

INTERPRETATION OF THE HCR FOR QRA – AND ITS APPLICATION BEYOND THE NORTH SEA

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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.

One of the difficulties with quantitative risk assessment is finding a suitable source for the release frequencies and ignition probabilities. The UK Health and Safety Executive's (UK HSE's) hydrocarbon release database (the HCR) is one of the best sources [UK HSE, 2005]. It is a collection of information on releases in the UK sector of the North Sea since 1992. For a modest annual fee the records for all hydrocarbon releases can be downloaded. The database also holds information on the amount of installed equipment, and, although this cannot be downloaded, the web-based interface allows queries to be posted which return the number of events, and the number of equipment years relevant to the query. In this roundabout way it is possible to obtain information on the installed equipment base.

The HCR has been the basis of many analyses of frequency of releases and probabilities of ignition, and the results from these analyses are increasingly being incorporated in the rule sets of operating companies, thereby displacing rules based on a number of older sources including the "Hydrocarbon Leak and Ignition Database" report by the E&P Forum (which subsequently became the International Association of Oil and Gas Producers) [E&P Forum, 1992] and the book "Classification of Hazardous Locations" published by the Institute of Chemical Engineers [Cox, 1991].

Although the HCR data has been gathered since 1992, and currently comprises some 3500 entries, it is still statistically sparse on the larger releases that result in major safety hazards. This provides a particular challenge for those wishing to estimate the releases from equipment for which the installed base is relatively small (for example there are a very large number of flanges but relatively few compressors).

However, for the HSE consultant with global reach, one of the biggest challenges is whether the release and ignition frequencies deduced from the HCR can be applied in operations where the gas contains appreciable H_2S (sour gas), or where the winter conditions might require enclosure of the modules and forced ventilation, or for completely unrelated areas such as service stations handling compressed natural gas or even hydrogen.

In order to decide whether the HCR data can be used it has been necessary to delve slightly deeper into the data, and aspects of this are discussed.

WHAT DATA IS RECORDED IN THE HCR ?

The requirement to report hydrocarbon releases stems from RIDDOR (the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995). The UK HSE has clarified the requirements under RIDDOR in OTO 96 956 "Revised guidance on Reporting of

Offshore Hydrocarbon Releases"[UK HSE, 1996]. This indicates that: "The definitions aim to obtain reports of confirmed hydrocarbon releases at the lower end of the incidents scale with a potential for escalation, in addition to fires, explosion and other serious stoppages."

Further clarification was published by UKOOA (the UK Offshore Operators Association), in co-operation with the UK HSE, in 2002 [UKOOA, 2002]. This states that all ignited releases are reportable, as are all 2-phase or condensate releases. "For all other releases to be reportable … then the potential for ignition/escalation needs to be examined, particularly in the case of releases in the minor range". It then goes on to state that amongst other things, if an alarm or withdrawal of people from the area occurs then the release is reportable.

The details recorded in the database are extensive, and include information about the module type, the equipment, the hole size, pressure, density, quantity, duration, and a variety of cause codes.

WHAT ARE NOT RECORDED?

Small releases and fugitive emissions that are no hazard, and cause no alarms.

The details of the release mechanism are not recorded in the database. Releases are coded so that they can be categorised, but there is no free text description of the event.

HOW IS THE DATA USED TO PROVIDE QRA RULES?

The approach adopted is usually to statistically analyse the hole size distribution for different classes of equipment, and derive frequencies, relative to the installed equipment population, of those holes. This hole size distribution is then applied to the same classes of equipment in a different situation and the release rates calculated based on the fluid type, and the pressure within the equipment.

In screening QRA several conservative assumptions are made, and one of the main ones is to group all holes in a specific size range, and assume their size is at the top end of the range. If such an analysis gives rise to concerns, then refinement to more narrower hole size ranges would often be a next step.

As a relatively small release rate can occur under negligible pressure from an opened pipe, in some circumstances analysts screen such releases out of the hole size distribution.

