Improvement in Release Frequencies for Quantitative Risk Assessment

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Introduction

The use of Quantitative Risk Assessment (QRA) has become widely accepted in the petrochemical industry as a way of assessing plant safety, both when considering design alternatives for new plant and when evaluating the safety of existing plant. The technique once mainly only used offshore has evolved into a well recognised way of discussing risk levels for both onshore and offshore, internally within a company but also with many regulators around the world.

One of the difficulties with QRA is finding a suitable source for the release frequencies. For onshore studies there are a number of respected published sources including the Manual Bevi Risk Assessments[1] used in the Netherland, FRED[2] used in the UK for Land Use Planning risk assessments. Within the offshore industry the availability of such data has been more structured since 1992 when UK North Sea release data were collected and now form the basis of the UK HSE Hydrocarbon Release Database (HCRD) [3].

The frequencies associated with releases from equipment have been explored many times by different researchers, and there now appears to be a consensus that the HCRD may be a good source of information on which to base such statistics. It has several advantages over other sources:

- It is backed up by a database of the population of equipment, so releases can be related to equipment years.
- Due to the outcome of the Piper Alpha incident[4], reporting has been carried out with unparalleled fidelity.
- The reporting is quite detailed, lending itself to detailed analysis, and the statistical size of the data sample is usefully large.
- The data are collated and made available in a useful format, by the UK HSE -

The population of some equipment types is substantial allowing the release frequencies for low frequency events to be inferred - so, for example, there are many millions of piping-years even though process piping runs are relatively short on platforms. However, for compressors the population is of the order of 4000 compressor years, which limits the ability to predict the frequency of one in 10,000 year events. It is these low frequency events that have the high consequences.

The HCRD is just a database of numbers which has then been taken by many users and reviewed to develop release frequency data for standard equipment types. A number of equipment types (flanges, valves, vessels, pipes etc) are common to both onshore and offshore operations therefore it makes sense to use one common database. This is also the conclusion reached in the OGP data directory[5]. Although the HCRD is only based on data from offshore releases.

So what is the concern?

QRA concerns modelling hazards, with each hazard linked to a release rate through an accidental orifice its location (potentially limited by inventory) and ignition probability (if flammable). The risk is calculated by combining the frequency for a particular hole size from a release rule set with the consequence, for each module or process unit according to the equipment population.

Using an unrealistic release frequency for a particular range of hole sizes can skew the results from a QRA, distracting focus from those areas that might actually represent the highest risk. Moreover, when reviewing the results of QRAs against absolute frequency criteria (such as the 10^{-4}/yr exceedance overpressure or a 10^{-5}/yr location specific risk contour), the use of inappropriate release frequencies can result in decisions on land take or design accident loads that represent excessive risk or are uneconomic. The focus of this paper will be on the less frequent but higher consequence releases. It will not touch on assessing the consequence or probability of ignition, these are papers in their own merit. It may be fair to say that common practice is to conservatively associate the calculated frequency with a steady state release consequence at the operating conditions and recently to use the EI Ignition Probability look up tables for the probability of ignition[6] when dealing with hydrocarbons.

Common Analysis Method of HCRD

Before starting an analysis a set of generic hole sizes needs to be set to cover the majority of the equipment types, each representing a range of hole sizes, so that release frequencies can be assigned to each of these releases. Historically for offshore this has been a split of 3 hole sizes 3mm, 25mm and 50mm (small, medium and large) or, for onshore, 10mm, 25mm,50mm and 100mm. More recently we have seen this range increase to five bands e.g. 2mm, 7mm, 22mm, 70mm, 150mm (Full Bore) increasing the resolution of the frequency analysis but also increasing the generic hole size for the final two bands. It was the increase in the influence of these last two bands to onshore and offshore QRA results that prompted us to look further into the source of the frequencies.

