies of hole sizes less than 1 mm.

EXAMPLE RESULTS

STEEL PIPES

The leak frequency functions obtained by applying the above method to the HCRD records for leaks from steel pipes during October 1992 to March 2003 (inclusive) are (DNV 2004):

Total leaks, as included in HCRD:

$$F_{total} = 3.7 \times 10^{-5}(1 + 1000D^{-1.5})d^{-0.74} + 3 \times 10^{-6}$$

Full leaks, suitable for modelling as outflow at the normal operating pressure, controlled by ESD and blowdown:

$$F_{full} = 8.0 \times 10^{-6}(1 + 1000D^{-1.3})d^{-1.42}$$

Zero pressure leaks, occurring with an actual pressure less than 0.01 barg:

$$F_{zero} = 9.0 \times 10^{-6}d^{-0.5} + 1 \times 10^{-6} \text{ but not exceeding } F_{total} - F_{full}$$

Limited leaks, where the pressure is not zero but the outflow is much less than from a leak at the normal operating pressure, controlled by ESD and blowdown:

$$F_{limited} = F_{total} - F_{full} - F_{zero}$$

where:

F_{total} = frequency of total leaks (per metre year).
F_{full} = frequency of full leaks (per metre year).
F_{zero} = frequency of zero pressure leaks (per metre year).
$F_{limited}$ = frequency of limited leaks (per metre year).
D = pipe diameter (mm).
d = hole diameter (mm).

Figure 6 illustrates the frequency functions for an example 150 mm diameter pipe. Table 3 gives the frequencies for selected leak size ranges.

A unique feature of the new frequencies is the ability to access the underlying dataset. For example, the frequency of full leaks above is based on 47 events with hole size ≥1 mm in pipes of diameters 3–11″. The HSE database categorises the circumstances, causal factors and consequences of each of these leaks, thus allowing further analysis of unprecedented detail, which as yet has barely started.

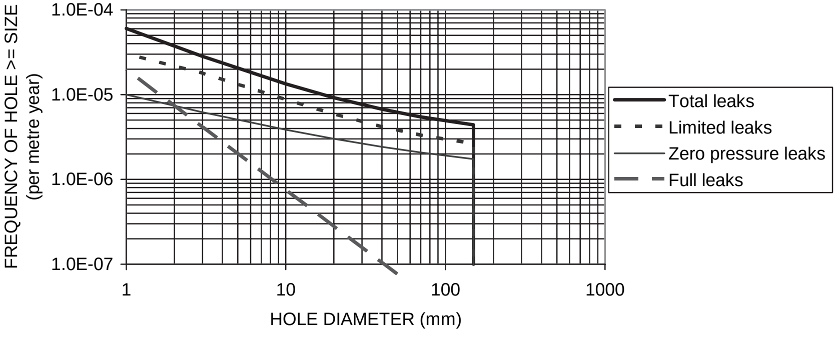


Figure 6. Leak frequencies for 150 mm diameter pipe

Table 3. Leak frequencies (per metre year) for selected hole sizes for 150 mm dia pipe

HOLE DIA RANGE (mm)	TOTAL LEAKS	FULL LEAKS	ZERO PRESSURE LEAKS	LIMITED LEAKS
1–3	3.2E−05	1.6E−05	3.8E−06	1.2E−05
3–10	1.5E−05	3.4E−06	2.4E−06	9.2E−06
10–50	7.2E−06	6.8E−07	1.6E−06	5.0E−06
50–150	6.2E−06	7.7E−08	2.3E−06	3.8E−06
>150	0.0E+00	0.0E+00	0.0E+00	0.0E+00
TOTAL	6.0E−05	2.0E−05	1.0E−05	3.0E−05

OTHER EQUIPMENT TYPES

Table 4 gives the frequencies of the full leak scenario for different types of process equipment. These are examples of the complete set of generic leak frequency results that now form the standardised leak frequencies for offshore projects, and are also considered suitable for onshore QRA studies.

SENSITIVITY TESTS

Sensitivity tests have been conducted to identify the main sources of uncertainty in the generic frequencies, focussing in particular on the full leak scenario. Although there is no evidence of systematic under-estimation of the release quantities in HCRD, it is an unavoidable limitation of the approach that the results would be very sensitive to any such bias. The results are also sensitive to the treatment of cases where the system inventory was not recorded, and so the importance of this parameter should be noted in any future data collection.

The results are very sensitive to the assumed ranges of isolation and blowdown times, and more realistic modelling of these aspects would be desirable in future work. The present work was hampered by a lack of open reporting of the details of any UK offshore process leaks since *Piper Alpha*, and future work in this area would be greatly assisted by investigation of individual releases to show why the release quantity was limited.

CONCLUSIONS

The hydrocarbon release database collected by the HSE in the UK offshore industry contains data of outstanding 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, and because of a desire to obtain consistency between the modelled risks and actual accident experience. The approach described here solves these problems by dividing

Table 4. Frequencies of full leaks (per equipment item year) for process equipment

EQUIPMENT TYPE	FREQUENCY OF FULL LEAKS ≥1 mm DIA	FREQUENCY OF FULL LEAKS ≥50 mm DIA
Steel pipes (2″)–1 m length	5.7E−05	0.0E+00
Steel pipes (6″)–1 m length	2.0E−05	7.7E−08
Steel pipes (18″)–1 m length	1.1E−05	4.2E−08
Flanged joints (2″)	3.2E−05	0.0E+00
Flanged joints (6″)	4.3E−05	3.6E−07
Flanged joints (18″)	1.2E−04	1.1E−06
Manual valves (2″)	1.4E−05	0.0E+00
Manual valves (6″)	4.8E−05	4.9E−07
Manual valves (18″)	2.2E−04	2.3E−06
Actuated valves (6″) (non-pipeline)	2.6E−04	1.9E−06
Instrument (0.5″)	2.3E−04	0.0E+00
Process vessel	5.0E−04	1.1E−04
Centrifugal pump	1.8E−03	2.4E−05
Reciprocating pump	3.7E−03	5.2E−04
Centrifugal compressor	2.0E−03	2.0E−06
Reciprocating compressor	2.7E−02	1.1E−05
Heat exchanger (h/c in shell)	1.4E−03	1.3E−04
Heat exchanger (h/c in tube)	1.0E−03	4.9E−05
Heat exchanger (plate)	6.0E−03	3.6E−04
Heat exchanger (air cooled)	1.2E−03	6.9E−05
Filter	8.9E−04	6.4E−06

leaks into three 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, non-zero frequencies are available for any equipment type and hole size.

ACKNOWLEDGEMENTS

This work in this paper is based on data collected by the Health & Safety Executive, and was funded by DNV, Statoil and Norsk Hydro. The author acknowledges their kind support; in particular Stine Musæus, Brian Bain, Jens Michael Brandstorp and Jan Pappas. Views expressed are those of the author and not necessarily those of DNV.

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