The rules on hole size distributions arising from this form of analysis have been used in locations significantly different from offshore in the North Sea (for example in refineries) and the predictions for the number of major events are, in broad terms, in agreement with reported experience.

This hole-size based approach has a number of disadvantages when the statistics are applied to significantly different situations, for example:

- A small release that poses no hazard in a low pressure system need not be reported in the HCR. However in a very high pressure system, or in a sour gas system this 'unrecorded' hole could pose a hazard.

- Some releases grow over time, and will be reported in the HCR when they are detected and acted on. In a high pressure or sour gas system these may be detected much earlier, and so the hole size at which they are acted on would be smaller than on a sweet gas system.

These two factors act in opposite directions, and it is far from certain that the under-estimation of risk arising from the first point will be balanced by the over-estimation of hole size arising from the second point.

Figure 1 shows the size distribution for gas releases in the HCR for both low pressure systems (<30 bar) and high pressure systems (>70 bar). The data have been normalised on the basis of the total number of releases of over 3 mm hole size in each case. Although the distribution of hole sizes is very similar for holes of over 3 mm (which is releases of 0.1 kg/s and over in the high pressure systems), it can be seen that the recording of holes of below 3 mm differs strongly between high and low pressure systems.

Analysis of the relative frequency of releases in high and low pressure systems is not possible as the UK HSE does not permit the installed equipment data to be downloaded – and it is not available via the web-based interface as a query. It is not known whether the equipment database stores the operating pressure.

It is also the case that in management of gas releases in ventilated modules it is primarily the release rate that poses the risk and not the hole size. Furthermore, it is the release rate that is used to determine the ignition probability for a release and not the hole size. This encourages us to analyse the HCR by release rate.

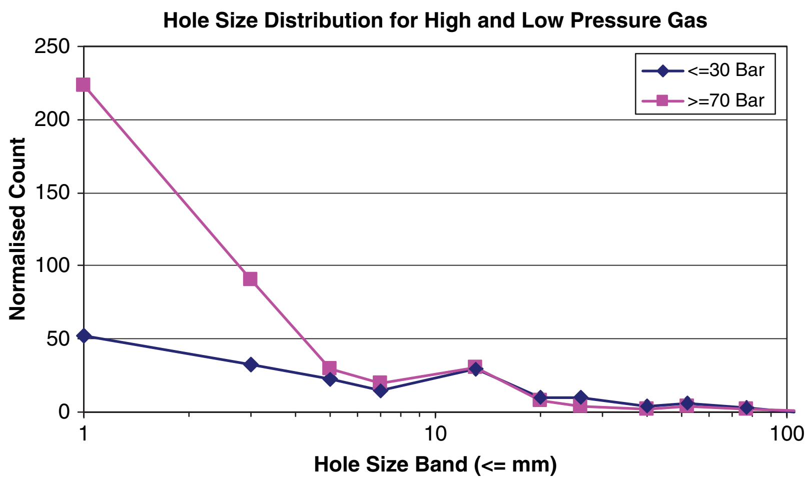

Figure 1. Gas releases from HCR for high and low pressure

ANALYSIS OF THE HCR BY RELEASE RATE

The HCR does not record the release rate, but it does record the actual pressure, hole size, and density of the fluid at that pressure. It also records the total quantity of the release and the duration of the release. Either or both of these can be used to estimate the release rate using standard relationships. The graph below is taken from all gas releases reported in the HCR database at the time of writing. In estimating the release rate the sonic flow relationship (with a discharge coefficient of 0.8) was used if sufficient data was available, otherwise the amount released divided by the duration was used (though this was in the minority of cases). The results show the distribution of gas releases according to release rate.

It can be seen that the recorded number of releases peaks between 0.01 kg/s and 0.1 kg/s. It is fairly evident that larger releases are less frequent, but the left hand side of the graph shows the effect caused by the fact that non-hazardous releases need not be reported under RIDDOR – and of course there is a size threshold below which a release might go undetected.