Using the release information from the HCRD which provided the size of the hole involved with the release, the number of releases in any particular hole size range can be obtained. Using this information with the current population data a frequency for each hole size range can be generated. Where no information is available similar equipment types are grouped and an extrapolation of a fitting function across all the holes sizes has been made. This is where we started to see the issues as different equipment type fitting functions being applied to a sparse data set. Also when using the information from the HCRD without completing a review of the release information to take into consideration the type of release, mass released, operating conditions at time of release etc. releases which should not be included in a QRA may have been included wrongly. These analysis methods were seen as being conservative but the best that could be completed. Unfortunately this has given rise to some anomalies in the 70mm and 150mm generic hole size bands. Examples of this are shown in Table 1 where the a simple approach was used with sparse data and applied to large diameter pipelines. Apart from the differences in the numbers both analyses show that a 150mm (full bore) leak is more probable than a 70mm leak and that its probability is similar to a 22mm release. This appears unrealistic as, from consideration of possible failure mechanisms, we would expect the probability of a very large release to be significantly lower than a smaller leak in a typical operating environment. It is normally the releases in the middle of this range that have the balance of serious consequences and high enough frequency that dominate the risk assessment.

Probability of Release	2	7	22	70	150
Analysis A	0.69	0.09	0.13	0.03	0.05
Analysis B	0.61	0.17	0.10	0.01	0.10
Analysis C	0.62	0.23	0.09	0.02	0.05

Table 1 Release Probabilities for large diameter pipe

Initial Review of HCRD data base for Pipe releases

To investigate the anomaly and to identify improved release frequencies an initial review of the HCRD was completed. This showed that apparently some large diameter releases were at little or no pressure or were releases of very small amounts – so it was inappropriate to use them as the basis for a frequency for full pressure process releases. These were typically not always removed from an analysis by users during their review of the database.

Other releases based on information visible in the data base were in the vent or flare system, but did not indicate an equipment failure. The suspicion was that these releases were via the vent or flare outlet, and the quoted hole size was a reflection of the diameter of the vent or flare outlet. However the free-text that is part of the initial reporting (all releases are reported on OIR/12 forms) is not available from the HCRD to prove this one way or the other.

Access to information previously unavailable

During 2012 through various discussion with the UK Health and Safety Laboratory and Health and Safety Executive we were able to obtain the free text information from the OIR/12 submissions for releases in the HCRD quoted as >100mm hole diameter (85 events in the period 1992 to 2011). This information is available to the HSE but is not freely available as it might reveal aspects of the release submission that would allow identification of the platform or company making the report. For our request the 85 entries of >100mm was a manageable number, and as a result the HSE were prepared to check the information to make sure there was no inadvertent disclosure of facility or company involved.

The additional information is extremely useful in the analysis of the large releases that are used to set the very large release frequency. There are two key findings :

- It showed we were correct in our hypothesis that the flare and vent releases were not piping failures, but ejection of gas or liquids via the normal vent or flare orifice. While it is important to understand such events, they do not in general give rise to hazardous conditions of the sort that are addressed using QRA.
- The HCRD contains no releases involving a full bore failure at process pressure of a pipe, valve or flange of over 100mm diameter. There has been a breakout of a 2 inch pipe from a 16inch pipe giving a 4inch diameter hole.

The extra details allowed a far better understanding of the nature of the most serious releases events so that we can guard against them in the future. This led to a further analysis of the HCRD with this new information on the >100mm releases.

Releases of over 100mm from Process Piping of > 11”

We consider here the largest process pipe size range, that is 11 inches and upwards. In this band 1148886 metre-years of piping have been recorded in the database.

Rather than concern ourselves with statistical arguments, to derive a fitting function, it has been found useful to look at the relatively small number of large release events associated with these piping populations to gain an understanding of what is recorded.

One of the problems with the HCRD is that some fields may not be populated, so a little care is required in locating the key releases that should concern us. In other cases a large hole diameter may be reported but negligible pressure - whereas in risk assessment it is always assumed that holes happen at normal working pressure.

For example there are 8 releases in the >11” piping that show a hole size of >100mm.