The UK HSE classify offshore gas releases as follows [UK HSE, 2005]:
Major (>1 kg/s for over 5 minutes OR over 300 kg released)
Minor (<0.1 kg/s for less than 2 minutes OR less than a kg released)
Significant (Anything lying between Major and Minor)

We could probably add
Insignificant (Minor releases not required to be reported under RIDDOR)

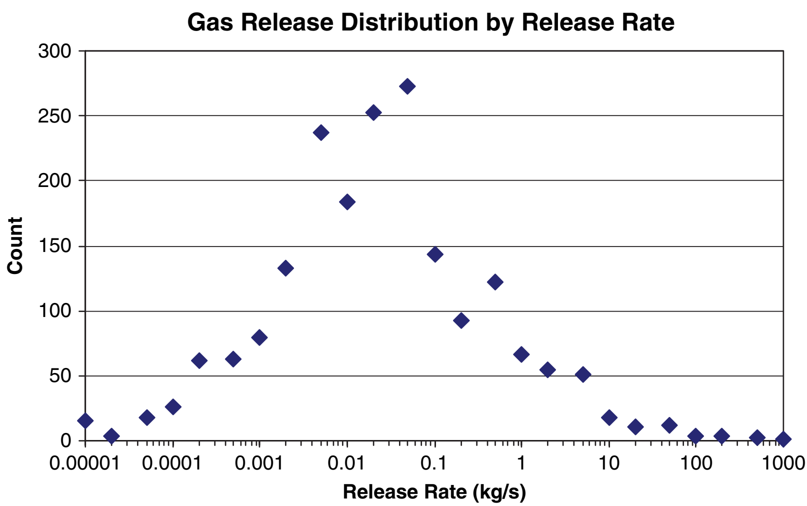

Figure 2. Gas releases in the HCR displayed by release rate

Let us simplify things by considering explosion hazards and using the following rules of thumb for naturally ventilated modules based on the above:

- Release over 1 kg/s can form a substantial flammable gas cloud in a naturally ventilated module.
- Releases between 0.1 kg/s and 1 kg/s could form a minor explosion hazard, and might trigger a gas detector.
- Releases of less than 0.1 kg/s are unlikely to pose a serious explosion hazard, and generally are of minor or no consequence.

These categories will be referred to later in the text. However it is clear that the transition from minor to insignificant occurs in the 0.01 to 0.1 kg/s region, and even for the releases reported in this area it must be appreciated that the estimation of hole sizes that may be a millimetre or less is extremely difficult.

When rules sets for calculating release frequencies are deduced from the HCR data a lower hole size or release rate threshold is normally applied so that the very large number of small releases are not all rounded up into the smallest release rate category (which will typically be in the **Significant** range).

STATISTICAL V MECHANISTIC UNDERSTANDING OF RELEASES

The UK HSE has, in the past, published analyses of the UK HCR data [UK HSE, 2002], but since making the data available for download in 2002 no further summaries have been published, although numerous analyses are carried out by consultants commissioned by petrochemical companies and other bodies such as UKOOA. These studies have in the main been statistical analyses of the data, and as such are quite good where the statistical sample is adequate. Where the HCR has a smaller population of a certain sort of equipment there has been a tendency to fit the same relationship as discovered for large populations to the sparse data.

The problem of applying a statistical relationship without regard for the mechanics of the equipment can lead to some odd conclusions – and there is the risk that this could lead to prediction of significant risk of major release events that cannot occur – something along the lines of a 6 inch hole in a 3 inch pipe – though slightly more subtle.

A further problem occurs when considering the failure rates for individual equipment types. There is very little scope for analysing improvements over time that might result from changes in equipment design or more sophisticated control systems. A mechanistic analysis of releases could lead to such improvements, and UKOOA have published some excellent guidelines on how to reduce the release frequencies for flanges, instruments and other equipment [OKOOA, 2004], but it could take years before the resulting improvements manifest themselves in the HCR, and as a result the benefits are not reflected in QRA studies.

Sometimes technology can make a step change, like computer-controlled compressors with dry gas seals, and it could have a significant impact. At present we have a problem in not being able reflect this in the rules, and the plant designer can make very little difference to the site QRA by selecting higher specification equipment.

A few examples of how a mechanical appreciation of equipment could help interpret release records are for instrument fittings and for compressors.

INSTRUMENT FITTINGS

In figure 3 it can be see that the data for releases from instrument fittings shows that small releases are more common, but also there is a second maximum in the size range of 7 to 13 mm. The reason for this peak is immediately evident if one considers the arrangement of a typical remote instrument (see Figure 4), where a small bore tube – typically of 3/8″ or 10 mm diameter connects the instrument to the valve and flange. It is this line becoming broken or pulled out of the screwed connector that gives rise to the peak in the recorded data.

The hole size arising from a full-bore break in a 3/8″ pipe is typically 7.6 mm (it may be smaller according to the pressure rating of the tube). Depending on the pressure this gives a release rate that is marginal in whether it results in a hazardous gas cloud. As it is bracketed by an interval of 7 to 13 mm in the analysis above, it will typically be rounded up to 10 or 13 mm even in a detailed study. This is quite conservative as release rates change as the hole area, not the hole diameter (i.e. the release rate from rounding a 7 mm hole up to 10 mm is TWICE what it should be). Due to the large number of instruments on

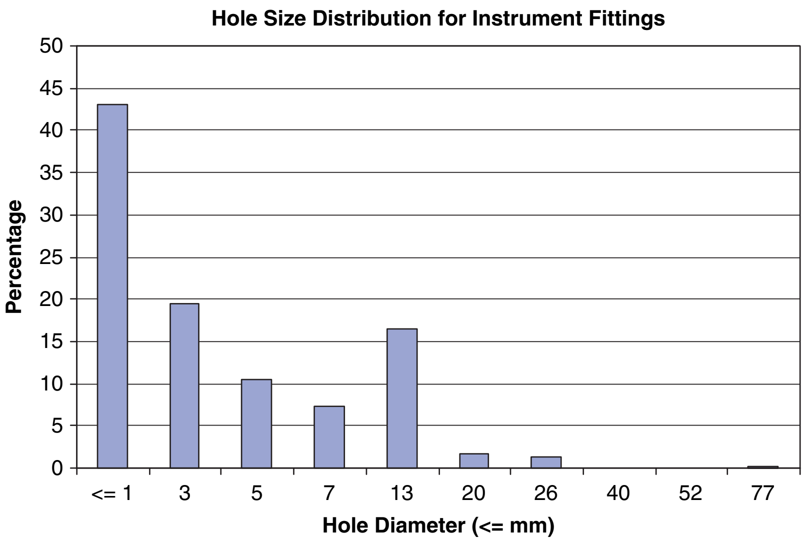

Figure 3. HCR data compared to statistical model for instrument releases

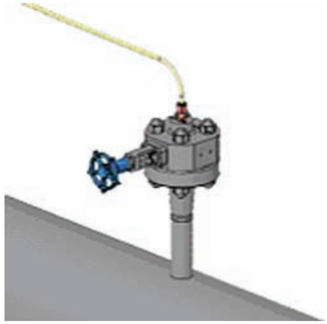

Figure 4. Schematic of an instrument fitting showing small bore pipe

some types of plant (there can be hundreds), and the frequency of small bore pipe breakage, this can have a significant effect on a QRA.

Understanding the mechanics of the release can prevent a smooth curve being fitted through this blip in the data, which would otherwise lead to over-estimation of releases in the larger hole sized bands – which could result in a lot of attention being focussed on managing a risk that doesn't exist – potentially masking some other hazard.

CENTRIFUGAL COMPRESSORS

Centrifugal compressors are a good example of sparse data. The HCR records only one gas release from a hole of over 13 mm diameter. This occurred in 1998, and the hole was 48.2 mm diameter.

Analysis of the release rates reported for centrifugal compressors (Figure 5) indicates that only the single large release was over 1 kg/s. The cause is recorded as "Opened" and the mode as "Routine Maintenance". The difficulty is in whether it is legitimate to extrapolate from the small releases to the larger ones – and it would help if we understood the mechanics of the smaller releases.