1. 8kg of gas over 12 seconds at 0.2barg while shutting down - no muster

2. 800kg of oil over 30minutes due to MECHFAIL - design fault - no muster
3. 17049kg of gas over 12 minutes at 16barg due to MECHFAT (fatigue) - design fault - muster is ATSTATIONS
4. 1.5kg of gas over 10 minutes at 0.13barg muster is ATSTATIONS
5. 1200kg of condensate over 10 minutes due to IMPROPOP - no muster
6. 2.7kg of gas over 60 minutes, cause code OPENED - no muster
7. 0.9kg over 30 seconds, due to defective procedure during cold work. This ignited - muster is ATSTATIONS
8. 486kg of oil over 1 minute at 0.9barg due to IMPROPOP. This ignited - muster is ATSTATIONS

What we are looking for are events where a release of >100mm diameter results in an appropriate hazard for the hole size. What we must avoid is using hole size statistics for events that happen at very low pressure and then modelling these in the QRA as full pressure releases.

Of the 8 releases above only release (3) may be representative of a full pressure release. A quick calculation using the release information recorded shows that the recorded release rate (23 kg/s), if assumed uniform over the 12 minutes, would require a hole of 110mm diameter. The next nearest candidate (5) is only 2 kg/s of liquid and could only be a gravity flow if the release rate is controlled by a hole of >100mm. It is quite likely that for some of these releases the gas or liquid may be emitted from an aperture of >100mm, but the flow will be throttled by a much smaller orifice, such as a valve not properly closed.

There is another release which is not in the list above because a hole size of "N/A" was recorded, but reports 314 tonnes being released over 10 minutes in the HP Vent system. The cause is given as IMPROPOP (Improper Operation), and with no emergency action taken, and no equipment failure code, it is assumed that this was not an equipment failure, and the release was via the vent and not due to failure of the vent. As such it should not form part of the QRA release statistics.

The nature of release (3) has been revealed by accessing the detailed description from the OIR/12 submission. This was a 2" pipe breaking out of 16" pipe, and as such it is exactly the sort of release that should be counted. The quoted actual hole size is 101.6mm (4"), so the hole was larger than the 2" pipe.

Note that there are NO full-bore releases for piping of over 11" diameter.

Releases of 50 to 100mm from Piping of > 11"

There are no releases recorded for large piping in this size range. This is perhaps not a surprise. Large diameter piping has substantial wall thickness, so this piping is particularly robust. Any progressive releases are typically addressed long before they reach the size of 50 to 100mm.

Analysis of smaller pipe diameters

The above style of review of the data, whereby type of release, mass released, operating conditions at time of release was also completed for two other piping diameter groups and focused on the 70mm and 150mm releases.

A summary of the number of releases which were left for analysis are shown in Table 2. Looking at the 70mm band it seems a little optimistic to give zero for the likelihood of a hole of that size in >11" piping. Notwithstanding, larger piping typically is expected to be stronger due to thicker walls, so the occurrence of holes is expected to be less likely than for the smaller piping.

For the 150mm hole size, since one incident is observed for piping greater than 11" but none for the more vulnerable smaller piping size, this one incident was assigned to the combined population of 3"<D<11" and D>11".

Table 2 also highlights the scarcity of data to complete a simple analysis with a level of confidence on the results. It was therefore decided that some confidence interval on the actual observed releases should be obtained. To complete this a Poisson distribution was selected as this is a discrete probability function that expresses the probability of a given number of events occurring in a fixed time period. If we take into account that these events occur within a known average rate and without knowledge of the time between the events, therefore random behaviour. Applying this method to the values in Table 2 and taking the total length of relevant piping into account a leak frequency (see Table 3) with an associated confidence level based on the actual recorded data can be derived. It was decided that a 50% confidence level would be used, meaning there is a 50% chance that the real release frequency is higher or lower than the value actually recorded in the HCRD.