One source of releases is the compressor seals. Modern compressors typically have dry gas seals backed up by labyrinth seals, and they tend to have fairly sophisticated seal gas management systems that can detect problems and even take executive action. However, even in the event of sudden and complete failure of the dry gas seals, the labyrinth seals restrict the flow of gas from the compressor. These are substantial metal constructs and would appear to set an upper limit on all conceivable seal leaks of about 10 mm equivalent diameter. For this reason a statistical extrapolation of small seal leaks above 10 mm would be completely misleading. Ideally any extrapolation of probabilities of larger releases should be based on a mechanistic understanding of the smaller releases, for which some

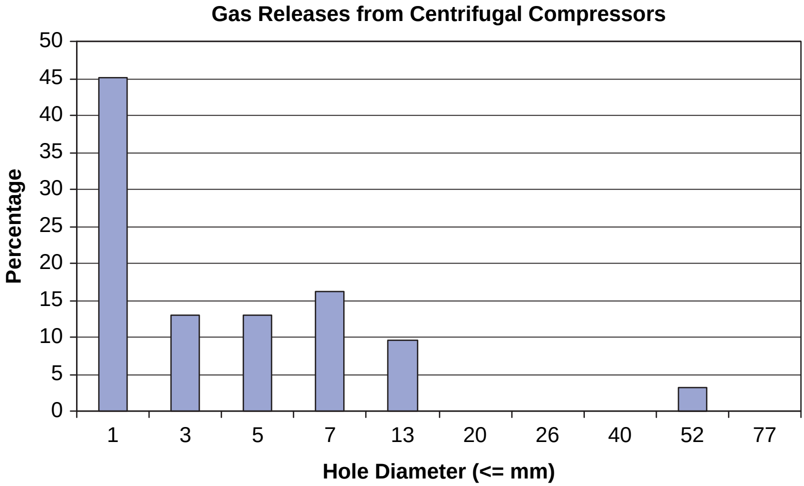

Figure 5. Gas releases from centrifugal compressors

text describing the nature of the release would be helpful (possible something that could be added to HCR recording).

APPLYING HCR DERIVED FREQUENCIES IN OTHER LOCATIONS

ARE RELEASES INSTANTANEOUS?

An assumption in the purely statistical analysis of reported leaks is that they occur instantly. Consider the instant forms of release:

- Dropped objects
- Overpressure burst
- Erosion burst
- Leaks on repressurisation
- Valve opened in error

And then there are releases that are more progressive

- Corrosion holes
- Flange leaks
- Fatigue (though this can be quite fast)
- Valve stem seals
- Seal leaks in pumps and compressors

No leak will ever be recorded in the HCR if it hasn't been detected – and in a noisy offshore environment with difficult access a small leak could be difficult to detect. Once a leak is detected, the action taken will depend on the hazard it poses and operational opportunities. A small leak forming a few bubbles on a valve stem might be standard fugitive emissions within specification for the valve. Such a leak will not be recorded in the HCR as it is not hazardous.

THE PROBLEM OF FORCED VENTILATION

In some environments, including the North Sea, the weather can be so cold that enclosure of the plant becomes important for the workers – and compressors too suffer from the cold and refuse to start unless at a comfortable temperature (e.g. 5C).

In cold conditions it is often the case that the ventilation rate achievable in a sizeable module is of the order of 12 air changes per hour (ACPH) – this being limited by the power required to heat the incoming air. This level of ventilation is roughly an order of magnitude lower than you would have on open process units in the North Sea – even on a fairly quiet day, and even allowing for the weather cladding around a North Sea process unit. As an example calculation - if you can get 1 m/s air flow through a 30 metre wide process unit, then the air is changed every 30 seconds, so that is 120 ACPH.

If the ventilation is an order of magnitude lower, then the release rate that can form a flammable cloud is also an order of magnitude lower. Referring back to figure 2 – releases above 0.1 kg/s that were classed as marginal become more serious in a forced ventilated module. Releases of below 0.1 kg/s that may not even have been included in the release statistics used to make the rules for release frequencies have become marginal and may need to be brought into the risk assessment – even though we can see that the data in the HCR for these small releases seems incomplete.

WHAT ABOUT SOUR GAS?

In a number of countries we are now seeing sour gas with considerable H_2S content, e.g. 10% or more. The LFL for methane is about 5%, which is 50,000 ppm. If our example raw gas contains 10% H_2S then at the LFL you have 5000 ppm H_2S. Sour gas alarms will likely be set at 10 and 20 ppm, and at 500 ppm (two orders of magnitude more dilution than for sweet gas flammability) you are at levels that can have serious consequences.

If a QRA study is going to determine the toxic risk it needs to predict release frequencies two orders of magnitude smaller than we need for North Sea QRA's.

- 0.01 kg/s will cause gas alarms
- 0.001 to 0.01 kg/s is marginal and may cause alarms
- <0.001 kg/s might be OK

It is clear from Figure 1 that the HCR doesn't record releases down to these low levels with any reliability. Many of these smaller releases might not even be detected with sweet gas.

However small releases of sour gas ARE detectable, thank to the H_2S which itself acts as a tracer. If the North Sea was mainly sour gas, then releases would be detected at much smaller sizes, and would be reported as such, and so the curve in Figure 2 would have far more reports at the lower release rates (although the difficulty in assigning hole sizes to such minor releases would remain).

Supporting evidence for this comes from Canada [CAPP, 2003] where a number of sour gas fields are in production. Tests of different plant using a variety of sensitive methods of leak detection and analysis have revealed that the emissions are an order of magnitude lower for the sour gas plants than for the sweet gas plants. Although this could be due to superior equipment, it is more likely that smaller leaks can be detected in the sour plant and are acted upon quickly.

If we could separate the progressive leaks from the instantaneous leaks in the HCR data then maybe we could offer a rule set more suitable for sour plant, as we could anticipate that the progressive leaks would be detected at much lower levels – but for now it is clear that using rules derived from the HCR and then applied to sour gas plants could lead to two problems:

- You could significantly over-estimate the toxic hazards by using hole sizes that would have been detected and repaired at a smaller size.
- You could significantly under-estimate the toxic hazards as the frequencies you are using could ignore all releases below 0.1 kg/s, which could still be significant as a toxic hazard.

Which of these two opposing factors dominates could depend on the individual plant. There is no reason to suppose that they cancel out.

SUMMARY

In this report we have focussed on two factors:

i) The nature of the events recorded in the HCR – statistically sparse for larger releases, and with a lower cut-off dictated by the RIDDOR reporting requirement
ii) The problem of interpreting the data in a statistical way without taking into account the mechanics of releases

It is hoped that some insight has been given into the suitability of using HCR data in areas where very high pressure or sour gas could make the statistics of small releases much more important.

Even with typical North Sea operations it can be seen that an understanding of the mechanics of releases can help in deciding whether release frequencies should be extrapolated to larger sizes where data is sparse or missing.

When attempting to apply HCR derived release frequencies in a predictive manner for very different circumstances (such as high pressure hydrogen) then it is doubtful the

HCR data can be used directly, and modifying HCR-based rules is difficult because it is not obvious which releases would have been detected earlier under other circumstances.

However the HCR provides a valuable insight into classes of failure, especially covering the mix of human, mechanical and design factors – though inevitably more detail would help further, even in current interpretations. Maybe the best route to deriving rules for very different operating conditions would be to decompose the HCR releases according to instantaneous or progressive releases, and causative factors, add in any new causative factors (e.g. different materials problems) and then use this to drive an FMEA approach for equipment types and thereby assemble a new rule set appropriate for plant operating under significantly different conditions.

Table 1. Emission factors for sour v sweet gas plant

Fitting	Emission factor (kg/hr/fitting)
Valves (sweet gas)	0.04351
Valves (sour gas)	0.00518
Flanges (sweet gas)	0.00253
Flanges (sour gas)	0.00031

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