Equipment Type	70mm band	150mm band
Piping / Steel / D < 3"	3	0
Piping / Steel / 3" < D < 11"	3	0
Piping / Steel / D > 11"	0	1

Table 2 Number of release for each hole size band – piping

Equipment Type	70mm band	150mm band
Piping / Steel / D < 3”	$1.51 x10^{-6}$/m yr	0
Piping / Steel / 3” < D < 11”	$9.09 x10^{-7}$/m yr	$3.23x10^{-7}$/m yr
Piping / Steel / D > 11”	$6.03x10^{-7}$/m yr	$3.23x10^{-7}$/m yr

Table 3 Calculated release frequencies for each hole size band – piping

Comparison with existing references

Comparisons have been drawn with two data sources: the UK HSE FRED for onshore studies and the OGP Data Directory relevant for both on and offshore studies.

Table 4 shows the UK HSE FRED release frequency information for piping of various sizes.

ITEM FAILURE RATES

Failure rates (per m per y) for pipework diameter (mm)					
Hole size	**0 - 49**	**50 - 149**	**150 - 299**	**300 - 499**	**500 - 1000**
3 mm diameter	$1 x 10^{-5}$	$2 x 10^{-6}$			
4 mm diameter			$1 x 10^{-6}$	$8 x 10^{-7}$	$7 x 10^{-7}$
25 mm diameter	$5 x 10^{-6}$	$1 x 10^{-6}$	$7 x 10^{-7}$	$5 x 10^{-7}$	$4 x 10^{-7}$
1/3 pipework diameter			$4 x 10^{-7}$	$2 x 10^{-7}$	$1 x 10^{-7}$
Guillotine	$1 x 10^{-6}$	$5 x 10^{-7}$	$2 x 10^{-7}$	$7 x 10^{-8}$	$4 x 10^{-8}$

Table 4 UK HSE FRED Release Frequencies - Piping

The frequencies for larger releases in Table 4 are comparable with those derived in this report from the HCRD. For example our 150mm band represents holes over 100mm up to full bore, which for the information in Table 4 is equivalent to the sum of the 1/3rd diameter and guillotine failure in their two largest pipe size categories. Our analysis calculates $3.2x10^{-7}$ per m yr, and Table 4 shows $2.7 x10^{-7}$ per m yr in pipes >300mm and < 499mm, and $1.4 x10^{-7}$ per m yr for larger diameter pipes.

Our analysis of the 3” to 11” pipe diameter range (76mm to 279mm) covers much of both the FRED 50mm to 149mm and their 150mm to 299mm ranges. In the latter range, the combined 1/3 diameter and guillotine (50mm to full bore) frequency is $6x10^{-7}$/m year. In the 50mm to 149mm range the large hole size frequency is $5x10^{-7}$/m year. Our analysis gives around a value a factor of two higher, $1.23x10^{-6}$/m year.

Table 5 shows the release frequencies as published in the OGP data directory for each of their release types. These release types, it is believed were introduced to differentiate between the different outcomes of the releases recorded in the HCRD and it is left for the QRA practitioner to decide which set of data to use with their chosen consequence modelling.

Recently a number of studies have been seen where the release type “All” has been applied to conservative consequence modelling. This is believed to be a too conservative approach and reference should be made to the descriptions in OGP where using ‘full’ and ‘limited’ would be more appropriate.

	Hole Dia (mm)	150	300	450	600	900
All	>50	$7.6x10^{-6}$	$7.3x10^{-6}$	$7.3x10^{-6}$	$7.3x10^{-6}$	$7.3x10^{-6}$
Full	>50	$6x10^{-7}$	$5.4x10^{-7}$	$5.3x10^{-7}$	$5.2x10^{-7}$	$5.2x10^{-7}$
Limited	>50	$3.2x10^{-6}$	$2.9x10^{-6}$	$2.9x10^{-6}$	$2.9x10^{-6}$	$2.9x10^{-6}$
Full+Limited	>50	$3.8x10^{-6}$	$3.5x10^{-6}$	$3.4x10^{-6}$	$3.4x10^{-6}$	$3.4x10^{-6}$

Table 5 OGP Release Frequencies - Piping

It is not meaningful to compare our analysis to the “All” type release as these cover all reported incidents in the HCRD including those which would not normally be included in a QRA.

To complete the comparison with OGP the last two holes size bands of OGP and our analysis require to be combined, therefore we are therefore looking at >50mm releases. This comparison shows that our calculated release frequency is approximately a factor of 2 higher that the ‘full’ and approximately a factor of 3 lower ‘full+limited’. What is not as obvious using this method of comparison is the effect of our analysis method on the last hole size band which when compared with similar grouping of hole size ranges has shown an order of magnitude difference. This finding is similar to the comments provided in OGP where it discusses uncertainties stating that it can be a factor of 3 (higher or lower) for very small releases and a factor of 10 (higher or lower) for large and very large releases.

It can therefore be seen, for the piping releases recorded in the HCRD, that the high level data include a range of releases that are inappropriate for consideration in a QRA. Identifying those releases involves reviewing the type of release, mass released, operating conditions at time of release and, the free field text describing more information on the release including if it was a uncontrolled or controlled release. This has shown overall a reduction in the release frequencies for the larger hole size ranges compared with OGP and previous analysis and closer in line with UK HSE FRED.

Other Equipment Items

The method described for piping has been applied to other equipment types relevant to both onshore and offshore taking into account the extra information obtained for the >100mm releases. A summary of this analysis is shown in Table 6. When comparing these new values with those previously used they are generally similar but there are a number of the values in the 150mm band where there has been an order of magnitude reduction.

Equipment	Units/Year	Hole Size Band (mm)	
		70	150
Compressors/Centrifugal	Per Item	$3.3x10^{-5}$	$2.9x10^{-6}$
Flanges <= 3”	Per Flange Face	$3.3x10^{-7}$	0
Flanges 3”<D<11”	Per Flange Face	$7.4x10^{-7}$	$4.7x10^{-7}$
Flanges >11”	Per Flange Face	$7.4x10^{-7}$	$4.7x10^{-7}$
Piping <= 3”	Per metre	$1.5x10^{-6}$	0
Piping 3”<D<11”	Per metre	$9.1x10^{-7}$	$3.2x10^{-7}$
Piping >11”	Per metre	$6x10^{-7}$	$3.2x10^{-7}$
Valves <= 3” Actuated	Per Item	$3.1x10^{-6}$	0
Valves 3”<D<11” Actuated	Per Item	$2x10^{-6}$	$2x10^{-6}$
Valves >11” Actuated	Per Item	$2x10^{-6}$	$2x10^{-6}$
Valves <= 3” Manual	Per Item	$3.1x10^{-6}$	0
Valves 3”<D<11” Manual	Per Item	$2x10^{-6}$	$2x10^{-6}$
Valves >11” Manual	Per Item	$2x10^{-6}$	$2x10^{-6}$

Table 6 Summary of calculated release frequencies

Conclusion

The approach which has been applied in this study has involved reviewing the type of release, mass released, operating conditions at time of release and, the free field text describing more information on the release including if it was a uncontrolled or controlled e.g. to a flare system. By gaining a detailed understanding of the >100mm releases actually recorded in the UK HSE Hydrocarbon Release Database it has been possible to make an estimation of the leak frequencies for the large and very large releases which has resulted in significantly lower values than those being used previously from analysis of the HCRD. With the analysis now having what looks like a more plausible split of release probabilities across each of the larger generic hole sizes. Therefore reducing the influence of these less frequent releases on the design parameters when looking at location specific risk contours or exceedance overpressures.

It would therefore be useful for all information in the free text description on the OIR/12 forms be made available as this would not only greatly help those deducing release statistics, but provide valuable insight to operators in how such releases can occur, and hence how they might be prevented.

The industry as a whole onshore and offshore may possibly benefit from a standardised reporting process instead of relying on an extrapolation of North Sea data to different environments, duties, locations etc.

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